DESIGN-BASED RESEARCH:

EDUCATIONAL CHEMISTRY CARD AND BOARD GAMES

Maiju Tuomisto

ACADEMIC DISSERTATION

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ABSTRACT

The rationale for this thesis was grounded on the general importance of finding novel, research-based chemistry teaching approaches to engage students in learning, because lower secondary students are commonly not interested in chemistry and their attitudes toward this subject are often negative. Educational games have been noted to promote motivation, interest and enjoyment in learning, but the research in the field has focused more on digital games than card and board games. There is also a need to develop quality evaluation criteria for educational games. Evaluation frameworks have been developed for digital games, but not for card and board games, and particularly not to support the use of educational games in chemistry education. In-game learning is the main purpose of educational games. Therefore learning with an educational game should be connected to a definition that explains how learning principles are tied to playing that game. In previous research, this line of reasoning has not been presented in studies concerning educational chemistry games.

The main research problem in this thesis was: how do we support the design and evaluation of educational chemistry card and board games and in-game learning using them? From the research problem, three aims for the study have been derived: 1) to develop a practical and high-quality tool for designing and evaluating educational card and board games for chemistry education; 2) to design research-based educational games for chemistry education in order to support both the learning of central chemistry concepts and the use of this knowledge and related skills in different daily life situations; 3) to achieve understanding of the relationship between educational games and students’ concept development and transfer of knowledge in context-based learning. In order to achieve the aims, design challenges 1, 2 and 3 were executed in this study.

This thesis followed the research-based principles of design-based research (DBR) and was based on a qualitative approach; hence qualitative research methods were executed in the problem analyses and game testing sessions of three design challenges (1–3) and their cyclic structures. Small-scale questionnaires, diaries, literature review, observations and video recordings were used as data collection methods. Data was analysed using content analyses and conversation analysis. Chemistry teacher educators, chemistry teachers, chemistry and home economics pre-service teachers, and students at upper and lower secondary levels participated in the six case studies of this study.

Design challenge 1 aimed to answer research question 2: which features of an educational game may support the development of lower secondary students’ skills to learn and use a piece of information included in the periodic table? Two educational card games, Periodical Domino and Collect a Triplet, were designed to promote the development of lower secondary students’ ability to learn and use information included in the periodic table. Argumentation and construction of students’ own models of the periodic table were the two specific features in these games. In the first design cycle, the games were developed based on theoretical frameworks about games and educational games, and the results of empirical problem analysis, in which Finnish lower secondary students’ (n = 38, 8th grade) understanding of the periodic table and related topics, and their skills in using it, were studied using two small-scale questionnaires. As a result, information about specific difficulties among students in understanding the concepts related to the periodic table was discovered. The first versions of the games were tested on chemistry teachers (n = 22), on whom a small-scale questionnaire was used. As a result, feedback and suggestions for improving the games were achieved. In the second design cycle, the games were developed further based on the results. According to CHEDU Game design Tool, the games were found to satisfyingly fulfill the quality criteria for educational chemistry card games, and consistency between the evaluators was substantial (Periodical Domino κ = 0.756; Collect a Triplet κ = 0.718). According to evaluators, in these games in-game chemistry learning is supported by making thinking visible, application of knowledge and with suitable challenges in the zone of students’ proximal development. But improvements should be made at least in the categories of pre- and postgame evaluation and connection to the macroscopic level and daily life. Even though Periodical Domino and Collect a Triplet card games were research-based and based on theoretical frameworks developed to support learning, they have not yet been tested with students. Therefore, in this research, it was not possible to present evidence about their actual ability to support lower secondary students’ learning and use of skills regarding the periodic table.

Design challenge 2 aimed to answer research question 1: what kind of game design and evaluation tool for educational card and board games supports both teaching and learning in chemistry education? The educational card and board game design and evaluation tool for lower secondary education (CHEDU Game Design Tool) was designed to support game developers and teachers in designing and evaluating quality educational games particularly for chemistry education purposes. In the first cycle of the design process, a theoretical problem analysis with integrative literature review was implemented. As a result, the elements of high-quality digital and non-digital games and educational games were
uncovered. The tool was developed based on these features and the current Finnish national core curriculum for basic chemistry education. In the second design cycle, the tool was tested on chemistry and home economics pre-service teachers (n = 25), while game design diaries were kept and the tool supported the design process. As a result, information about pre-service teachers’ ability to benefit from the game design tool in their game design processes were achieved. The tool was further developed based on the results. The first version of the educational game design and evaluation tool was used in evaluation of the games developed in design challenge 1, and the second version was used in designing an educational board game in design challenge 3.

Design challenge 3 aimed to answer research question 3: how does an educational game in a food and cooking context help students with development and transfer of knowledge between theory, everyday life contexts and hands-on activity? The Proteins in Backyard board game was designed to support lower secondary students in learning about protein chemistry, and in enhancing transfer of knowledge in daily life contexts and in hands-on activity. The theoretical framework about context-based learning, criteria in the CHEDU Game Design Tool and the results of two empirical problem analyses were exploited in the first cycle of the design process. In the first empirical problem analysis, pre-service teachers’ (n = 25) game design processes were analysed and as a result, information about specific quality game elements in their games was collected. In the second empirical problem analysis, upper secondary students’ (n = 22) interest and attitudes toward chemistry, food and cooking, and molecular gastronomy were studied using a small-scale questionnaire. As a result, information about their cooking behaviors, discussions related to chemistry and cooking, as well as their favourite topics in the field of molecular gastronomy were collected. The top three among these students were: fudges, cream foam and meringues. The board game was first tested on chemistry educators (n = 3) and, based on observation, feedback and video recording, important information concerning the game’s playability and video recording settings was collected. In the second cycle, the game was further developed and tested on 9th grade students (n = 6) using video recording, observation and a small-scale questionnaire. As a result, information about in-game activities, such as engagement, in-game learning and transfer of knowledge was collected. Based on the results, development and transfer of knowledge, as well as engaging game elements were noted to be apparent during play, but bridging them to hands-on activity was not observed. Based on the results, the game mechanics and difficulty level of missions in the playing cards in particular were further developed in the third design cycle for the game. This board game was found to fulfill the quality criteria for educational chemistry and home economics pre-service teachers (n = 22) interest and attitude and engaged in activity into the board game and made教师 also in particular laudably, although there was still room for improvement – for example, increasing difficulty during play was missing.

In general, in this thesis different design solutions were developed to draw on the research on educational games and chemistry education. The Periodical Domino and Collect a Triplet card games, the Proteins in Backyard board game and the CHEDU Game Design Tool are four guiding development models which follow the research-based design processes described in this thesis. Hence, in this study, four prescriptions for successful design processes were developed.

During the design processes, descriptive and guiding theories were also developed. The results of this research suggested new theories about quality educational card and board games by revealing elements that play important roles in increasing the quality of non-digital educational games, and particularly in chemistry education. Simultaneously, the need to develop tools to systematically assess quality of educational games was answered. A theory about using educational game design as a part of chemistry teacher education was developed, and it was observed not just to support previous studies, but also to give new information about the quality game elements in the games designed by pre-service teachers. Also, a new theory about developing educational games to support chemistry learning and about in-game chemistry learning was developed. Theoretical bases for developing research-based quality educational chemistry games were presented so that design decisions concerning both game mechanics, game dynamics and game material were justified in a transparent manner, showing how they are designed to support possible in-game learning. These processes and embedding a hands-on activity into the board game make this study unique compared to previous research in the field. According to this study, when using quality educational games, in-game engagement and learning is possible at least via in-game transfer of knowledge in daily life contexts. This kind of research concerning in-game learning and in-game engagement has not been reported in the previous studies of educational games in chemistry education. However, due to the qualitative nature of this design research, these results are not generalizable, only indicative.

This study presents theory and tools to use quality educational card and board games as an effective teaching approach in chemistry education, as well as providing ideas about how to carry out studies in the field of in-game learning research. It also offers ready-made tools, such as game materials, for chemistry teachers and teacher educators to apply in their teaching.

KEYWORDS: chemistry education, context-based learning, educational game design, transfer of knowledge


Tämän tutkimuksen päätutkimusongelmana oli: Miten tukea kemian opetuksen suunnattujen kortti- ja lautapelien suunnittelua ja arviointia ja pelinaikeista oppimista niiden avulla? Tästä tutkimusongelmasta joidenkin kolmea tutkimustavoitetta: 1) kehittää kätevä työkalu tutkaamaan kemian opetuksen suunnattujen kortti- ja lautapelien kehittämistä ja arviointa; 2) kehittää tutkimusohjaisesti kemian opetuksen suunnattuja oppimispelejä, jotka tukevat sekä keskeisten kemian käsittäen oppimista että kään antun tiedon käyttöä ja soveltamista erilaisissa arkielämän tilanteissa; 3) saada uutta tietoa ja ymmärrystä oppimispeleistä ja oppilaiden käsittelemuodon vertailusta ja tiedonsiirron välisistä pelinaikeista yhteyksistä. Kehittämishaasteet 1, 2 ja 3 toteutettiin tässä tutkimuksessa näiden tavoitteiden saavuttamiseksi.


pelinkehittämisprosessin työkaluna tutkittiin kemian ja kotitalouden opetetaopiskelijoiden (n = 25) pelin ideointiprosessissa, jonka aikana opiskelijat pitivät ryhmissä pelinkehittämisväiksirjoja. Tuloksena saatiin tietoa sekä opetetaopiskelijoiden pelinsuunniteltelukyvyystä että CHEDU-oppimispelityökalun toimivuudesta suunnittelutyökaluna. Tässä kehittelyn pelityökalun ensimmäistä versiota käytettiin myös kehittämishaasteessa 1 kehitettyjen oppimispeleen arviointiin ja toista versiota kehittämishaasteessa 3 raportoidun lautapelin kehittämiseen.


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Helsinki, April 2018

Maiju Tuomisto
The people using your game are not you and have a little of your knowledge about what you have built or why, so make sure you explain it to them.

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1 INTRODUCTION

A game is a particular way of looking at something, anything. – Abt (1970)

1.1 Rationale and purpose

Learning chemistry is challenging: one must move between the macro, submicro and symbolic (and mathematical) levels of chemistry knowledge (Gilbert & Treagust, 2009) and construct models and knowledge of abstract concepts that cannot be seen. In Finland, adolescents’ performance in chemistry in general is very good compared to other OECD countries, but it has decreased over the last few years (Kupari, Välijärvi, Andersson, Arffman, Nissinen, Puhakka & Vettenranta, 2013). Finnish adolescents are not interested in chemistry (Lavonen, 2009; Kärnä, Hakonen, & Kuusela, 2012). Their interest is lower than in OECD countries in average (Lavonen, 2009) and attitudes toward studies in chemistry are often negative, especially among girls (Kärnä, Hakonen, & Kuusela, 2012).

The rationale for this research is grounded on the general importance of finding novel, research-based chemistry teaching approaches to engage students in learning. According to the 2011 national follow-up assessment in natural sciences (Kärnä et al., 2012), the learning outcomes of Finnish 9th grade students were found to correlate with their working and operating methods. In chemistry, experimental work and demonstrations, reflection about causes and effects of phenomena, making observations about phenomena, and discussing concepts and problems correlated strongly with good learning outcomes. It was also noted that both a positive impression toward the school subject and a positive impression about one’s personal performance in that subject were key elements in improving learning in natural sciences. This is why, particularly in chemistry education, there is a need to design and choose teaching approaches which support the development of these two impressions (Kärnä et al, 2012). According to Hofstein & Lunetta (2003): “Classroom-based research and development associated with curriculum and teaching is important in helping science teachers and students achieve important science learning outcomes (p. 48)”.

How can we then motivate students to like chemistry, learn chemistry and to use both chemistry knowledge and its related skills, for example in daily life situations? Educational games are noted to promote motivation, interest and enjoyment in learning (e.g. Annetta, 2010; Tüysüz, 2009), but the research in the field has focused more on digital games than card and board games. There is also a need for improving the quality of educational games, as well as developing quality evaluation criteria for them (e.g. Dondi & Moretti, 2007; Koskinen, Kangas, & Krofkors, 2014; Owens, Sanders, & Murray, 1997;
1.2 Limitation

In this study, games are limited to educational games and board and card games in particular, which support students in learning chemistry in basic education and at lower secondary level (grades 7th–9th, age 13–16). However, research literature about digital games is used in the theoretical background.

1.3 Structure of research

The structure of this study (Figure 1) follows a typical structure of design-based research (DBR), in which the process is constructed of cyclical phases, so-called design challenges (Edelson, 2002).

DBR was selected as a strategy, because it is developed specifically for education research purposes (Perna, 2003) and it is particularly focused on linking processes with outcomes (The Design-Based Research Collective, 2003). DBR connects research to authentic teaching situations and problems in learning environments (Juntti & Lavonen, 2006), and as a result it produces design solutions (Edelson, 2002). These design solutions are theory development, prescription of successful design processes and prescription of successful design solutions, for example concrete artefacts (Edelson, 2002).

The overall schematic structure of this DBR can be seen in Figure 1. First a design-based research as a strategy is presented and then the theoretical framework in three separate chapters (Chapters 3–5). The theoretical framework forms the basis for three design challenges, which are included in this study (Chapters 6–8). In each of the chapters dealing with these design challenges, the whole design decision from problem analysis to design solution is described in the sections of the chapter. The more detailed description about the structure, the content, and relations between different phases of the research is presented in Section 2.4. and in Figure 3.
Figure 1. The structure of the research about educational chemistry games follows a typical cyclic structure of design-based research (DBR) and consists of a theory framework and three design challenges derived from the theoretical framework and previous design challenges in this thesis. In the figure, the design challenges are situated concurrently with the related theoretical frameworks.
2 RESEARCH STRATEGY: DESIGN-BASED RESEARCH

In this chapter, the research problem and main research question for this design-based research (DBR) are revealed (Section 2.1). Both design-based research methodology in general and its applications in this research are presented (Sections 2.2 and 2.3). A detailed description of the research design and methodology is presented at the end of the chapter (Section 2.4).

2.1 Research problem, aims of the research and research questions

The main research problem in this thesis is: how do we support design and evaluation of educational chemistry card and board games and in-game learning using them? From the research problem, three aims for the research have been derived:

1) To develop a practical and high-quality tool for designing and evaluating educational card and board games for chemistry education;
2) To design research-based educational games for chemistry education in order to support both learning of central chemistry concepts and use of this knowledge and skills in different daily life situations;
3) To achieve understanding of the relationship between educational games and students’ concept development and transfer of knowledge in context-based learning.

This is further operationalized into the following research questions (RQ):

RQ 1: What kind of game design and evaluation tool for educational card and board games supports both teaching and learning in chemistry education?

RQ 2: What features of an educational game may support the development of lower secondary students’ skills in learning and using a piece of information included in the periodic table?

RQ 3: How does an educational game in a food and cooking context help students with development and transfer of knowledge between theory, everyday life contexts and hands-on activity?

2.2 Validity and reliability in design-based research

Openness, authenticity and uniqueness are characteristics of design-based research (DBR), and there is potential for using many different kinds of data as well as methods of data collection and analysis (Pernaa, 2013; The Design Research-Based Collective, 2003). The topic and design decisions of a study determine which methods are most suitable for collecting and analyzing data. Reliability and validity
should be uniquely defined for all of them. (Juuti & Lavonen, 2006). To achieve systematic validity for a DBR, a practice should be informed by theories, and theories should be informed by design solutions (Hoadley, 2004).

One strength of DBR is its potential to take advantage of different data collection and analysis methods (Pernaa, 2013). Mixed methods research makes it possible to use both qualitative and quantitative analysis within the same study. A data set collected with mixed methods can be analyzed in different ways: (1) qualitative and quantitative data can be analyzed together; (2) future data can be based on previous sets; (3) subsequent data can be included into previous sets, supporting and strengthening them (Cohen, Manion, & Morrison, 2011).

The validity and reliability of a DBR study can be evaluated using five general quality criteria:

1. Holisticity: Guiding models and theories, and describing theories as design solutions;
2. Cyclicity: Ongoing iterative development, testing and evaluation;
3. Mobility: Guiding and describing theories, guiding models, and development models as design solutions are transferable out to the field of education and applicable for education specialists;
4. Testing: In the design process testing are applied in authentical circumstances;
5. Documenting: All the cycles of the design-based research are documented in detail (The Design-Based Research Collective, 2003).

Under the guiding models, (1) holisticity means that the general, coherent and consistent guidelines or recommendations for a certain kind of design challenges are presented in this guiding model (Edelson, 2002). A quality design solution is always also a guiding model, because it, as such, is a description about the properties that are to be reached, if the aims for the quality design solution in this certain context are also desired (Edelson, 2002).

(2) Cyclicity also indicates that the first design solution is rarely the most optimized, and more iterative design cycles are needed, with teachers operating as testers, not researchers themselves (Juuti & Lavonen, 2006). Normally, (3) mobility is first local and later wide-scale. According to Barab & Squire (2004), this kind of sequence indicates that a design-based research study is valid and reliable. The level of mobility goes hand in hand with usability. A usable design solution lies within the teachers’ zone of proximal development, meaning that it must both be applicable with the teachers’ present skills, and offer new knowledge to improve the teacher’s teaching (Juuti & Lavonen, 2006). Teachers rarely apply a design solution in their teaching if it seems to be too complicated or difficult to use (Lavonen, Juuti, Aksela, & Meisalo, 2006). Validity and reliability in (4) testing can be improved by the number of design cycles and by the use of standardized measurement tools (Pernaa, 2013).

Validity and reliability for this research are presented in more detail in Chapter 9, where they are delved into one design challenge at the time.
2.3 Design-based research in education

Research in a field of chemistry and science education is applied to support a teacher in his/her learning environment in acting more reasonably and intelligently than before (Juuti, & Lavonen, 2006). The methodology of DBR was developed in the 1990s specifically for education research purposes (Edelson, 2002). DBR in the field of education connects research to authentic teaching situations and problems in real learning environments (Juuti, & Lavonen, 2006). Over the last decade, this method has been established as a part of education research. Several research articles concerning the principles and applications of DBR in science education have been published in the 21st century (e.g. Edelson, 2002; Joseph, 2010; Juuti & Lavonen, 2006; Pernaa, 2013).

For this study, DBR has been chosen as a strategy for two reasons: 1) to develop novel material for chemistry education and 2) to develop a descriptive theory about educational games for lower secondary chemistry education, especially for teaching and learning exemplified by two specific topics. The design process is planned to proceed in cycles so that the material and the theory are designed better from phase to phase, in an iterative manner.

2.3.1 Definition of design-based research

For design-based research, several different definitions with small variations exist (Pernaa, 2013; Juuti & Lavonen, 2006). Edelson (2002; 2014) defines DBR as a process in which the development and characteristics of both design solutions and education-related knowledge or theory are emphasized. Design-based research has three aspects, which should all be included into a design process:

- the theory development
- the prescription of successful design process
- the prescription of successful design solution (Edelson, 2002).

DBR is a scientific approach to education, having a practical base and needs arising from real-life problems in teaching or learning for improving teaching and learning praxis (Juuti & Lavonen, 2006). The aim of DBR is to examine one exact problem or phenomenon to be developed in a learning environment as realistically and authentically as possible. Also, research participants are explicitly capitalized on in the design process. (Barab, 2006; Juuti & Lavonen, 2006).

DBR has three main parts: problem analysis, design procedure and design solution. There might be some variation, and these parts may be repeated during the design process (Edelson, 2002). Based on successful design processes, new descriptive educational theories, guiding development models or guiding models for learning are developed. A learning tool and a teaching method can be mentioned as
examples of the guiding models based on design procedure. Guiding development models are produced by the design procedure, and descriptive theories by empirical or theoretical problem analysis. (Barab, 2006; Edelson, 2002). In this study, both descriptive theory about educational games in chemistry education and guiding models, meaning game design and assessment tool, and educational card and board games, are designed.

There are at least four important factors that indicate differences between DBR and pure design: design-based research is led by research knowledge, systematically documented, formatively assessed and generates results that can be universalized (Edelson, 2002). Whereas in action research, developing the teacher’s own teaching is the focus, not necessary generalizable solutions (Juuti, & Lavonen, 2006).

2.3.2 Methodology for design-based research in education

A remarkable problem in science education research has been the disconnect between research-based knowledge and actual practice in education. In DBR, representatives of these two fields, science researchers and teachers, collaborate to support each other. (Juuti & Lavonen, 2006)

The methodology of DBR is grounded in pragmatism (Juuti & Lavonen, 2006). Pragmatism is a philosophy of science, emphasizing the practical nature of science. It tries to answer a question: how can information from the world structured by matter be gathered by the immaterial mind? The answers are gathered by practicing in the real world (Pihlström, 2007). Pragmatism as well as design-based research are strongly directed towards a serious connection between thinking and praxis (Juuti & Lavonen, 2006).

In pragmatism, the truth is seen to be contingent on context, not to be proved by scientific tests only. Consensus about the truth can be found by communicating with each other. (Juuti & Lavonen, 2006) For example, a (chemistry) teacher may first construct (chemistry) education knowledge independently and then re-construct the knowledge by communicating with other (chemistry) teachers and researchers in science education. From a design-based research perspective, a local design product can be transferred to more common use in this way.

2.3.3 Cyclic structure of design-based research

The three parts of DBR may be repeated during the design process (Edelson, 2002), but the process always starts with problem analysis to ensure that the design approach is based on a real-life problem and that it encompasses a theoretical framework. The problem analysis can be empirical or theoretical,
or both. This part is necessary for specifying and redirecting the research aims for the research over the whole research process. (Edelson, 2002)

A design solution that is applicable to general and wider use is a prerequisite for DBR. But there is no demand for a design solution to be perfect for use as such, because a user's knowledge about the topic is generally less than the researcher's knowledge. (Juuti & Lavonen, 2006) On the other hand, the cyclic structure of DBR allows a design solution to be tested more than once.

The construction of design-based research is about three questions (Figure 2) which concern design, and which are all answered by a certain design decision (Edelson, 2002). Every design decision aims to produce knowledge (Figure 2). In other words, design-based research is to produce three different types of knowledge, consistent with the three main aspects of design-based research. The idea is represented visually in Figure 2.

<table>
<thead>
<tr>
<th>Questions concerning the design</th>
<th>Objectives for knowledge</th>
<th>Design decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the needs and the possibilities for the design?</td>
<td>Knowledge about the needs and the possibilities for the design</td>
<td>Problem analysis</td>
</tr>
<tr>
<td>How will the design progress?</td>
<td>Knowledge about the design process</td>
<td>Design procedure</td>
</tr>
<tr>
<td>What kind of design solutions will the design approach?</td>
<td>Knowledge about the design solution</td>
<td>Design solution</td>
</tr>
<tr>
<td>Testing</td>
<td>Evaluation</td>
<td>Updating a research plan</td>
</tr>
</tbody>
</table>

*Figure 2. The basic structure and content of design-based research (DBR) (based on Edelson, 2002; Pernaa, 2013).*

This cyclic structure makes DBR a complex and multifaceted approach. The entire content of a study usually cannot be described before all the parts of the research are finished. (Edelson, 2002). It is possible to separate one or more design challenges from a study, for which it is then possible to describe the whole design process from problem analysis to design solution (Edelson, 2002). In this study, three design challenges are described (Chapters 6–8).
2.4 Description of the design process: Educational chemistry games

The design process of the work described herein is visually represented in Figure 3, which includes the main elements of the research and their connections to each other. In each of these three design challenges, three processes are described: problem analysis or analyses, design procedure and design solution. Figure 3 also shows how and in which phases there are connections between the three design challenges, the theoretical framework and the development processes of novel theory and design solutions. For example, the third cycle in the development process for educational games also served as the empirical problem analysis in the second cycle of developing the game design and assessment tool.

The numbers of the main chapters of the thesis are also embedded into the figure to give the reader a visual view of the entire structure of this thesis. The whole of Figure 3 can be seen both as the structure of a DBR study in general, and a meta perspective on the educational resources in the present design-based research, which in this case is about educational chemistry games in lower secondary education.

Several different data collection and analysis methods have been used in the three design challenges of the study and data has been collected using mainly qualitative methods, for example case studies and small-scale questionnaires. Case studies can be seen as situations which have been documented in detail. A goal in using qualitative depth-study methods was to understand educational games as a teaching approach. However, remaining loyal to the strategy of design-based research, the design solutions of this research, meaning the three educational chemistry games and CHEDU game design tool, are generalizable and ready-to-use for chemistry education. Data collection and analysis methods are described in detail for each the three design challenges (Chapters 6–8).

Reliability and validity of this research are discussed in Chapter 9. The whole research is then composed in conclusions and discussion (Chapter 10).
Figure 3. The visual description of the realized design-based research (DBR). The main contents and the cyclic structure of the research have been described with the boxes, lines and arrows. Three typical aspects (or aims) of the design-based research are colored in blue: Description of design processes, theory development and design solution (Edelson, 2002). The phases of the research are situated in three columns from top down. Arrows between the boxes and columns show how different phases of the research are connected to each other. Links between the first and the third columns are shown with dashed line arrows in the figure. The first column describes how and what kind of novel theory or education-related knowledge has been developed or supported in this research process. In the second and third columns the cycles of two design processes for the design solutions, meaning three educational games and a game design and assessment tool, are described. The second and third column also describe two successful design processes.
3 THEORETICAL FRAMEWORK: EDUCATIONAL GAMES

Play cannot be denied. [...] You can deny seriousness, but not play. – Huizinga (1949/1998)

Theories about games, playing, educational games and game design are presented in this chapter. The central concepts of game, play and playing are discussed, as well as theories about educational games and their features. In the end, educational games in education and particularly in chemistry education are discussed. Based on this theoretical framework, three educational games, one design and evaluation tool and new theories were developed in design challenges 1, 2 and 3.

3.1 Games and playing

Play can be seen as a special form of activity, which has a social function in culture (Huizinga, 1949/1998). For example Domino traveled from China into Europe in the 14th century, and the present rules were developed in 18th-century Italy. (Casbergue & Kieff, 1998) Many contemporary card, board and digital games are based on game mechanics and rules in older and traditional games.

Card and board games play an important role in almost every Finn’s childhood: Afrikan Tähti (en. Star of Africa), Kimble and Musta Pekka (pres. Pekka-peli, similar to en. Old Maid) are easily played, without having to re-read the rules every time. In the 1980s, the number of different board games and the complexity of game materials increased in parallel with increasing living standards in Finland (Keskitalo, 2010). But these games were based more on luck than knowledge and skills. At the same time, video and role-playing games arrived in Finland (Keskitalo, 2010). Because of the video games, playing games became an increasingly acceptable way of spending spare time not only for children, but also for youths and adults.

Since the 1970s, digital games have flooded homes, computers, tablets and smartphones and most people in developed countries have played them or at least recognize them (Warren & Jones, 2017). In the 1990s, playing video games was so popular that it was feared that the culture of card and board games would vanish (Keskitalo, 2010). But this did not happen. Instead, a new generation of board and card games appeared on the market at the beginning of the 21st century. These games challenged players to think and use their skills by combining traditional ways of playing card and board games with role-playing and the ways in which video games are typically played. One well-known example is Carcassone. In Finland, digital games are played widely, regardless of age or sex, even though young men and boys are the most eager players (Kallio, Kaipainen, & Mäyrä, 2007; Kallio et al, 2009). This thesis focuses on card and board games.
3.1.1 Games classification

Games can be classified in many ways, depending on what purpose the classification is made for. For the purpose of differentiating digital games and other games, for example the following classifications are possible:

- computer games vs. other games (Juul, 2003)
- digital games vs. non-digital games (Deterding, Dixon, Khaled, & Nacke, 2011)
- digital games (technology-based games) vs. traditional games (Casbergue & Kieff, 1998)
- video games vs. board games (Keskitalo, 2010).

Rules and mechanics in games can be considered to follow the needs and the priority orders in society:

- collaborative games: people need to act as one group to survive
- competitive games: domination is needed to survive in society
- strategy games: the society works under the order of social hierarchy and complex rules
- simulation and role games: to solve real-life problems (Casbergue & Kieff, 1998).

Games can also be classified into entertainment games or educational games, depending on the learning purpose. In previous research, educational games have also been called learning games or serious games (e.g. Charsky, 2010; Dondi & Moretti, 2007; Warren & Jones, 2017). In this research two parallel classifications are used: games vs. educational games, and digital games vs. card and board games. This research focuses on educational card and board games.

3.1.2 Definition of a game

All games consist of rules, objectives or goals, choices, challenges and imagination. Games and educational games differ from each other in the way in which these typical element are used. (Charsky, 2010)

The classic game model specifies six features that all games should include:

1. A game is based on rules;
2. A game has an quantifiable outcome, which can be changed;
3. Outcomes in a game are unequal: some are positive and some are negative;
4. In a game session players have to strive when they are trying to affect the game’s outcome: in other words, a game is challenging;
5. In a game session players are keen on an outcome: a positive outcome makes a winner happy and a negative outcome makes a loser dissatisfied;
It is possible to play one game in two different ways: either it has consequences in real life or not (Juul, 2003).

Based on a review of game design literature by Warren, Jones, Dolliver, & Stein (2012), to be defined as a game, three basic criteria must be filled:

1. an interactive rule set governing play;
2. a conflict to drive play; and
3. a win scenario / condition.

Over the years, what constitutes a game has been defined in various ways. Piaget (1951/1999) has defined that a game has conserved rules which can be used in competition with the hope of winning. According to Adams (1973), “games are like play except that they usually have an end, a payoff” (as cited McSharry & Jones, 2000, p. 74). Suits (1967) has stated that “to play a game is to engage in activity directed toward bringing about a specific state of affairs, using only means permitted by specific rules, where the means permitted by the rules are more limited in scope than they would be in the absence of the rules, and where the sole reason for accepting such limitation is to make possible such activity” (p. 156). Kelley (1988) defines a game in a slightly different way: “A game is form of recreation constituted by a set of rules that specify an object to be attained and the permissible means of attaining it” (p. 50).

Based on the game model developed by Juul (2003) and in line with basic criteria (Warren et al, 2012), Salen & Zimmerman (2003) define a game as follows: "A game is a system, in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (p. 80).

On the grounds of the definitions presented above, it can be said that a game typically consists of some kind of artificial conflict, meaning a competitive position between players toward winning and a quantifiable outcome, which will be either positive or negative for the player.

### 3.1.3 Game playing

Having a game is not enough. To generate an enjoyable game experience, the game has to be played in a meaningful way. A meaningful game can be defined to be a game in which the relationship between in-game actions and outcomes are discernable and integrated (Salen & Zimmerman, 2003). **Discernable** means that the game communicates players’ actions and there are comprehensible meanings to their actions. **Integrated** means that any action a player takes affects the player experience immediately, but also at a later point in the game. Meaningful play should be an aim whenever games are designed. (Salen & Zimmerman, 2003)

According to Salen & Zimmerman (2003), playing requires players to have a *lusory attitude*, meaning that every player accepts the game’s rules and its artificial world. An artificial conflict,
defined by the rules of the game, drives players to play (Salen & Zimmerman, 2003; Warren & Jones., 2017). Rules can be seen as constraints that limits the actions a player can or cannot take (Charsky, 2010). In the play-state a player is surrounded by the magic circle of a game (Figure 4), where the real world is excluded and the players are under the order of the game rules. Play is not real life, but stepping into a temporary sphere: being apart from real life together with other players (Huizinga, 1949/1998). In the the expanded game experience model (EGE model) of Kultima and Stenros (2010) six different transition phases for game users are presented: choosing to play, choosing a game, choosing to start, choosing to quit, abandonment and choosing to replay. In this model, the real world and everyday life are connected to game experience with user factors, like the situation and context, the worldview and beliefs, and motives and resources.

Figure 4. A frame for an act of playing and a whole game session can be described as the magic circle, in which there exist both open and closed systems affecting a game: rules, play and culture (based on Kultima &Stenros, 2010; Salen & Zimmerman, 2003).

Every game has a beginning, a middle and an end with a quantifiable outcome (Salen & Zimmerman, 2003). A play session begins, moves on, and at a certain moment, it is over (Huizinga, 1949/1998). In general, playing a game is about a repeated series of actions and making decisions: every
decision made by players results in a change, which changes a whole game system and creates new meanings (Salen & Zimmerman, 2003). While a game and play are in progress, movement, change, alternation, succession and separation exist (Huizinga, 1949/1998). Inside the magic circle, a game can be rules, playing, or culture, or all of them at the same time. All play has its rules, but in games the rules are normally stable, and therefore defined as a closed system (Huizinga, 1949/1998; Salen & Zimmerman, 2003). The rules are a very important factor: they determine what is permitted in the temporary world of the game (Huizinga, 1949/1998). Rules must not be questioned, and if they are transgressed, the magic circle will be broken. A play session may end, when the quantifiable outcome is reached (Salen & Zimmerman, 2003), or when a player or players choose to quit a game for a reason or another (Kultima & Stenros, 2010).

Playing can be either a closed or an open system. As a closed system it pays attention only to actions following the game rules, but as an open system it also takes into account, for example, players' expectations and relationships in the real world. As culture, a game is always an open system, because every game inevitably reflects on something about the culture in which it has been created. In this way a game brings into each game session something from the real world otherwise excluded. (Salen & Zimmerman, 2003) Game playability (Section 3.2.2.1) and engaging game elements (Section 3.2.2.2) are discussed in section 3.2.

3.1.4 Game players

Game players can be categorized in different ways. The quantitative division into hardcore players and casual players depends on in-game differences in skill and time investments (Ip & Jacobs, 2005). They also can be classified into different types, according to players' way of playing a certain digital game (e.g. Drachen, Canossa, & Yannakakis, 2009) or their behaviors when playing a certain kind of digital game, for example Multi-User Dimensions (MUDs) (e.g. Bartle, 1996). In recent studies, these typologies have been criticized as expressing overly simplified perspectives about the diversity of game players. In a study by Tuunanen & Hamari (2012), a concept-centric listing of the player typologies in the previous game research was constructed, in which a total of seven concepts is used to describe players: gaming intensity and skill, achievement, exploration, sociability, killer, immersion and in-game demographics. Achievement and sociability were found to be the most common dimensions, but this research covered only certain types of games: Massive Multiplayer Online Games (MMOs), Role-Playing Games (RPGs) and First Person Shooter games (FPSs) (Tuunanen & Hamari, 2012).

In their 3-year study of Finnish digital game players, Kallio et al (2009; 2011) tried to approach more general and domain-free player typology, where games are seen as an integral part of the everyday lives of Finnish people. According to their results (Kallio et al, 2009; 2011), players' gaming mentality can be
classified as social, casual or committed. Even though the research was about digital games, at least the social and casual player mentalities are common to all gaming and playing activities, including card and board games (Kallio et al, 2011). Social mentality is about gaming for company and the games to be played are already familiar for all or easy to learn and play. Those who have a casual mentality play for entertainment and they contrast games with movies and music. Games are played if there seems to be a suitable time. A casual player plays to kill time, to fill gaps or to relax. Committed playing is the opposite of casual playing, because gaming is important as such. The committed player requires persistence, originality and storytelling from the game. Enjoyment in committed playing is different from casual playing: some players enjoy emotional experiences, some projecting themselves into the game, whereas some enjoy skill development. In Finland, casual gamers are in the majority and the form of gaming ranges between “casual relaxation” and “committed entertainment” (Kallio et al, 2009; 2011).

In a study by Harviainen, Lainema and Saarinen (2014), impediments to game-based learning in games and simulations were examined. According to their results, four key issues prevent some players from learning during play. One of them is unrealistic trust, increased or lessened, amongst players compared to trust in the real world. Another one is excessive competitiveness, which means that if in-game competition is at a high level, there is no room for error, and therefore winning is more important than learning. Because the magic circle of the game is isolated from the real world, players may take unnatural risks during play. In-game dishonesty was also mentioned as hindering learning, particularly in simulations. It means that the skill practice opportunities offered by a game or a simulation have not been taken seriously or seen to be connected to the real world.

### 3.1.5 Game design

Former game design has been based mostly on game design guidebooks with principles and elements of game design and an idea of “player advocacy”, where consumerism and pleasing the player have been in focus (Kultima, 2015; Wilson & Sicart, 2010). Recently game design has turned to “abusive design” direction to surprise and displease the player (Kultima, 2015; Wilson & Sicart, 2010). Still, explicit descriptions of game design processes are needed, as well as ways to bridge the gap between the game researchers and industrial game developers: Following academic research disciplines also in the commercial game industry is challenging (Kultima, 2015).

Much of the game research is still lacking of theoretical grounding (Whitton, 2014). But, in recent years game design has got closer to educational game design and constructivist learning theories has been seen to be relevant addition, for example in understanding about players as meaning makers and knowledge constructors in simulation games (Lainema, 2009).
In order to make game design process explicit and transparent, Kultima and Sandovar (2016) have developed a framework to describe multitude of game design values, to make them explicit and to help understanding of the pluralistic nature of game design (Table 1). The framework has potential to give game designers’ awareness of which kind of values they are aligning with.

Table 1. Multitude of design values in the field of game design (Kultima & Sandovar, 2016).

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DESCRIPTION OF CATEGORY</th>
<th>DESIGN VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of player centrism</td>
<td>Emphasis on player centric game design</td>
<td>Player’s advocacy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co-creativity and user inclusion</td>
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<tr>
<td></td>
<td></td>
<td>Usability and playability</td>
</tr>
<tr>
<td>Casual game design values</td>
<td>Emphasis on digital games as products for mass markets and in heterogeneous user groups</td>
<td>Accessibility (ease of play and to acquire)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acceptability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flexibility</td>
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<tr>
<td></td>
<td></td>
<td>Simplicity</td>
</tr>
<tr>
<td>Traditional game design values</td>
<td>Emphasis on themes of traditional video games</td>
<td>Immersion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Challenge and competition</td>
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<td></td>
<td></td>
<td>Community</td>
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<tr>
<td></td>
<td></td>
<td>Other-worldliness</td>
</tr>
<tr>
<td>Value of artistic expression, innovation and experimentation</td>
<td>Emphasis on exploring and advancing the medium of digital games instead of creating polished experiences and successful products</td>
<td>Visual design and aesthetics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experimentation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Divergent design</td>
</tr>
<tr>
<td>Ludological values</td>
<td>Emphasis on digital games as special form of art</td>
<td>Enjoyment and value of fun</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological agnosticism</td>
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<tr>
<td></td>
<td></td>
<td>Nostalgia and retro aesthetics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value of game mechanics</td>
</tr>
<tr>
<td>Societal impact and cultural values</td>
<td>Emphasis on a certain social agenda</td>
<td>Games for good and impactful games</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversity and accessibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ethics and morality</td>
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<tr>
<td></td>
<td></td>
<td>Cultural diversity and tradition</td>
</tr>
<tr>
<td>Values of production and creation process</td>
<td>Emphasis more on the development culture than the game itself</td>
<td>Peer respect and professional identity</td>
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<td></td>
<td></td>
<td>Collaboration and value of teamwork</td>
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<tr>
<td></td>
<td></td>
<td>Open source ideology</td>
</tr>
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<td></td>
<td></td>
<td>Polish and details</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological advancement</td>
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<tr>
<td></td>
<td></td>
<td>Development as a challenge</td>
</tr>
<tr>
<td>Values of independency</td>
<td>Emphasis on cultivating autonomy, freedom and subversive game design</td>
<td>Autonomy and artistic freedom</td>
</tr>
<tr>
<td>Values of commercial</td>
<td>Emphasis on game design as business</td>
<td>Anarchy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economical success</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Opportunism and disruption</td>
</tr>
</tbody>
</table>

3.1.6 Special features for card and board games

This research focuses on card and board games. It is impossible to embed them with the same effects, razzle-dazzle and multifacetedness, and themes to the same extent as digital games (Keskitalo, 2010). With paper-based games a player is not able to feel the same kind of immersion as with, for example, complicated video games individually and with a committed mentality. Instead, card and board games
have some special features, which differentiate them from digital games in a positive way. (Keskitalo, 2010)

During card and board game session, players have a face-to-face interaction in a real life situation. For this reason, the playing experience is diverse: as a player you have to take other players into account using different tactics and strategies. Card and board games are independent on the user interface. Game sessions with card or board games are often quicker compared to video games. Industrial production of card and board games is normally a short, easy and cost-effective process. This enables the use of even conflicting themes in card and board games, and thus generate the potential to affect players’ values, attitudes and opinions. (Keskitalo, 2010)

3.2 Educational games as a teaching approach and in learning

Educational games are games that have been developed for educational purposes. They can be seen as a combination of the teaching and learning approaches, which has the power to turn a teacher-centered learning process into a student-centered one by enforcing interplay between the students (e.g. Lujan & DiCarlo, 2006; Ke, 2008). Warren & Jones (2017) have named educational game players as player-learners.

In their meta-analysis, Wouters, van Nimwegen & van Oostendorp (2013) confirmed the effectiveness of educational games in promoting learning and retention compared to conventional instruction methods, such as lectures, reading or drill and practice. But according to a literature review by Qian and Clark (2016) and a review of meta reviews by Whitton (2014), no consensus about the effectiveness of educational games in learning has been reached and studies in the field reveal varying degrees of success depending on topic and age level. In Ke’s meta-analysis (2009), 34 of 65 studies reported computer games as having significant positive effects on learning, 17 reported mixed results, 12 reported computer games as having similar effects on learning as conventional instruction, and one study reported conventional instructions to be more effective. One example of mixed results is a study by Cameron & Dwyer (2005), where simple gaming was uneffective, whereas gaming with questions and elaborative feedback was significantly more effective than mere gaming or conventional instructions.

Potential for teaching 21st century skills to students has been seen in educational games, especially in digital games, (Qian & Clark, 2016). Critical thinking, creativity, collaboration and communication epitomize 21st century skills. Game elements, such as providing players with adaptive challenges, immediate feedback, variable rewards or low-stakes failures can be linked directly to the 21st century skills, but also to the theoretical bases of social constructivist learning and the concept of flow (Qian &
Clark, 2016). According to Vygotsky’s learning theory (1978), learning is social, active and situated. A literature review by Wu et al. (2012) revealed that playing educational games tended to provoke positive learning outcomes if learning theories were used as the basis of game design.

3.2.1 Definition of an educational game

As a game (see Section 3.1.2), an educational game can be defined in different ways. The terms learning games or serious games can be used as synonyms for educational games (e.g. Warren & Jones, 2017). But actually as a category, serious games refers to a slightly different purpose than educational games, because they are defined as instructional and carefully thought-out games and simulations that can be used to train decision-makers in industry, military, government and (medical) education (e.g. Abt, 1970; Bergeron, 2006; Breuer & Bente, 2010). But, for example, a board game designed primarily to be played for amusement can be used in military training to teach strategic thinking (Breuer & Bente, 2010). In this study, the name educational games is used.

Each of the definitions for an educational game combines a definition of a game with a definition of learning. Dondi & Moretti (2007) have given a very precise definition of educational games: “we mean games that have an explicit didactic purpose and that can be used, adapted and adopted for supporting, improving and fostering learning processes within formal, nonformal and informal learning scenarios.” (s. 508). Saarenpää (2009) gives a slightly simpler, standard language definition: “Educational games are games, which are designed to teach certain knowledge or skill. They can be used both at home and at school, but their main purpose is to support teaching. In these games a problem solving is typically progressed in linear way”. Garris, Ahlers, & Driskell (2002) and Landers (2014) see an educational game consisting both an instructional content and game characteristics, also called as game elements (features or mechanics), which together affect player motivation and engagement during a play session and this way cause learning.

In this study an educational game is defined as a game, which can be used and adapted for improving, enhancing and supporting the teaching and the learning process for certain fields of knowledge or skills.

3.2.2 Features of a quality educational game

At the beginning of the 21st century, assessment of educational games was mainly based on research about entertainment games: the distinction between games and games for educational purposes was absent (Prensky, 2001; Squire, 2002; de Freitas & Oliver, 2006). But it is important to differentiate these two types of games and create a culture of quality game assessment within the educational game band
(Dondi & Moretti, 2007). Warren and Jones (2017) highlight that “without the ability to link the [educational] game activities to learning outcomes, anything else one produces is just an entertainment game” (p. 6).

In the research, educational games are noted to possess the potential to make learning enjoyable and fun, yet effective (e.g. Akkuzu & Uyulga, 2016; Bayir, 2014), although fun is not necessary the key element in educational games (Henriksen, 2008) but arises out of mastery (Koster, 2005). Playing educational games provides students with opportunities to take responsibility for their own learning, emphasizing student-centered learning processes instead of teacher-centered ones (e.g. Akkuzu & Uyulga, 2016; Ke, 2008; Lujan & DiCarlo, 2006). Hence, educational games have the power to enhance the interplay between students and enable the construction of meaningful knowledge together (e.g. Franco-Mariscal, Oliva-Martínez, Blanco-López, & España-Ramos, 2016; Ke, 2008; Lujan & DiCarlo, 2006). In other words, with educational games it is possible to execute a social constructive way of learning. According to Whitton (2014) simple drill-and-practice educational games are based on principles of behaviorism and they are still prevalent, possibly due to easiness of design and evaluation. Whereas research-based educational games are based on principles of constructivist learning theories (Whitton, 2014).

Well-designed educational games are able to develop the social skills, critical thinking and higher-order thinking skills of the player-learners, meaning problem-solving skills, application and analysis of knowledge, and creation of novel knowledge (e.g. Chee, 2015; Ke & Abras, 2013; Maltese, 1995). Chee (2015) describes games with meaning-making and contextualization activities as games-to-learn, instead of content and right-answer focused games-to-teach. Instead, mistake-making is seen as an inevitable part of gaming, not as failure (Whitton, 2014).

Quality educational games also maintain students’ interest, engage them to finish the task and supply possibilities for wider societal discussions (e.g. Koskinen, Kangas, & Krokfors, 2014; Owens, Sanders, & Murray, 1997; Tüzün, Yılmaz-Soylu, Karakus, İnal, & Kizilkaya, 2009).

Educational games are suitable for use in parallel with other teaching and learning approaches. For example, hands-on activities in chemistry education cannot be replaced by games (Brendzel, 2004). Wouters et al. (2013) noted that involving multiple methods of teaching the same topic enhanced game-based learning in particular.

Educational games can be used in at least three different ways in education (Grady, Vest, & Todd, 2013):

1) as a primer for a new topic prior to the actual teaching;
2) as a sole teaching approach for teaching a new topic; and
3) as a reviewer or a reinforcer for a previously taught topic.
In the previous research, educational games are mostly used for reviewing, reinforcing or deepening and broadening a previously taught and learned topic (e.g. Bayir, 2014; Franco-Mariscal, Oliva-Martínez, & Bernal-Márquez, 2012; Kurushkin & Mikhaylenko, 2016; Pippins, Anderson, Poindexter, Sultemeier, & Schultz, 2011). Findings by Grady et al. (2013) indicated that, at least in large classroom settings, university students preferred traditional lectures instead of educational games as a more effective way of learning a new topic, but games were preferred as primers and reviewers. In the use of a task involving play (TIP) method, in which teaching units included both educational games and tasks involving play, the educational game was perceived as a positive factor for the learning of the periodic table (Franco-Mariscal et al., 2016).

There is also evidence against games as effective learning tools (e.g., Randel, Morris, Wetzel, & Whitehill, 1992; Emes, 1997). The conclusions of these studies propose that games are effective only for learning certain content and in situations where the objectives are clearly defined.

### 3.2.2.1 Playability

A game can be divided into three distinct, parallel components: mechanics, dynamics and aesthetics (Hunicke, LeBlanc, & Zubek, 2004), which all affect the playability of the game. Hunicke et al. (2004) define these components as follows:

- **Game mechanics**, which are a game rule-based relationship between particular components of the game: the board, the cards, the pieces, and various actions and behaviours within the game context.
- **Game dynamics** is supported by the game mechanics, and it describes the use of the game: the players’ inputs and outputs in the game session.
- **Aesthetics** of the game describes players’ emotional responses in interaction with the game, including fantasy, narrative and challenge discovery.

Rules and playing time are important parts of game mechanics. The simpler the rules are, the easier a game is to play, particularly for younger players (Galus, 2003; Tsai, Tsai, & Lin, 2015). The rules should also be short and unambiguous (Galus, 2003). Over the course of one lesson, it would be reasonable to have time to both read the rules and then play a game once or twice. The playing times in many card and board games targeted for lower secondary chemistry education are relatively short, 10–15 minutes (e.g. Bayir, 2014; Franco-Mariscal et al., 2012), but in educational chemistry games meant for upper-secondary or university level, game sessions are normally longer, for instance 30–40 minutes (e.g. Kavak et al., 2016; Knudtson, 2015). Even though the game rules are normally stable during play, the students can be encouraged to tailor new rules for prefabricated educational card and board games (Casbergue & Kieff, 1998; Ke, 2009).
According to Gredler (2004), educational game dynamics should be easily understood by and attractive to all the students. In addition, the game should offer relevant in-game information regarding the game content in order to enable learning to occur.

By specifying the aesthetics of the game, it is possible to reveal why different games appeal to different players (Hunicke et al., 2004). However, according to Warren and Jones (2017), the attractiveness of the game is less important than its function, as long as it can deliver the learning content in a fun and engaging way.

### 3.2.2.2 Engaging game elements

Emotional experiences, such as fun, enjoyment and excitement, are generally mentioned as one of the main goals of games (e.g. Akkuzu & Uyulga, 2016; Bayir, 2014; Chanel, Rebetez, Bétrancourt, & Thierry, 2008). The fun element characterizes the essence of play, yet the contrast between seriousness and play is fluid (Huizinga, 1949/1998). There exist critique against fun to be treated as a key factor in educational games, while being the prime purpose of commercial games (Henriksen, 2008). In the study of Henriksen (2008), the fun was visible but not dominant to the game nor among different game-related participational incentives. Instead, a small token of mastery and positive in-game feedback worked as motivating factors for the players. Papert (1998) has described a concept of hard fun, meaning that gaming is fun because it is hard, and fun is a result of in-game frustration and challenge. “Fun from games arises out of mastery” (Koster, 2005, p. 40).

Specific emotions have the power to engage students and immerse them into the game (e.g. Chanel et al., 2008; Hamari et al., 2016). This is in line with the learning theories of cognitive and social constructivism, in which attitude and interest are seen as two factors that affect student’s learning motivation in addition to cognitive processes (Nieswandt, 2007; Rahayu, 2015). Educational games also have the potential to engage students in learning (e.g. Poondej & Lerdpornkulrat, 2016). But according to Whitton (2014), relatively few studies are supporting changes in students’ attitudes.

Winning and losing scenarios must be present in a game to drive learning (Warren & Jones, 2017) and the winner should not be evident too early (Gredler, 2004). The chance to win has been noted to be an engaging element (Zhang, 2017). There should be a degree of tension, meaning uncertainty, unpredictability and unexpected events in every game: then the player who masters the content knowledge will not always be the obvious winner (Gredler, 2004; Huizinga, 1949/1998; Salen & Zimmerman, 2004). For example, the possibility of stealing another player’s points can be classified as unpredictability, and it was found to engage university students in the ChemKarta game (Knudtson, 2015). When rewards and positive feedback alternate with challenges and conflicts in actual game situations, players will experience alternating feelings of anxiety and boredom, which for their part
engage players to play and learn (Annetta, 2010; Tüysüz, 2009). In-game challenges fulfill learning games (Annetta, 2010; Charsky, 2010; Tüysüz, 2009) and they possess a positive effect on learning both directly and via engagement (Hamari et al., 2016). In single-player and multiplayer video games, challenge was found to be the top motivational element (Hainey, Connolly, Stansfield, & Boyle, 2011). At the university level, older students were less enthusiastic about in-game prizes and awards than younger students (Grady et al., 2013). For experienced and skilled university students, more real-life examples in game and fewer game-design elements are suggested (Daubenfield & Zenker, 2015).

These emotions of anxiety and boredom engage students in play and in learning during play. Both the feeling of attendance and the feeling of achieving the game objective have a similar effect as feelings of anxiety and boredom. (e.g. Annetta, 2010; Tüysüz, 2009) In the previous research, it also has been determined that despite being engaging, a game does not necessarily help a player to achieve the aim of learning, for example, how to calculate the amount of supplies (Ke & Abras, 2013). In general, emotionally arousing moments tend to be better remembered than neutral moments (LaBar & Cabeza, 2006) and positive emotional climate in the classroom are engaging students with learning (Hardiman, 2010).

A decrease of arousal and pleasure was observed when players played a game twice under the same conditions (Chanel et al., 2008). According to Chanel et al. (2008), different levels in a game inspired different emotional in-game states in the players, but staying on the same level of difficulty for a long time elicited only boredom. Engagement will occur if the skills of the player meet the challenge of a new task. Anxiety and frustration will occur instead if the difficulty increases too quickly compared to the player’s competence, and similarly boredom, if the difficulty remains the same while the skills of the player have increased (Chanel et al., 2008; Henriksen, 2008). To be motivating, in-game challenges should be yet challenging but attainable, so called appropriate challenges (e.g. Henriksen, 2008; Whitton, 2014), and lie in the zone of player’s proximal development (Vygotsky, 1978). Game structure is capable to enhance enjoyment and engagement of the players, if the type and level of challenge is right (Whitton, 2014).

Particularly in digital game design, it is important to develop a narrative, a story and a backstory with interwoven narratives (Dickey, 2005; Warren & Jones, 2017). According to Namkee, Kwan, Seung-A & Sukhee (2010), both a visual video backstory and a non-visual backstory text are able to improve students’ positive attitudes towards a game to be played. As vehicles for narrative, game characters are one of the engaging elements in games (e.g. Dickey, 2005; Ermi & Mäyrä, 2003). According to a study by Ermi and Mäyrä (2003), immersion into the imaginary game world was one of the pleasurable aspects of digital game play for Finnish children (age of 10–12 years). While playing roles, students are able to explore social roles (Qian & Clark, 2016), perhaps similar to real-life society. For diverse learners, the ability to create their own avatar reinforced their sense of control in a game session (Ke & Abras, 2013).
Additionally, Wouters et al. (2013) and Whitton (2014) have both suggested that students' intrinsic motivation for playing educational games can possibly be dependent on their lack of control over other aspects of their lives. Lack of control means that leisure games are engaging and intrinsically motivating, because they are chosen by the players, and played whenever and as long as wanted, whereas educational games are normally played during the lessons and under teacher's orders.

3.2.2.3 Sociality

Students' in-game interactions should allow exploration of models for learning to happen (Warren & Jones, 2017). Playing games in groups was observed to enhance learning (Wouters et al., 2013). In player-game interaction, student learn new strategies and tactics from the experience and, as a result of this learning, the next game play will be dissimilar, but familiar (Warren & Jones, 2017).

When playing games together in player-player interaction, students may interact with each other by discussing the learning topic in parallel with processing knowledge by themselves, as well as comparing the existing knowledge by themselves and with each other (Lujan & DiCarlo, 2006). The whole group of players may learn. This is called meaningful learning, because, the students construct novel knowledge together by understanding the wholes, not just remembering single facts (Lujan, & DiCarlo, 2006). This kind of learning takes time, but also follows the principles in the learning theories of Piaget (1951/1999) and Vygotsky (1978). According to Whitton (2014) there is a different dynamic in pairs compared to small groups, especially in the context of education.

According to previous research, students mostly enjoy playing educational games (e.g. Carney, 2014; Franco-Mariscal et al., 2012; Franco-Mariscal et al., 2014; Kavak & Yama, 2016; Zhang, 2017). Along with learning new knowledge, engagement with the group, feelings of team spirit and enhancement of self-courage may increase, and societally important group work skills may be developed as well (Nemerow, 1996; Lujan, & DiCarlo, 2006; Costa, 2007). In a study by Wouters et al. (2013), games' effect on motivation were not found to be significant.

It has been shown that low-achieving students, students with special learning needs, and those, who lose their motivation and interest quickly benefit most from quality educational games (Ke & Abras, 2013; Ke 2009; Virvou, Katsionis, & Manos, 2005). For many learners, open-ended game challenges that allow for partial success are suggested, together with sufficient cognitive processing time, particularly on abstract topics (Ke & Abras, 2013). For higher-achieving students educational games do not have similar effects, yet they also enjoy playing them (Ke 2009; Virvou et al., 2005). Gender has an influence on how a student plays rather than what a student learns in the game session (Ke, 2009). Younger students tend to enjoy playing educational games more than older students, at least those at the university level and in large classroom settings (Grady, Vest, & Todd, 2013).
If educational games are used as a learning tool for all the class, it is important to design or choose a game that allows all students to participate in gaming at the same time, for example in parallel gaming sessions (Galus, 2003). This is possible if there are several sets of the same or analogous card or board games available in the school, or sufficient numbers of computers, tablets or smartphones available.

### 3.2.2.4 Competition, cooperation and collaboration

Competition is a part of our culture and competitiveness is a part of play within culture (Huizinga, 1949/1998). Most games are grounded on the idea of competition between players. In Nemerow’s study (1996), a majority of students were noted to have a positive attitude towards performance anxiety during a play session, but not for the anxiety and pressure of hinting and possible failure during a teacher-centered lesson. However, there still might exist students who experience both of these situations as similarly distressing. Even though a competitive element is typically included in the games, it has been observed that a cooperative, collaborative or individual aim helps the progress of learning more than competitiveness (Bornstein, Kugler, & Ziegelmeyer, 2004; Zagal, Rick, & Hsi, 2006; Ke, 2008). Competition between groups rather than individuals has potential to support learning (Johnson & Johnson, 1999), but according to Harviainen et al. (2012), competitiveness may even hinder in-game learning.

A cooperative game can be described as a game in which it is possible, for example, to buy something from other players, whereas collaborative game is a game in which all the players play together against a shared opponent (Zagal, Rick, & Hsi, 2006). In cooperative or collaborative play, students focus on a shared aim and because of that, they play more rationally and more quickly, and make fewer mistakes than in competitive play (Bornstein, Kugler, & Ziegelmeyer, 2004; Zagal, Rick, & Hsi, 2006). Decision-making in cooperative or collaborative play often differs from individual play (Bornstein, Kugler, & Ziegelmeyer, 2004; Ke, 2008). It also seems that boys engage in cooperative game and in-game problem-solving better than girls (Ke, 2008). When university students were encouraged to engage in peer-to-peer discussion during play to help each other in problem-solving, it was noticed that in order to win, players did not give peer-to-peer support to others, but attempted to solve the in-game problem by themselves (Knudtson, 2015).

Winning the game should depend both on skills and on luck, and every player should learn something (Gredler, 2004). The most skilled student should not be the evident winner, nor should wrong answers be penalized by loss of points (Gredler, 2004).
3.2.2.5 Instructions, support and feedback

Instructions and feedback has been noted to be essential for learning (Whitton, 2014). Particularly, feedback from a game or a teacher must be available for learning to occur (Warren & Jones, 2017). Prior research in the field of educational games points out that the teacher plays an active role in the use and guidance of game sessions, and in planning the entire game-based learning process (Koskinen et al., 2014). Educational games offer the teacher opportunities to observe actions and behavior in player-learner groups, and also specifically to give support, guidance and feedback whenever it is needed in the game session (Koskinen et al., 2014). Mapping preconceptions or misconceptions is also enabled with educational games (Costa, 2007).

According to previous studies in the field of educational games, peer support and guidance given by the teacher in pregame, in-game and postgame situations are strongly linked with motivation and thus enhance learning (Barab et al., 2010; Casbergue & Kieff, 1998; Ke, 2009). If a teacher or game itself does not offer sufficient in-game guidance, the players will learn how to play the game, but not necessarily the immersed learning goals (Casbergue & Kieff, 1998; Ke, 2009).

Under the guidance of the teacher and together with all the player-learners, it is appropriate to arrange a postgame session to sum up the learning goals and knowledge achieved while playing (Koskinen et al., 2014). To achieve a transformation of knowledge in parallel with a generalization of the knowledge in students’ minds, it is recommended to cover and discuss the same content knowledge in different contexts, either as embedded within the game, during a game session, or during other teaching situations (Barab et al., 2010). Whitton (2014) suggests reports on actions taken and decisions made, with critical analysis of consequences of decisions, as one possible way to assess in-game learning.

3.3 Educational games, teachers and pre-service teachers

That is to say, the teacher has many responsibilities when integrating an educational game into education. But at the same time, the teacher offers students opportunities to see and learn one topic from many perspectives and in different contexts (Barab, Sadler, Heiselt, & Zuiker, 2010; Kangas et al., 2016).

Pre-service teachers, in turn, stand between the perspectives of students and teachers. It has been shown that pre-service teachers tend to engage with the teaching methods they were exposed to during their studies, and it was necessary for them to experience, in particular, active learning, meaning collaborative knowledge construction, during their studies (Niemi, 2002; Putnam & Borko, 1997).
3.3.1 Educational game playing potentials and possibilities for teachers

The teacher is responsible for determining when and why to use an educational game in teaching and to specify when and what to learn: a specific phenomenon, skill or knowledge (Kangas, Koskinen, & Kroksfors, 2016; Rastepargour & Poopak, 2012). When using educational games for learning, the orders of the national curriculum should be followed. The teacher decides which of the objectives in the curriculum are to be implemented by playing. For instance, based on the Finnish National Curriculum for Basic Education (Finnish National Board of Education, 2014) types of bonds, cooperation and critical thinking could be the three main aims for a chemistry-related educational game. It is also the teacher’s duty to decide how to prepare students for the game and how to establish that the aims for a game-based learning session have been achieved (Kangas, Koskinen, & Kroksfors, 2016).

The teacher acts as a guide between the real world and the artificial world of a game by asking relevant questions during the game, answering the students’ questions and strengthening dialogues between students or between a student and the game (Barab et al., 2010; Kangas et al., 2016). The teacher can briefly introduce the game rules to the students, or do it in greater detail by teaching the key concept of the topic before the game (Costa, 2007; Kangas et al., 2016).

By using educational games, the teacher may map and collect students’ conceptions about the learned topic or key concepts. During the game, the teacher is able to follow the choices, decisions, discussions and other actions applied in the playing groups. Guidance and support can be provided in parallel, as well as feedback whenever the teacher deems it necessary. Sometimes it might be appropriate for the teacher to stop the game for a while and to clarify a certain concept or some key point of the game, or to create a discussion about the topics that are being learned. After the game, it is sensible to have a teacher-guided session in order to check if the learning aims for gaming have been achieved. (Costa, 2007; Kangas et al., 2016)

Play is normally meant to be a voluntary activity and stepping into the magic circle of the game should also be done with a lusory attitude (Salen & Zimmerman, 2003; Suits, 1978/1990). At school, students are usually ordered to play by the teacher. Extrinsic motivation provided by the teacher should be removed to allow the player to build their own intrinsic motivation over time (Warren & Jones, 2017), although students often perform tasks for both intrinsic and extrinsic reasons (Rahayu, 2015). It is therefore particularly important to have an educational game in which engaging game elements (see Section 3.2.2.4) are embedded and available to motivate students to play further and achieve both the aims of the game and the aims of learning.
3.3.2 Educational game playing challenges and barriers for teachers

There is significant variance among teachers in using educational games as teaching tools: some use them often, some have never used them. Declarative factors in the cases of (digital) games are teaching resources, the suitability of the games and anxiety about the unknown (Lean, Moizer, Towler, & Abbey, 2006). There are teachers who assess educational games as an unknown area that they have no time or courage to explore (Rastegarpour & Poopak, 2012). Some of these teachers see games as a waste of time, because they have not found a suitable game for a certain topic, their own knowledge or experience about games is insufficient, or they are not aware of the methods and products available. (Faria & Wellington, 2004; Lean, Moizer, Towler, & Abbey, 2006; Rastegarpour & Poopak, 2012). For example, they may feel that digital games are updated too often to be slightly different than the last time, or that some digital games are too complicated relative to the age level of the students (Faria & Wellington, 2004). There are also teachers who have had a positive attitude toward educational games, but have not achieved the desired outcomes and learning results by using the games (Faria & Wellington, 2004), and the teachers who consider other teaching approaches to be more effective than educational games (Can & Cagiltay, 2006).

3.3.3 Teachers as game developers

In designing an educational game, a teacher should take into account the aspects mentioned in Section 3.2.2. Moreover, a teacher can move into the role of facilitator, providing resources and scaffolds for the player-learners by designing in-game tasks for which there is no single right answer (Talja, Tuominen, & Savolainen, 2005).

The development process for a new educational game might take a lot of time, and this will be a problem for a teacher who already is overloaded with work (Galus, 2003). Naturally, this will delay the transformation of a good game idea into an actual teaching and learning tool (Mosher, Mosher, & Garoutte, 2012). The design process can be simplified by using a well-known game and its rules as a base.

It is also possible for students to construct own game ideas or even complete games together (e.g. Artym, Carbonaro, & Boechler, 2016; Kafai, 2006; Tokmak, 2015). This kind of game preparation has been seen to both engage and motivate students (Franco-Marsical et al., 2012; Kafai, 2006). In a study by Kafai (2006) it was found that in video game design, gender differences between 10-year old boys and girls were visible in all virtual design aspects, from feedback to the goal of the game. Yet, when the same children were asked to construct science games instead of fraction games, these gender differences disappeared (Kafai, 2006).
3.3.4 Pre-service teachers as game developers

Teacher education should prepare students for future teaching challenges and give them tools for skilfully executing motivated and engaged learning. In the Finnish teacher education system, pre-service teachers are taught to be autonomous teachers, and they are provided with research-based knowledge, competencies for reflection, exploration and decision-making, and skills in using various tried and true teaching methods in their own pedagogy for future learning purposes and challenges (Tryggvason, 2009). According to Sardone & Devlin-Scherer (2016), practice in game development and facilitation must be introduced at the pre-service teacher level if educational games are to be seen as a useful teaching method.

According to Ke (2009,) there is little research about the effects of educational games as part of teacher education. Only a few research articles have considered educational games from the perspective of pre-service teachers as game developers (Artym, Carbonaro, & Boechler, 2016; Sardone & Devlin-Scherer, 2016; Tokmak, 2015), and these studies were focused mostly on digital games. Only one of the recent studies combined pre-service-teachers with board games, although board and card games are making a comeback (Sardone & Devlin-Scherer, 2016).

In a study involving 21 early childhood education (ECE), pre-service teachers on developing educational digital games for primary school purposes with Power Point, Tokmak (2015) found the following categories and sub-categories concerning the planning state of the games:

- Design principles: color use in design, screen design, rhythm of elements, size of interface elements, places of elements, appropriateness to curriculum goals
- Appropriateness for children: attractiveness for young children, color selection, drawing, complexity of game, paying attention to detail
- Providing motivation: scoring, levels and characters, time limitation
- Usability: easily understood, easily used.

When these pre-service teachers were asked to describe their games with five adjectives, they most frequently described their games with the words: instructional, entertaining, colorful, attractive, specific to content, creative, original, easy to use and specific to young children (Tokmak, 2015). Though-provoking, exciting to play and task-based were mentioned quite often. In this study, game development elements belonging to creativity were found: thinking many things together, student level, subject matters, planning how to integrate into instruction, awards in the game, character use, levels, scoring, time limitation, color use, placement of elements in the game, and function of elements in the game (Tokmak, 2015).
In a study by Artym et al (2016) 40 pre-service teachers designed digital games in *Scratch* and their ability to operationalize the learning principles for good digital games was investigated. A Game Design Assessment Survey (GDAS) were used to determine the degree to which a core set of learning principles was present in these digital games. GDAS includes six literature review-based major categories for learning principles: problem-solving opportunities, customization of player experience, game atmosphere, player interaction, player motivation and interface usability. The main results suggested that most pre-service teachers were unaware of the learning principles that belong to a good digital game, but they were familiar with quality principles of interface usability. In 40 % of games, challenges became harder as the game progressed. Only 15 % of students were able to design a game that incorporated the aim of challenging students’ higher-order thinking skills consistent with Bloom’s taxonomy. Results for player interaction criteria were unexpectedly low: none of the games gave the player a wide range of choices in play (Artym et al, 2016). There were only a few games in which embedded narratives or roles were used to motivate players, but when these elements were used, they were done well (Artym et al, 2016).

In a study by Sardone and Devlin-Schere (2016) pre-service teachers (n = 60) from varied curricular fields were tasked to develop a board game for K-12 classroom use in order to challenge students’ higher-order thinking skills consistent with Bloom’s taxonomy. First the researchers developed a board game, *Econopoly*, to serve as a quality design model for the students. This game included a narrative, an element of variability to promote surprise, tension and flow of play, embedded debriefing, feedback, practices and instructional support during gameplay. The students played the game and then they received assignment guidelines and game resources, e.g. links to different information pages. A total of eight different board games were developed for learning geography or literature. As a main result, all the pre-service teachers expanded their teaching tool repertoire by developing educational game materials (Sardone & Devlin-Schere, 2016). Board games were also noted to be a good starting point to develop educational games, because they offer a different way to deal with current issues and contents, which are normally taught traditionally (Sardone & Devlin-Schere, 2016).

### 3.4 Educational games in chemistry education

Piaget (1951/1999) defined play and games as necessary for intellectual development in children. However, it has been observed that the older students grow, the fewer opportunities for play they get at school (Nemerow, 1996). Educational games and interactive models are tools to elicit active and independent learning in a student (Lujan, & DiCarlo, 2006). Learning is not remembering facts, but the capacity to use, apply and evaluate knowledge and construct novel knowledge based on it (Lujan & DiCarlo, 2006).
In Finland, current basic chemistry education leans on a social constructivist perspective of learning: students construct new knowledge by discussing and exploring together, sharing and clarifying ideas and opinions, and learning from one another (Finnish National Agency for Education, 2014; Powell & Kalina, 2009). Every student has an active and accountable role in the learning process. A teacher’s role, in turn, is to guide and support this process. (e.g. Eilks, Prins, & Lazarowitz, 2013; Powell & Kalina, 2009)

"Knowledge is not something that is ‘owned’ by an individual, but something that exists in the collective consciousness of a community" (Whitton, 2014, p. 56). Constructivist learning theories in general emphasize on the active process of knowledge construction based on learner’s prior knowledge, experience and meaning making (e.g. Bednar, Cunningham, Duffy, & Perry, 1992). A positive perception of one’s capability and of chemistry as a school subject has been proved to enhance learning (e.g. Chee, 2015; Ke & Abras, 2013; Tejada & Palacios, 1995; Tüysüz, 2009). This is one reason why it is necessary to use teaching and learning methods that promote students’ capabilities and their emotions toward chemistry as a school subject (Kärnä, Hakonen, & Kuusela, 2012). For example, in a study by Tüysüz (2009), learning chemistry by using computer-based games caused statistically significant positive effects (n=176, p>0.05) in chemistry achievement and attitudes towards chemistry among pre-service teachers on primary level.

In science education, learning chemistry is particularly challenging, because the same concept should be understood on all three levels of chemistry triplet: on the macroscopic, submicroscopic and symbolic levels, which also includes the mathematical level (Gilbert & Treagust, 2009; Johnstone, 1991; Johnstone, 1993)(Figure 5). During chemistry lessons, a teacher might move easily between these levels, while students are often struggling (Gilbert & Treagust, 2009).

![Figure 5. Sucrose as an example of chemistry triplet (based on: Gabel & al. 1987; Johnstone 1991; Nakhleh & Krajcik 1991).](image-url)
Both computer and card games have been demonstrated to exert a positive effect on chemistry learning and attitudes towards chemistry among upper secondary and university students (Sherman & Sherman, 1980; Kavak, 2012; Rastegarpour & Poopak, 2012). Chemistry-related digital games and card games that can be played in groups help in learning abstract concepts in particular (Rastagarpour & Poopak, 2012). The research results concerning other card and board games oriented to chemistry education have also been encouraging, and they will be discussed in Sections 3.3.1 and 3.3.2. A review was conducted and the educational card and board games for chemistry education discovered there have been listed in Table 2.

As previously argued, good educational games are able to engage students in enjoying learning chemistry. The teacher’s role is to plan a pedagogy for educational gaming so that the chosen games support the contents and objectives in the planned teaching (Koskinen et al., 2014). The chemistry-oriented games should be designed specifically to support a learning process for a certain chemical phenomenon or concept (Tüysüs, 2009; Schank & Kuzma, 2002). According to the national core curriculum for basic education (2014), Finnish chemistry teachers should cover both the themes of multiliteracy and sustainable development among the other general curriculum themes in their lessons, and broaden the chemistry phenomena and concepts to different contexts in students’ daily life and recent chemistry research (Finnish National Agency for Education, 2014). Civics for the 21st century is also included in the curriculum: creativity, critical thinking, problem-solving and decision-making skills, communication and collaboration (Finnish National Agency for Education, 2014).
Table 2. Educational card and board games designed for chemistry education between the years 1971–2018 (March). If any research results about the game (including observations, students’ opinions) are mentioned in the article, it is marked ‘Researched’.

<table>
<thead>
<tr>
<th>Educational game</th>
<th>Topic</th>
<th>Level</th>
<th>Researched</th>
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<tbody>
<tr>
<td>Chemsyn</td>
<td>(Eglinton &amp; Maxwell, 1971) synthesis</td>
<td>university</td>
<td>no</td>
</tr>
<tr>
<td>Organocards 2</td>
<td>(Kristol &amp; Perimutter, 1971) functional groups</td>
<td>upper-sec.</td>
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<td>Acid</td>
<td>(Ziegler, 1974) scientific working</td>
<td>lower-sec.</td>
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<td>Synthetic Dominos</td>
<td>(Kavak &amp; Yamak, 2016) laboratory equipment</td>
<td>upper-sec.</td>
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<tr>
<td>Orbital Battleship</td>
<td>(Kurushkin &amp; Mikhaylenko, 2016) atomic structure</td>
<td>upper-sec.</td>
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<td>Retrosynthetic Rummy</td>
<td>(Carney, 2015) syntheses, retrosynthesis</td>
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<td>Chemical Canasta</td>
<td>(Sivan 1977) elements, compounds, mixtures</td>
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<td>Mendeleev Bingo</td>
<td>(Swan, 1977) periodic table</td>
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<td>(Sherman &amp; Sherman, 1980) elements</td>
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<td>Organic Chemistry Squares</td>
<td>(Schreck, 1992) elements, compounds</td>
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<td>CHeMoVER</td>
<td>(Russell, 1999b) elements, ions</td>
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<td>Nucleogenesis!</td>
<td>(Olbris &amp; Herzfeld, 1999) fusion</td>
<td>upper-sec.</td>
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<td>The Old Prof</td>
<td>(Granath &amp; Russell, 1999) elements</td>
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<td>Nomenclature Bingo</td>
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<td>(Cummo, &amp; Matthews, 2002) elements</td>
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<td>(Capps, 2008) general chemistry</td>
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<td>(Sevcik, Hicks, Schultz, &amp; Alexander, 2008)</td>
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<td>Go Chemistry</td>
<td>(Morris, 2011) formulas compounds</td>
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<td>Educational Game</td>
<td>(Antunes, Pacheco, &amp; Giovanela, 2012) molecular geometry polarity, intermolecular forces</td>
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<td>(Kavak, 2012) ionic compounds</td>
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<td>Chempoker</td>
<td>(Kavak, 2012) elements</td>
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<td>(Knudtson, 2015) functional groups</td>
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<td>(Carney, 2015) syntheses, retrosynthesis</td>
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<td>(Akkuza &amp; Uyulgan, 2016) functional groups</td>
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<td>Picture Chem</td>
<td>(Kavak &amp; Yamak, 2016) laboratory equipment</td>
<td>upper-sec.</td>
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<td>(Farmer &amp; Schuman, 2016) organic synthesis</td>
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<td>Acid-Base Poker</td>
<td>(Zhang, 2017) acids and bases</td>
<td>university</td>
<td>yes</td>
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<td>Chemical Pursuit</td>
<td>(Adair &amp; McAfee, 2018) definitions, naming, calculations</td>
<td>university</td>
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3.4.1 Previous card and board game materials for chemistry education

The development of educational games for chemistry education began as early as the 1930s (see Russell, 1999a). Almost 40 research articles concerning the development of card and board games for chemistry education were published between the years 1971–2018 (March), (Table 2). Around one-third of these games have been tested and the results reported regarding students’ learning, attitudes and/or learning outcomes. If any research results about the game (including observations, students’ opinions) are mentioned in the article, it is marked “Researched” in Table 2.

Next, all the educational games in Table 2 which address the topics of elements and/or the periodic table, are meant for lower secondary or upper secondary chemistry education, and have been researched on some level, will be introduced in detail. Chemical Elements Bingo (Tejada & Palacios, 1995), Families of Chemical Elements, Elemental Periodica (Bayir, 2014) and Groupica (Bayir, 2014) focus on the structure of the periodic table and the typical properties of the eight main groups in the periodic table. Element Cycles (Pippins et al., 2011) combines the properties of four elements into the ecosystem. In Compundica (Bayir, 2014), monoatomic ions are constructed from the main group elements. In Orbital Battleship Kurushkin & Mikhaylenko, 2016), the orbital structures of atoms with the linked rules and periodicity are in focus. All of these educational games have been studied with lower secondary students or upper secondary students and three of the games have in addition also been studied with teachers.

3.4.1.1 Chemical Elements Bingo

In the study by Tejada and Palacios (1995) Mexican students played Chemical Elements Bingo before and after the teaching session for principles of the periodic table. In total 103 upper secondary students and 58 lower secondary students participated in the research. As pregame guidance, students were informed of the game idea and basic concepts concerning the structure of matter and the elements.

Chemical Elements Bingo was played for around 20 minutes in groups of 2–3. A short periodic table with blank spots in the cells of the main group elements was used as a game board. The game consisted of 44 element cards with the name, the chemical symbol and the outer shell electronic structure on one side of the card, and three typical properties for the element on the other. The cards were laid on the table name side down and were arranged on the board as quickly as possible during play. No clues were offered. During a postgame session, the students were encouraged to discuss the structural similarities and differences both between the elements in the same main group and between the elements in the same period. Also based on the information and knowledge gathered during the play session and discussions, they were asked to derive the definition of periodicity. Afterwards, the structure of the periodic table was taught by the teacher.
At the end of the learning session, the students answered seven questions about the contents of the periodic table. On a scale of 1–10, students at the upper secondary level scored 8.7 points on the post-test and at the lower secondary level 6.0 points on average. A control group was not used in the study. The students liked *Chemical Elements Bingo*, because according to them it helped them to understand the logic of the periodic table and it also enhanced the concept knowledge to some degree (Tejada & Palacios, 1995).

### 3.4.1.2 Element Cycles

*Element Cycles* (Pippins et al., 2011) was developed to enhance students' understanding of the biochemical cycles of the four important elements carbon (C), nitrogen (N), phosphorus (P) and sulphur (S). The game can be expanded with hydrogen (H) and oxygen (O). In this board game, the elements are move from one location in an ecosystem to another according to the playing cards. Depending on player-learners’ skills, the ecosystem consists either of air, water, earth and life, or of atmosphere, hydrosphere, geosphere and biosphere. As a pregame task, the students must clarify the meaning of one or two of these elements in the ecosystem and in the biochemical cycle. These findings are shared and, based on them, the students make a game board and 48 playing cards (Figure 6).

![Figure 6. The game board for the Elements Cycles (Pippins et al., 2011).](image)

There will be 12 cards for each location in the ecosystem, and at least three of them must include the name of one of these elements on one side, and a command to move onto another location in the ecosystem. Because phosphorus (P) is absent in the atmosphere, a phosphorus card with a command to go to the atmosphere will return the player back to the start, to the earth or to the geosphere.

*Element Cycles* can be played in groups of five at most and the winner is the player who first traverses the entire board. First, the playing cards are shuffled and placed on the colored spaces in the middle of the game board, the side with the chemical symbol upwards. The player who rolls the highest with the die is appointed game supervisor. Instead of participating in the actual gaming, the supervisor verifies the other players' answers from the information pages, which have been constructed together before the game session. The earth/geosphere square acts as a starting point. On their turn, the players move clockwise on the board, according to a die roll. If they stop in a square with a chemical symbol, a card from one of the location decks on the board with the symbol of this element must be drawn. After each draw, the card drawn is returned to the deck, which is then shuffled. Then the player moves to the board corner where this location is situated. Also, they must name one example of the element’s form in this location. For instance, in the case of carbon (C) in the atmosphere location, an answer could be carbon dioxide or organic aerosols produced by the trees. If the answer is right, the player can stay in the location. If the answer is wrong, the player’s token is removed from the board, and replaced at the start point after one turn.

The *Element cycle* game was tested in the United States with 2nd year high school students (n = 95) and there was no control group used in the study. Before the game session, students participated in either pre-AP lesson (three groups, n = 46) or regular chemistry lesson at high school level (three groups, n = 49). As homework, the students searched for information about the elements in the game, and filled it into the blanks. Information sources were freely chosen by the students. After two days, the level of students' pregame knowledge about the topic was tested, the right answers were revealed, and the game was introduced. After 15–20 minutes of play, the level of knowledge was re-tested. In the postgame test the students from the pre-AP lesson group in particular improved their level of knowledge significantly, as much as 30 % compared to the pregame test (Pippins et al., 2011). On the other hand, it was observed in the game sessions that some of the players concentrated solely on remembering the right answers. The groups consisting of athletes were particularly competitive, but there were also playing groups with more supportive attitudes.
3.4.1.3 Families of Chemical Elements

The *Families of Chemical Elements* card game was developed by Franco-Mariscal et al. (2012) to improve students’ understanding of the periodic table, particularly of the groups and the connections between the elements and daily-life compounds and products. The 44–45 playing cards are made by the students, and they include all the main group elements with 1–2 joker cards. The border color and the number on the face of the card indicate the element’s main group. In addition, the element’s name, chemical symbol and a picture describing the daily-life compound or product are included on the card. To start the game, the cards are shuffled and divided among the players. Each player in turn introduces one of his/her cards and ask the other players one by one if they have a card that shares the same group with the element in question. If they do, they must give it to the asking player, who thus attempts to form an entire group. If the other player does not have a matching card, the asking player’s turn ends and another player takes their turn to ask for matches. When the cards for the whole group have been collected, they are set on the table. The player who has collected the most groups is the winner.

The *Families of Chemical Elements* game was tested with 15–16 year-old Spanish upper secondary students (n = 38) (Franco-Mariscal et al., 2012). A control group was not used in this study. The game was played after the lesson concerning elements and the periodic table. During the lesson, games about naming the elements and about the octet rule were played. In a pre-game test, students were asked to name all the elements sharing the same group with chlorine (Cl). Two-third of the students’ answers covered all or all but one of the elements. On a scale of 0–10, the *Families of Chemical Elements* received the highest points (8,8) from the students among all the games played during the lesson. Around half of the students thought that this game was the simplest and the most enjoyable. According to the researchers’ (Franco-Mariscal et al., 2012) observations, making the playing cards developed both students’ classification skills and variable mastering skills.

3.4.1.4 Elemental Periodica, Compoundica and Groupica

Bayir (2014) has developed two card games and one board game, all of them aiming to teach students to skilfully synthesise related knowledge about elements, the periodic table and compounds. The *Elemental Periodica* card game is a mixture of card and board game. Each player has a long periodic table in front of them as a game board with s- p- and d- blocks marked in it. Before the game begins each player prepares ten cards for themselves, on which the chemical symbols of ten elements, decided by the group, are marked. The game is played by drawing the element cards from the shared deck (Figure 7). One of the players reads the written clue from the card drawn, and the, other players try to place a card with the correct chemical symbol onto the periodic table board on front of them. A player who
places the card in the wrong location is taken out of the game. The winner is the player who manages to locate all ten cards correctly on the board and first shouts, "Periodica".

The aim of the Groupica card game is to support students in learning the features of the elements situated in s- and p-blocks. Players try to collect five cards in hand, all describing the features of the elements in the same one group. The number of the main groups (1, 2, 13–18) in the game has to be the same as the number of players. One of the players acts as an evaluator, who checks from a checklist if the players’ five-card hands match the criteria. The game begins with shuffling the cards and dividing them among the players. The player who receives six cards chooses one of the cards to be removed and sets it on the table, to their right. The next player on their right takes this card and similarly removes one of the cards in their hand. The game continues like this until one of the players thinks that he/she has collected five cards describing the elements in the same group. The player has to show these cards to the other players and the evaluator checks them. If the cards are correct, the player wins, otherwise he/she is out of the game for one round. This game is short and can be played several times up to ten points, with one collection of five cards scoring one point. The first to collect 10 points wins the whole game.

The Compoundica board game (Bayir, 2014) teaches how monoatomic ions construct ionic compounds. The structure and the rules of the game are reminiscent of both Ludo and the Finnish Kimble. Every group of gamers consists of four players and one evaluator, and the game material consists of a game board (Figure 8), a die and 16 cards (4 O\(^2-\), 4 Br\(^-\), 4 Cl\(^-\), 4 I\(^-\)).
First the players roll the die to determine the order in which they choose their own anions and then place the tokens of that anion on the spaces on the board. The player who rolled the highest starts the actual game session by rolling again and moving their token forward on the board according to the die roll. The in-game task is to state the formula for the compound formed when the cation on the board square and the player’s own anion combine. The evaluator checks from a checklist whether the answer given is correct. A correct answer grants a new turn, and the number of ions in that compound advances the token by that number of spaces. Then it is the next player’s turn. If there is a noble gas on the space where a player lands, they have to go back to the start. This also happens if there is another anion on the square. Each of the players plays all of the four anions in the game. The winner is the player who first moves all four anions around the game board.

Bayir (2014) studied these three games with 250 students (grades 9–12) and 30 in-service and pre-service teachers at the Chemistry Games Days event in Turkey. All the players had chemistry and science as their major subject. The players were observed during play and their oral answers were written down. According to the coded data, themes and entries were constructed to explain series and links in the data. According to the teachers, the three main benefits of using the games were facilitating the learning of the main concepts, teaching the concepts in an interesting and enjoyable way and enabling the students to understand the relationships between the concepts. Based on these results, Bayir (2014) suggested that games spark students’ interest in chemistry and facilitate the learning of the chemistry concepts at hand.
3.4.1.5 Orbital Battleship

*Orbital Battleship* (Kurushkin & Mikhaylenko, 2016) is a card game, which has its roots in the traditional *Battleship* game, but instead of ships, atoms with their orbital structures are the targets that players try to sink. The game is targeted at upper secondary and university levels to enhance their understanding of Madelung's and Hund's rules, the values of quantum numbers and periodicity. The game is played in pairs, one game takes 5–10 minutes to play, and every player receives a sheet of paper with two similar orbital maps, one for the player's own orbital structure and another for sinking the opponent's atom electron by electron (Figure 9). In the beginning, each player chooses one element and displays its ground state orbital structure on the paper. It is important to follow both, Madelung's and Hund's rules. The player attempts to sink the opponent's atom by naming the symbol of the sublevel, the value of the magnetic quantum number and the spin. During each player's turn they are allowed to try to sink the opponent's element or name it. The answer is always either "hit" or "miss". The winner is the player who first guesses the opponent's element correctly. It is also possible to organize a Battleship Cup with semifinals and final, if a number of players is $2^n$ where $n = 3–5$.

*Figure 9. The orbital map for Orbital Battleship game (Kurushkin & Mikhaylenko, 2016).*


*Orbital Battleship* (Kurushkin & Mikhaylenko, 2016) was tested with a total of 50 students in five groups using a survey. When the cup model of this game was used, students really felt their knowledge of atomic structure was reinforced, as well as their understanding of periodicity. They also said that gaming was a fun and refreshing alternative to traditional lesson.
3.4.2 Other previous research about educational chemistry games

In the field of educational chemistry games research, card games have been shown to have positive learning effects (Rastegarpour & Marashi, 2012). This study investigated how card and digital games made by teachers affected upper secondary level students’ concept learning in chemistry. The participants were 105 girls with mathematics or science as a major subject, divided into three groups. The first group studied in the traditional way, the second group with card games and the third group with digital games. The games tested were about naming chemical compounds, and the teaching session lasted three weeks. There were both pre-tests and post-tests, which showed a significant difference between the control group and both player groups [F(2,101)=9.4, p<.001]. It was particularly interesting that there was no difference in learning outcomes between these two player groups. Rastegarpour and Marashi (2012) drew the conclusion that both card and digital games were of similar value in teaching abstract concepts.
4 THEORETICAL FRAMEWORK: THE PERIODIC TABLE IN BASIC CHEMISTRY EDUCATION

This chapter focuses on the central principles of the periodic table and its use as a model. It also describes the periodic table as a piece of content in the current Finnish national core curriculum for basic education (Finnish National Agency for Education, 2014). Based on this theoretical framework, two card games to enhance the students’ skills in using the periodic table were developed in design challenge 1.

4.1 Basic principles of the periodic table

The periodic table of elements is a model which contains information about the fundamental building blocks of chemistry, the chemical elements, and displays the trends between them (Atkins, 1995). In chemistry education, teaching and learning is based on the use of different models. By means of such models, students learn to explain and understand the central phenomena, principles and concepts in chemistry.

The International Union of Applied Chemistry (IUPAC) publishes a standardized and updated version of the periodic table (https://iupac.org/what-we-do/periodic-table-of-elements/), but a variety of versions of the periodic table exists, developed over the years for different purposes (Figure 10). Some of them are simplified or very visual versions, hence more teaching models for basic education than scientific models.

The official IUPAC version of the periodic table is divided into the numbered columns 1–18, which are called groups or families of the elements. Columns 1,2 and 13–18 are the main groups. Columns 3–12 are the side groups. Typical elements are situated in the main groups and transition elements are situated in the side groups. The periodic table is also divided into seven rows, called periods. These periods describe the atomic orbitals $s$, $p$ and $d$. The $s$- and $p$-orbitals fill in the atoms of main group elements, whereas atoms of the side group elements are have incomplete inner $d$-orbitals. This is why the side groups are also called the $d$-block. Because they have complete $d$-orbitals, Zn, Cd and Hg in the group 12 belong to the side group elements, but not to the transition elements. The lanthanoid series (4f-orbital) and the actinoid series (5f-orbital) have been moved below the actual periodic table in order to make the table more compact. In the IUPAC periodic table, every element is situated in a cell of its own, in which the element’s name, chemical symbol, atomic number and relative atomic mass (atomic weight) is marked (Zumdahl, 2007). But, among other things, the element’s possible allotropes are not mentioned.
The shapes of different periodic tables can vary from short to medium and long versions. The IUPAC periodic table is an example of the long version. Short and medium versions of the periodic table are useless nowadays, because short ones follow the law of octaves and in medium ones similar elements are not situated in the same groups. (Mazur, 1974). In alternative long, paper or online versions of the current periodic table, the following properties of the element may be mentioned: isotopes, state of matter, melting and boiling points, electron configuration, even a photo of the element or an artefact made of the element (e.g. Crew, 2018; Dayah, 2017).

*Figure 10.* Two examples of different models of the long periodic table of elements (based on Jensen, 2003, 959; Mazurs, 1974, 109).
4.2 The periodic table as a model

The periodic table of elements can be seen as a compact source of information and as a tool to describe the relationship between the atomic structures of the elements and their physical and chemical properties. From the periodic table it is also possible to derive what types of compounds an element can potentially form, and how. The periodic table is a model that describes the properties of the elements and trends in their periodical changes.

4.2.1 Definition of a model

A model is a description for a phenomenon, which resembles the actual phenomenon in its structure and function but is simplified and limited in its area of validity (e.g. Boulter, 2000; Saari, 2000). A model makes it possible to simplify and isolate a phenomenon from its environment in a way that enables users to observe and explain it (Gilbert, Boulter, & Elmer, 2000a). Additionally, a model also makes it possible to visualize a complex phenomenon.

Models describing natural scientific phenomena change over time and with new research. A scientific model is developed by researchers for a certain purpose, and in it, the real phenomenon and the related theory are connected in a way that make it possible to explain a phenomenon using theoretical, scientific concepts (Gilbert et al., 2000a). Consensus models are models that are approved by certain societal communities; hence all the scientific models that are accepted by the public are also counted as consensus models (Gilbert et al., 2000a). Currently approved scientific models and consensus models have been developed on the basis of historical models (Gilbert et al., 2000a). For example, the historical basic structure created by Mendeleev is still visible in current models of the periodic table.

Scientific models rarely fit into the basic education as such. These complex models must be modified and simplified into teaching models, which are more appropriate for education (Gilbert et al., 2000a).

4.2.2 Using models in teaching

A teaching model is a simplified version of a scientific or consensus model targeted particularly at a certain age group. Its aim is to help students to construct their own mental models of the phenomena based on the scientific model (Saari, 2000). Chemistry as a science consists of many models, which connect macroscopic observations with their explanations at the submicroscopic and symbolic levels (Oversby, 2000). When used properly, teaching models can make it easier to learn abstract concepts, which in chemistry are normally submicroscopic phenomena.
It is important to clarify for students both the validity area of a teaching model and its limitations, to minimize the likelihood that they learn misconceptions instead of attaining a more scientific understanding of the topic (Saari, 2000). The teacher must explicitly explain the similarities and differences between the actual phenomenon and the model of it. Otherwise students might become confused about all the imperfect, simplified and undefined models presented as if they were real phenomena. (Boulter & Buckley, 2000) One example of this kind of misconception is given in the results of empirical problem analysis in the Section 6.1: "Electron energy levels [in an atom] are determined by the periodic table" (K16); as if atomic structures were constructed based on elements' locations in the periodic table and not vice versa.

The following are the criteria for a good teaching model (Gilbert et al., 2000a; Mayer, 1989; Saari, 2000):

- familiar looking, visual and clear in its structure
- clearly connects the theory and the phenomenon at hand
- corresponds with the actual phenomenon in a certain area of validity and with clear limitations
- includes the essential structures and properties of the phenomenon at hand
- includes a sufficient number of structural, functional or structural-functional similarities with the scientific model
- the level of explanations a model can offer is in balance with the needs of the student
- uses language that students can understand
- takes into account student’s age and does not include irrelevant details.

A good teaching model alone is not enough: it has to be clarified and explained in an appropriate way. Of course it is possible to memorize a teaching model, but without understanding, the capacity and contents of a model cannot be capitalized on nor applied (Tynjälä, 2002).

It is recommended that teachers use several different kinds of teaching models to describe each phenomenon (Saari, 2000). This allows them to demonstrate multiple features of the actual phenomenon, as well as to support their students to understand the concept of models as limited descriptions of reality. (Harrison, 2000; Saari, 2000) Historical models with linked stories can improve students' motivation and make natural sciences easier to understand (Matthews, 1992).

4.2.3 Students’ own models

Students are not able to create scientific models. Nevertheless they can develop their own models, based on teaching models, and in this way better understand the phenomenon at hand (Saari & Viiri 2003; Solomon 1995). Again, the teacher has the responsibility to ensure that their students are able to connect the features of their own models with the features of the actual model (Saari & Viiri, 2003).
Students’ perceptions about the models and their usability will progress if sufficient teaching time is reserved for developing, making and testing the students’ own models (Saari, 2000). The more that students participate in the development process of the models, the more effective will this teaching model be (Saari, 2000), and at the same time, the learning process will become student-centered and motivational (Saari & Viiri, 2003).

According to the constructive learning approach, it is possible to test the level and correctness of students’ mental models with dialogical argumentation (Gilbert & Boulter, 2000). With a teacher’s guidance, a student may self-assess and other students peer-assess the validity of their mental model. In this thesis, two educational games for enhancing students’ skills in using the periodic table have been designed, and in these games player-learners both construct their own models of periodic table, and explain the correctness of the model to other players through dialogical argumentation.

4.2.4 The periodic table as a teaching model

The table-shaped long periodic table is simultaneously a scientific model approved by the IUPAC, a consensus model in general use, and a teaching model frequently used in lower and upper secondary education. However, several models of the periodic table exist with variations in length and shape (e.g. Mazurs, 1974) (see also Section 4.1).

In lower secondary education, a version of the periodic table without side groups can be used side by side with a long version. In Finland, only the basics of the periodic table are taught at the lower secondary level, meaning the characteristics and periodicity of the elements in the main groups, according to Bohr’s atomic model. Quantum mechanics principles and atomic orbitals are meant to be learned at the upper secondary level.

If only versions without side groups are used as teaching models, misconceptions might arise (Ben-Zvi & Genut, 1998). A student might for example think that a law of periodicity is valid all over the periodic table, even though this is not true; the similarity in properties is valid by group in the main groups, whereas it is periodically valid in the groups of lanthanoids and actinoids.

To achieve the skills in using the periodic table demands that a student grasps 1) the concepts concerning atomic structure: proton, neutron, electron, electronic shells, nucleus, atomic number, mass number, (and isotope); 2) the concepts concerning the structure of the periodic table: a group, a main group, a period; 3) and the relations of the concepts to each other and to the structure of the periodic table (Murray, 2003).
4.3 The periodic table in the Finnish national core curriculum for basic education

The national Finnish core curriculum for basic education (Finnish National Agency for Education, 2014) is based on the cognitive and the social constructivist learning theories (e.g. Palincsar, 1998; Powell & Kalina, 2009). It defines both general and subject-specific aims and contents and their connections in chemistry educations, as well as the criteria for grade 8 in final assessment (9th grade). The knowledge regarding the periodic table is included in lower secondary level education (grades 7–9). The periodic table was and still is one of the key concepts in chemistry education. In the current Finnish core curriculum for basic education (Finnish National Agency for Education 2014), connections between the periodic table and the properties of the elements is particularly emphasized.

Several related issues with the periodic table are mentioned in the curriculum (Finnish National Agency for Education, 2014). First, teaching and learning must proceed from the students’ previous experiences and observations in their daily life and living environment. Secondly, the development of students’ scientific thinking must be supported, as well as the construction of concepts related to chemistry and understanding the phenomena. Although the curriculum emphasizes the macroscopic level, the submicroscopic and symbolic levels are used in accordance with the development of students’ skills and abstract understanding. Similarly they move from observations to descriptions and explanations. They learn to describe the structure of matter using the language of chemical symbols.

The following four Objectives (O) of instruction in chemistry in grades 7–9 are connected with managing the information embedded into the periodic table:

- "Research skills, O7: to guide the student to process, interpret, and present the results of his or her own research, and to evaluate them and the whole research process"
- Knowledge of chemistry and its use, O10: to guide the student to use the concepts of chemistry accurately and to develop his or her conceptual structures to be increasingly consistent with the concepts of scientific theories
- Knowledge of chemistry and its use, O11: to guide the student to use different models to describe and explain the structure of matter and chemical phenomena
- Knowledge of chemistry and its use, O14: to guide the student to understand the basic principles of the characteristics and structure of matter and changes in substances” (Finnish National Agency for Education, 2014, p. 424–425).

In core content areas related to the objectives in chemistry the periodic table is explicitly included in content area C5 Properties and structure of substances (Finnish National Agency for Education, 2014):

- "Based on the characteristics of chemical elements, the students familiarise themselves with the atomic structure of matter, the structure of an atom, and the periodic table.
• Models and simulations are used to help the students perceive the structure of chemical compounds.
• The students familiarise themselves with carbon and its compounds."

(p. 426).

It is expected that in teaching, the core content C1 Scientific research will be combined with other content areas (C2–C6), and all of these content areas will then be used to construct different entities for the three levels of lower secondary education (Finnish National Agency for Education, 2014).

The Assessment of the pupil’s learning (Finnish National Agency for Education, 2014) states that students at lower secondary level are guided to recognize their prior knowledge, skills and preconceptions. Encouraging feedback is mentioned to support the development of motivation in particular. The assessment must be based both on different products of the students and on observation of the student’s working processes as well as the learning process and the working stages, such as forming questions, information acquisition, justification of viewpoints, use of concepts and clarity of expressions. Self-assessment, peer feedback and discussions with a teacher are also ways to support assessment. (Finnish National Agency for Education, 2014). During the three lower secondary years, the periodic table with its contents will be a part of students’ formative and summative assessment. The Final assessment criteria for good knowledge and skills (numerical grade 8) in the four aforementioned skills and knowledge objectives are (Finnish National Agency for Education, 2014):

• “Research skills, O7: The student is able to process, interpret and present research results; The pupil is able to evaluate the correctness and validity of results and describe the functionality of the research process
• Knowledge of chemistry and its use, O10: The pupil is able to use key concepts of chemistry in correct contexts and to connect them with one another; The pupil is able to describe and explain phenomena using key concepts of chemistry
• Knowledge of chemistry and its use, O11: The pupil is able to describe the structure of matter and chemical phenomena using models and descriptions
• Knowledge of chemistry and its use, O14: The pupil is able to use key concepts, phenomena, and models related to the properties, structures, and changes of substances” (pp. 427–429).
5 THEORETICAL FRAMEWORK: EVERYDAY CHEMISTRY

This chapter focuses on chemistry in everyday life. The concepts of humanistic science education, context-based learning, transfer of knowledge and molecular gastronomy are presented. Food and cooking as a potential context in teaching and learning chemistry is discussed. Based on this theoretical framework, a new theory and a board game about proteins' chemistry in daily life contexts, particularly in food and cooking contexts, were developed in design challenge 3.

5.1 Chemistry in everyday life

A lack of connection to real and daily life has been observed to be greater for chemistry than for physics or biology (Childs, Hayes, & O’Dwyer, 2015). From the 19th century to the 21st, science curricula have mostly been discipline-based, marginalizing the practical utility of knowledge and concentrating only on ‘pure science’ (Aikenhead, 2003), and courses of a content-dominated nature (Osborne & Collin, 2001). Therefore, chemistry education has faced a number of challenges: content-overload in curricula, isolated facts, lack of transfer of knowledge, lack of relevance for students and inadequate emphasis (Gilbert, 2006; Pilot & Bulte, 2006).

Nowadays, students’ own experiences and observations concerning their daily life and the living environment are part of a fundamental focus in learning chemistry (Osborne & Collins, 2001) and in the chemistry curriculum for lower secondary education at least in Finland, the Netherlands, Germany, UK, and the USA (Childs et al., 2015; Finnish National Agency for Education, 2014; Linthorst, 2012). In their research, Osborne and Collin (2001) discovered that students’ self-esteem improved from being able to explain everyday phenomena to their family or peers using scientific knowledge.

5.2 Context-based learning

Context-based learning (CBL) is defined as pedagogical methodology, “which centers on the belief that both the social context of the learning environment and the real, concrete context of knowing are pivotal to the acquisition and processing of knowledge” (Rose, 2012). Bennett & Holman (2002) showed that, compared to conventional teaching, students developed better understanding of a learning topic if different contexts were used several times during a course.

According to Aikenhead (2003), whenever people use science in their daily life, they integrate scientific knowledge to fit the non-science context at hand. At school, such integration with everyday examples is up to the teacher (Aikenhead, 2003). It is important to offer the students ‘human contexts’ of science
(Childs et al., 2015). Teaching examples connected to everyday life situations should be interpreted as contexts (Linthorst, 2012). A context "must provide a coherent structural meaning for something new that is set within a broader perspective" (Gilbert, 2006, p. 960).

The context-based, human curricula have been pointed out as one possible solution in addressing the previously mentioned challenges in chemistry education (Gilbert, 2006; Pilot & Bulte, 2006). In the 21st century, pupil-centred and practical science curricula are challenging abstract and science-centred curricula (Aikenhead, 2003). Such an emphasis can be called "humanistic science education" or "science-technology-society (STS) education" (Aikenhead, 2003). The trend towards context-based curricula is most apparent at secondary level (Bennett & Holman, 2002), and even if no one best way to apply humanistic science education exists, it is most easily achieved in lower secondary education (ages 12–16), where the focus is placed more on engaging students with school than on learning topics widely and deeply (Aikenhead, 2003).

In earlier studies, the reasons why the humanistic view in science classroom teaching may fail have been mentioned:

- Integration inside the subject is not enough, a broader perspective with other school subjects and with cross-curricular linkages is required (Aikenhead, 2003; Childs et al., 2015; Gilbert, 2006)
- The link between science and contemporary events is ignored or rushed because of overloaded curricula: applications are left to the end of the lesson (Childs et al., 2015; Osborne & Collin, 2001)
- Starting teaching with the abstract and moving to the concrete instead of starting with the familiar and moving to the unknown (Childs et al., 2015).

Bennet (2003) has reviewed the research concerning the implementation of context-based curricula and found several positive effects:

- Improvement in students’ interest and enjoyment in science lessons.
- Better understanding and appreciation of links between science and daily life among students.
- Learning science concepts at least as effectively as students participating in traditional courses.
- Better involvement and decreased anxiety toward innovations in education among teachers.

In the Finnish core chemistry curriculum for lower secondary education (Finnish National Agency for Education, 2014), the following connections to adolescents’ everyday life and living environment are explicitly mentioned:
The instruction of chemistry helps the pupils understand the significance of chemistry and its application in daily life, the living environment, the society, and technology. The instruction supports the pupils' ability to make choices and to use their knowledge and skills in different life situations." (p. 423)

The instruction of chemistry helps the pupils understand the significance of chemistry and its application in daily life, the living environment, the society, and technology. The instruction supports the pupils' ability to make choices and to use their knowledge and skills in different life situations.” (p. 423)

[...] guide the pupils to think in a manner characteristic of science, to acquire and use knowledge, to form ideas, and to be interactive as well as to evaluate the reliability and significance of knowledge in different situations (p. 424).

5.2.1 Transfer of knowledge

Lack of transfer was mentioned to be one of the problems in chemistry curriculum, which can be addressed through the use of contexts in teaching (Gilbert, 2006). The value of learning is to be able to transfer situated outcomes across situations (Gilbert, 2006).

Transfer of knowledge (or transfer of learning) can be defined as the skill of solving problems using the same concepts in different ways, for example in everyday life situations (Gilbert, 2006). Therefore, concept development is an essential prerequisite for transfer of knowledge to occur (Gilbert, Bulte, & Pilot, 2011). A careful selection of contexts makes it possible to focus on key concepts, to avoid excessive content load and to facilitate the capacity of transfer of knowledge to other contexts (Gilbert et al., 2011).

5.2.2 In-game transfer of knowledge

Few studies have been carried out concerning in-game transfer of knowledge in digital games, whereas context as such or connections of digital game contexts with real life have been mentioned as important game features in several studies (e.g. Bayir, 2014; Chin, Dukes, & Gamson, 2009; Hainey, Conolly, & Boyle, 2010; Ibrahim et al., 2012; Li & Tsai, 2013)(see Table 8 and Appendix 1). The literature review by O'Neil, Wainess and Baker (2005) concerning learning outcomes found two studies on adults using video games for transfer of learning to job settings, like flight performance.

In the majority of digital games a context for play is integral to activities of the game, helping players immerse in authentic activities and problems, at least in theory (Whitton, 2014). Despite that, many
games do not offer players space to reflect what has been learned and how to apply the learning to other contexts or situations, nor does digital in-game assessment provide any evidence of the transferability of learning to other contexts (Whitton, 2014).

In their study about videogames supporting science education, Barab et al. (2009) defined in-game transfer of knowledge as *transformational play*, which "involves a sense of narrative, perceptual, interactive, and/or social immersion within a situation where the individual has some level of agency in terms of transforming the context and effects on how the events unfolds" (p. 316). Transformational play consists of three interconnected elements: person, content and context, with an emphasis on game environments to integrate these three (Barab et al, 2010). These environments position a player as a first-person change agent in the storyline, binding contents to in-game challenges, and binding context with content in a way that the player’s decisions change the in-game context.

In the study by Barab et al. (2009), the context of water quality problems in *Taiga Virtual Park* game was offered to university students (n = 51) in three different versions. The first group received the information as an electronic textbook, the second group as a simplistic version of a 3D environment in third-person perspective and the third group as a realistic 3D version in first-person perspective. Students solved the problem in dyads. According to the results of this study and a pilot study with single users, the students who worked in dyads and used the most realistic and immersive version of the game did significantly better in transforming contextualized knowledge. Based on these results, Barab et al. (2009) have argued that the pedagogical importance of learning environments facilitated this kind of transformational play.

### 5.2.3 Possible contexts for everyday chemistry

Because there is chemistry everywhere in our lives, there also exist many opportunities to relate everyday chemistry to classroom teaching and to the interest of students in secondary education (Childs et al., 2015). And if students are made to solve problems related to daily life contexts, a need-to-know science relevance for chemical knowledge might appear. Need-to-know relevance is defined as a field of knowledge being "relevant for the general public who have faced and resolved real-life problems related to science and technology" (Aikenhead, 2006, p. 32). According to Bennett and Holman (2002), it is possible to use social, economic, environmental, technological and industrial contexts with their applications in chemistry education.

Childs et al. (2015) have suggested five possible daily life areas as sources for contexts in secondary education (Figure 11). The majority of everyday objects and materials are produced by chemistry and often taken for granted. These topics can be tailored to specific situations and to teach specific concepts.
The selection of topics might differ, depending on country or continent. Everyday issues are very current and rapidly changing topics in media and under public debate. Advertising materials and the chemistry behind their claims are other possible approaches. These real-world issues are complex and interdisciplinary in nature. For example, right now in the context of food and cooking, milk and meat versus plant-based proteins is a socio-scientific issue (SSI), without any single right answer. A variety of daily activities involves chemical components, thus overlapping with the areas of everyday objects and materials (Childs et al., 2015). A good example of such activities is cooking, in which food ingredients are modified into dishes and meals by utilizing chemical and physical phenomena. Other areas of interest include other disciplines and areas capable of broadening the scope: culture, attitudes and values, or economical and aesthetic issues.

![Diagram of Possible areas of everyday chemistry](Image)

*Figure 11. Possible areas of everyday chemistry (Childs et al., 2015, p. 36).*

### 5.2.4 Use of context in chemistry education

The criteria for the use of context in chemistry education have been developed to address five challenges within the area (Gilbert 2006; Pilot & Bulte, 2006):

- A valuable (everyday chemistry) setting as a social, spatial and temporal framework for a community of practice, where focal (meaningful) events in the zone of proximate development are situated
- A high quality learning task, which brings the behavioral environment into focus with problem(s) that offer examples of chemically important concepts
• Talk and discussions about the problem in the behavioral environment and with specific chemical language
• The focal (meaningful) event is related to relevant background knowledge (transfer of knowledge, see Section 5.3.2).

Pilot and Bulte (2006) have developed “an ideal context-based curriculum”, which is based on the criteria mentioned above and the need-to-know principle. Four models for context-based courses have been derived from these criteria (Gilbert, 2006) and Gilbert et al. (2011). The first model, “Context as the direct application of concepts”, actually does not meet the criteria for context-based courses. Here concepts are taught first and an application is only mentioned briefly at the end.

In the second model, “Context as reciprocity between concepts and applications”, one situation is selected to be a context, in which all the key concepts are taught. Thus, this second model does not enable transfer of knowledge across the situations.

The third model, “Context as provided by personal mental activity”, tries to follow a social constructivist view of learning. Here a student already has an understanding of a concept at hand, and expresses this to another student, enabling them to form their own interpretation of it. The third model is preferred for use only in individual learning by individuals working from textbooks or other such information sources.

The fourth model, “Context as social circumstances”, fully meets the criteria for the social construction of knowledge, and it can be seen as the desired model. Here the context is situated within society and with importance to the students’ everyday life. Problem-centered joint work is executed through a series of events in the context, thus developing the coherent use of scientific language and enabling transfer of knowledge. An educational board game designed as part of this thesis (Chapter 8) is based on the basic principles of this fourth model.

5.3 Chemistry of food and cooking as a context

Food, cooking and baking are part of our everyday life. In preparing food, the textures and tastes of ingredients are modified not only to make a delicious meal but also to improve the digestibility of the food and enable the effective absorption of nutrients. It is a routine activity, whose processes are rarely questioned (This, 2009). But chemistry plays an important role in all of this, and food, cooking and baking is a potential context for teaching and learning chemistry (e.g. Västinsalo, Aksela, & Hopia, 2010). Childs et al. (2015) give an example of how to teach an upper secondary science curriculum through food as a context. Every topic and related concept in the chemistry curriculum is linked to appropriate
topics and subtopics in the food context with ideas for possible activities, for example Food additives – Natural colourings – Solvent extraction – Extraction of chlorophyll from spinach. In a study by Miles and Bachman (2009) a compulsory chemistry course was run at a university in the context of food and cooking. Multiple food and ingredient groups were covered as teaching and learning topics, for example eggs, meat, herbs and spices, and sugars. It was found that the course inspired university students with non-science majors like arts and humanities.

Food and cooking is also a good example of everyday chemistry and context, which is relevant in cross-curricular linkages. For example, in Finland, Norway and Sweden, home economics as a school subject already covers this topic from nutritional, technical, hygienic, cultural, aesthetic, consumitional and sustainable perspectives (e.g. Tuomisto, Haapaniemi, & Fooladi, 2017).

5.3.1 Adolescents’ interest in and attitudes toward chemistry of food and cooking

Adolescents and students’ attitudes and interest toward food and cooking play an important role in making “food and cooking” a motivating and relevant context in teaching and learning chemistry. Attitude is an internal state, a subjective reaction in relation to objects. In social psychology, there are three major theoretical perspectives towards attitude.

According to the tri-component perspective, attitude consists of three components: the cognitive, the affective and the behavioral. The cognitive component consists of a set of beliefs one holds about the attitude object (Eagly & Chaiken, 1993). This can be measured using questionnaires (Salta & Tzougraki, 2004). The affective component refers to the subject’s feelings and emotions towards the object and the behavioral component consists of behavior and responses towards the object (Eagly & Chaiken, 1993). The second perspective sees the three component as separate entities. Emphasizing the effective component, it defines attitude as the amount of effect for or against the object (Cheung, 2009). The third, latent process perspective, is shared by contemporary attitude researchers. Attitude is seen as a latent variable explaining the relationship between certain observable stimuli and behaviors (Eagly & Chaiken 2005; Oskamp & Schultz, 2005). Observable stimulus events may arouse latent affective, behavioral and cognitive processes within an individual, which can be summed up as an attitude, whose existence can hence be observed by measuring affective, behavioral and cognitive responses (Cheung, 2009; Eagly & Chaiken 2005; Oskamp & Schultz, 2005). An attitude can be unidimensional or multidimensional, depending on how many types of response it produces (Cheung 2009; Oskamp & Schultz, 2005).

Interest is the object of attitudes (Scharw & Lehman, 2001). Attitudes are subjective, while interests are objective. Two individuals can have the same object of interest, but their attitudes toward the object are necessarily different. Interest is divided into individual and situational interest. Individual interest is
Educationally important. Individual interest is defined as a relatively permanent preference for an individual, and both topic-specific and based on previous experience (Palmer, Dixon, & Archer, 2017; Schraw & Lehman, 2001). Individual interest has been observed to both associate with increased knowledge, value and positive feelings (Hidi & Harackiewicz, 2000), and correlate with the achievements of the topic (Christidou, 2017; Hidi & Renninger, 2006). Situational interest, as the name implies, has a temporal nature, can be evoked spontaneously, and is context-dependent (Hidi, Renninger, & Krapp, 1992). It is more amenable to change than individual interest (Schraw & Lehman, 2001). There are three dimensions of situational interest: text-based, task-based and knowledge-based, and they all receive a similar focus in research. They are all also indicated to be in relation to learning (Schraw & Lehman, 2001). Situational knowledge-based interest and individual interest are both related to pre-knowledge, whereas knowledge is more strongly related to individual interest (Schraw & Lehman, 2001).

For measuring and understanding students’ attitudes and interest towards chemistry and science in general, data from international surveys and projects has been used, as well as questionnaire instruments developed for different school levels and purposes. Nowadays, the three most important international surveys in which data about students, science, attitudes and interest are collected are: Trends in International Mathematics and Science Study (TIMSS) for students aged 10 and 14, Program for International Student Assessment (PISA) for 15 year old students in OECD countries and Relevance of Science Education project (ROSE) for 15 year old students to survey affective factors of importance of learning science and technology.

Scientific Attitudes Inventory II (SAI II) (Moore & Foy, 1997) and Test of Science Related Attitudes (TOSRA) (Fraser, 1978) are widely used science-related questionnaires for students. SAI II was developed to examine the relationship between learning environment and secondary school students’ attitudes toward science. With TOSRA the effect of group work on attitude toward science can be examined among students who have only a little knowledge about science.

Few questionnaires have been advanced especially for chemistry education purposes. Salta and Tzougraki (2004) developed and applied a questionnaire with Likert scales to measure 11th grade Greek students’ (n = 576, age 16–17) attitudes regarding the difficulty, interest and usefulness of chemistry courses. They found that boys and girls share similar attitudes regarding interest in and usefulness of the chemistry courses. They also perceived the courses’ importance almost equally. The majority of students recognize the usefulness of chemistry knowledge in interpreting aspects of their everyday life. The level of interest was noted to be neutral, but when compared to students specializing in humanities or engineering, the students specializing in science-medicine had more positive attitudes toward chemistry courses in general (Salta & Tzougraki, 2004). For first year university students, the Chemistry Attitudes and Experiences Questionnaire (CAEQ) has been developed to measure the students’ attitudes...
toward chemistry, chemistry self-efficacy and learning experiences (Dalgety, Coll, & Jones, 2003). Scientific and science-related attitudes and experiences towards chemistry have been studied among high school students (Coll, Dalgety, & Salter, 2002) and first-year chemistry students (Salta & Tzougraki, 2004), as well as attitudes towards science from a cultural perspective in the physics classroom (Krogh & Thomsen, 2005).

Several studies have been executed to discover attitudes towards eating (e.g. Indran & Hatta, 1995; Yeung, 2010), food system (e.g. Harmon & Maretzki, 2006), nutrition (e.g. Watson, Kwon, Nichols, & Rew, 2009) and vegetables (e.g. Cunningham-Sabo & Lohse, 2013; Wall, Least, Gromis, & Lohse, 2012) among children or adolescents. Only a few studies have been done to cover adolescents’ or young adults’ attitudes towards and interest in food and cooking. In a recent study about adolescents’ cooking abilities and behaviors among secondary school students in New Zealand (n = 8500, age 13–17) (Utter, Denny, Lucassen, & Dyson, 2016) half of the students (54 %) reported that they cooked 1-2 times per month or more. More boys (15 %) than girls answered that they had not cooked at all in the past year. According to the results (Utter et al, 2016), secondary school students with high cooking frequency were observed to learn cooking skills and to have high levels of family connections.

A consumer study by Worsley, Wang, Ismail, and Ridley (2014) of 18–56 year-old Australian customers (n = 1023) revealed that 71 % of respondents wanted to learn more about cooking. Soup, lasagna, pasta, lamb, pork, roast dinners and desserts as cooking topics interested young adults aged 18–29 in particular. In the same age band, watching TV programs (62 %) or reading newspapers and magazines (40 %) were the preferred ways to learn about cooking. They also favored learning via You Tube (37 %) more than older people, but attending cooking classes (34 %) shared quite similar interest levels among all age groups. According to this research (Worsley et al, 2014), discussing with friends or family about cooking or searching for information from the internet (13 %) seemed not to be in favor among customers in the age band 18–29. One explanation for the results might be that cooking is a skill development process, hence communication for learning cooking should either show skills or allow participants to practice them (Worsley et al, 2014).

### 5.3.2 Molecular gastronomy

Chemistry in food and cooking has officially been under scientific interest from the year 1998, when the term *Molecular gastronomy* was first used by Hérvé This and Nicholas Kurti (This, 2009). Molecular gastronomy itself differs from nutritional sciences, in which food is studied from the perspective of nutritive molecules and atoms in food and in the human body. In molecular gastronomy, however, food is seen as ingredients and dishes, and between them, chains of culinary transformations, meaning chemical and physical changes, determining the final composition of the food (This, 2009).
Molecular gastronomy (MG) is defined as a scientific study of three components of food, cooking and preparing dishes: artistical, social and technical (e.g. This, 2009). The artistical component includes the aesthetic perspective in enjoying food, like setting and colors. The social component is about company, shared food memories and other social links. The technical component is focused on the physical and chemical transformations during cooking and their effects on the textures, colors and smells of ingredients and dishes. The technical perspective is also interested in the use of technology in creation new dishes and culinary techniques. This study focuses on the technical perspective of MG.

5.3.3 Molecular gastronomic hands-on activities

5.3.3.1 Hands-on activities and learning

Hands-on activities help students to relate real-life observables to scientific thoughts and ideas (Abrahams & Millar, 2008). Hands-on activities and practical work in general are seen as essential parts of chemistry education, yet their effectiveness and role in learning were being questioned even in the early 1980s (Hofstein & Lunetta, 2004). However, students have self-reported to like them: hands-on activities both inspire the students and give them some personal ownership of chemistry as a school subject (Osborne and Collin, 2001). Previous studies in the field have supported these findings by mentioning improvement in attitudes, stimulation of interest and enjoyment (Hofstein & Lunetta, 2004), as well as engagement in chemistry and science in general (Hampden-Thompson & Bennett, 2013).

Hands-on activities are seen as learning environments in which cooperation is natural and possible (Hofstein & Lunetta, 2003). Such informal student-student and student-teacher interactions promote cooperative learning and collaborative inquiry, as well as a positive and healthy atmosphere (e.g. Hofstein & Lunetta, 2003; Johnson et al., 1981). Collaborative, inquiry-based practical work also gives students an opportunity to work as a “classroom community of scientists” (Hofstein & Lunetta, 2003). Collaboration during hands-on activities has been noted to be more effective for learning than competition or individual practical work (Okebukola & Oggunyi, 1984). These results are similar to results in game research (e.g. Zagal et al., 2006), yet in games collaboration means that then there is competition between collaborative players and the game itself.

However, Abrahams and Millar (2008) have revealed that teachers’ objectives for learning by doing hands-on activity rarely matched the actual learning outcomes of their students. In 25 observed practical works, students mostly learnt domains of observables (objects, materials and phenomena), instead of domains of ideas. Knowledge of domain ideas means that “the student can later show understanding of the idea the task was designed to help them learn” (Abrahams & Millar, 2008, p. 1949). In this study, teachers were focused on the substantive science content of the practical, not inquiry-based, task. According to Hofstein & Lunetta (2003), students should be helped to understand the aim
of every hands-on activity by having them set out clearly. Similarly, clear and understandable rules are an important element in educational games (Galus, 2003; Tsai, Tsai, & Lin, 2015).

According to Hofstein & Lunetta (2004), a new era in science education in 21st century has improved science teaching and design, and implementation of hands-on activities, yet the teacher still has an important role (Hofstein & Lunetta, 2004):

Well-designed science laboratory activities focused on inquiry can provide learning opportunities that help students develop concepts and frameworks of concepts. They also provide important opportunities to help students learn to investigate, to construct scientific assertions, and to justify those assertions in a classroom community of peer investigators in contact with a more expert scientific community (p. 47).

If it is not possible to perform inquiry-based hands-on activities in school with real materials or in a limited time, simulations can be used (Lunetta & Hofstein, 1991). According to Lunetta and Hofstein (1991), both simulations and hands-on activities similarly enable students to confront and resolve problems, to observe the effects and to make decisions. In simulations, instead of real substances and equipment, students are engaged in action with meaningful representations of inquiry experiences. Yet, it is probable that learning resulted from simulation differs from learning that results from well-designed inquiry-based hands-on activity (Hofstein & Lunetta, 2003).

5.3.3.2 Inquiry-based molecular gastronomic hands-on activities

Specific hands-on activities derived from molecular gastronomy have been developed in recent years for educational purposes and for students of different ages, focused on inquiry (e.g. Mata, 2013; Tuomisto, Hopia, & Aksela, 2015; Töyrylä, Aksela, Hopia, & Fooladi, 2013; Vilhunen, Aksela, & Hopia, 2013). Food is always complex: almost every ingredient consists of tens or hundreds of different substances, and when these ingredients are mixed together and perhaps also cooked, multiple chemical and physical changes occur. In MG, the phenomena under examination are always more complex than isolated chemical reactions between two pure substances. However, a teaching method and age-appropriate level of content will transform the complex reality of food into simple phenomena that the students will be able to understand. For example, in the hands-on activity called Blueberry Trio, three differently-colored blueberry layers in a glass of dessert are scoped with the support of argumentation (see Figure 17).

In the e-book by Tuomisto et al. (2015), chemistry and home economics teachers collaborated in a research-based and empirical fashion to develop inquiry-based molecular gastronomic teaching materials for chemistry and home economics for lower and upper secondary education purposes.
Vilhunen et al. (2013) designed a context- and inquiry-based way of teaching protein chemistry, in which students act as participants in a Top Chef competition, trying to develop the best possible recipe for meringues. *Fluffy Meringues* is based on a recipe for Italian Meringues, theoretical framework and empirical experiments. The participants make their meringues in the Home Economics classroom and, while their creations bake in the oven, create a poster in which all the chemical secrets behind the fluffiness of meringues are unveiled. The winner is the group that wins the blind taste evaluation implemented by the teacher. In other words, the factors affecting proteins’ denaturation, like adding acid into the egg white foam, are revealed and their effects on the meringues’ taste and structure are proved by taste evaluation.

In this thesis an educational board game with a link to the context of food and cooking and strong bridging with the *Fluffy Meringues* hands-on activity has been designed (Chapter 8). It is recommended to execute a hands-on activity concerning factors affecting protein denaturation with students before the game session.

### 5.3.4 Students’ interest in and attitudes toward molecular gastronomy

Molecular gastronomy (MG) has already been shown to have the potential to be an interesting and relevant context for teaching and learning chemistry adapted to different ages: for lower secondary students (Västinsalo et al., 2010) and for children and their families (Mata, 2013). In a study by Västinsalo et al. (2010), lower secondary students (n = 52, 26 boys and 25 girls, 7th–9th grades) in Finland first participated in multiple MG workshops and then answered a questionnaire. In the workshops the properties of egg white foam were investigated, and dry ice sorbet, mustard foam and carrot caviar were made. In the questionnaire, interest toward MG, its usefulness in daily life and interesting topics within the area were mapped. The study revealed that the scientific background of cooking was apparently the most interesting area in the context of MG. It was also noted that some students were especially interested in myths related to food preparation and cooking (*aka* kitchen stories or culinary precisions (Fooladi & Hopia, 2013; This 2009)) as learning context.

In 2001, Mata (2013) organized *The Kitchen is a Laboratory* (KiL) in Portugal to motivate teachers and children with their families to get involved with experimental science in the context of food and cooking, and in this way make scientific concepts more accessible and meaningful. As a result, a book with 37 short texts was published, in which for example “Water in Food” and “Understanding baking” had been used as contexts. At the end of the project, it was concluded that a positive attitude and better understanding of science in daily life were achieved, based on feedback from the teachers and children. It was also suggested that food and cooking can be used to motivate teachers and particularly those students who are not very familiar with science culture.
6 DESIGN CHALLENGE 1: EDUCATIONAL GAMES FOR LEARNING THE PERIODIC TABLE

In design challenge 1, two educational games for promoting lower secondary students’ usage skills of the periodic table were designed. These educational games are *Periodical Domino* and *Collect a Triplet*. During the design process, Research Question 2 was addressed: which features of an educational game may support the development of lower secondary students’ skills in learning and using a piece of information included in the periodic table?

6.1 Empirical problem analysis

The aim for this empirical problem analysis was to give information about Finnish lower secondary students’ learning and understanding regarding the periodic table and related topics. The empirical study revealed what shortcomings the Finnish lower secondary students (n = 38, 8th grade, age 14–15) had in understanding the basic contents of the periodic table, as well as in usage skills of the table, after studying the topic.

6.1.1 Method

Two different small-scale questionnaires were developed for this empirical problem analysis. The first questionnaire was developed to find out students’ understanding of the relationships between different concepts related to atomic structure and the periodic table. A mind map with concept boxes and lines between them was created, based on the map presented in the teacher resources of the Royal Society of Chemistry (2017). Similar frameworks and maps from Finnish chemistry workbooks were also used (e.g. Aspholm et al., 2003). Twenty of these lines were numbered and students were asked to explain these relations with a maximum of two sentences.

The second questionnaire was developed to find out students’ skills in using the periodic table. Students were asked to tell a fact about magnesium (Mg) by using the periodic table, and then explain it. The IUPAC periodic table was available in the questionnaire.
6.1.2 Data collection

Data collection was executed at a Finnish lower secondary school between December 2004 and March 2005. Before data collection, the students had studied both the periodic table and ionic and molecular compounds. Answering time was 45 minutes for both groups and in the beginning, the purpose of the research was explained and the content of the questionnaire was presented briefly.

A total of 19 students (10 boys and 9 girls, age 14–15) answered the first questionnaire. This group had studied the periodic table over four lessons (4 x 45 min). While they answered, the IUPAC periodic table was projected on the wall. A total of 19 students (9 boys and 10 girls, age 14–15) answered the second questionnaire as well. This group had studied the periodic table over two lessons (2 x 45 min).

6.1.3 Data analysis

Data was analysed with content analysis (Krippendorff, 2004). Students were coded according to the type of questionnaire: G1–G19 and M1–M19). One answer was used as a unit of analysis and answers were roughly categorized into groups of correct answers and answers with misinformation. Some answers were not related to the topic at all, and therefore it was decided to exclude them from the data. Then, the answers with misinformation were first divided into categories according to general themes in the topic (Table 3) and then more descriptive subcategories were extracted from the data. In the end, the information gathered was reduced to eight descriptive sentences.

Table 3. Categorization of 8th grade students answers with misinformation, concerning the concepts related to atomic structure and the periodic table.

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SUBCATEGORIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic structure</td>
<td>Element and atom</td>
</tr>
<tr>
<td></td>
<td>Atomic nucleus and electron energy levels</td>
</tr>
<tr>
<td></td>
<td>Atomic nucleus and protons</td>
</tr>
<tr>
<td></td>
<td>Protons and atomic number</td>
</tr>
<tr>
<td></td>
<td>Atomic nucleus and (atomic) mass number</td>
</tr>
<tr>
<td></td>
<td>The outer electron energy level</td>
</tr>
<tr>
<td></td>
<td>The number of protons and electrons</td>
</tr>
<tr>
<td>Groups and the periodic table</td>
<td>Columns, groups and main groups</td>
</tr>
<tr>
<td></td>
<td>The outer electronic energy level and main group</td>
</tr>
<tr>
<td></td>
<td>Similarity between same group elements</td>
</tr>
<tr>
<td></td>
<td>Ion formation</td>
</tr>
<tr>
<td>Periods and the periodic table</td>
<td>Rows and periods</td>
</tr>
<tr>
<td></td>
<td>Periodical location and element's properties</td>
</tr>
<tr>
<td></td>
<td>Atomic size (radius)</td>
</tr>
<tr>
<td>Other</td>
<td>Metallic / nonmetallic</td>
</tr>
<tr>
<td></td>
<td>Radioactivity</td>
</tr>
</tbody>
</table>

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For example, the following answers with misinformation, in the subcategory of periodical location and element properties, were mentioned in the questionnaires:

- Electron energy levels and periods are the same thing. (G13)
- Electron energy levels are determined by the periodic table. (G16)
- In different periods, there is a different number of electrons on the outer electron energy level. (K1)
- Numbers on the left side tell to which group an element belongs, which means electron energy levels. (M4)
- [Magnesium] belongs to period 2 and group 3. (M2).

6.1.4 Results and discussion

The study discovered information about specific difficulties among students in understanding the concepts and structure related to the periodic table. The difficulties among Finnish 8th graders in understanding of the periodic table and related concepts can be reduced to the following concepts and their relations:

- similarity between elements in the main groups
- relation between an element’s atomic structure and its location in the table
- relation between the main group elements and electrons in the outer energy levels
- connection between the groups and the periods
- reasoning, whether an element is a metal or nonmetal
- reasoning, what kind of ion a main group element can form
- change of atomic size (radius) along the groups and the periods
- difference between an element’s atomic mass and mass number.

These results are in line with previous studies in the research field. According to a study by Schmidt, Baumgrätner and Eybe (2003), the most common misconceptions among German lower secondary students (n = 3074) concerning atomic structure are: an atom is neutral, because it contains an equal number of protons and electrons; and in the periodic table, only normal atoms with whole numbered atomic masses are presented. In a study by Abraham, Grzybowski, Renner and Marek (1992), lower secondary students (n = 247) in the USA were asked to answer deductive questions concerning an imaginary periodic table with five groups and three periods. Only two students (< 1 %) were able to correctly answer the question concerning the element’s ability to form compounds, whereas 37 % of the students deduced the correct answer to a question concerning atomic number.
6.2 Design processes

In this section, the prescriptions of successful design processes for two educational card games are presented. Based on the theoretical framework (Chapters 3 and 4), it was decided to apply the rules and game mechanics of already well-known card or board games to create the educational games. *Domino* and *Pekka-peli* (similar to en. *Old Maid*) were chosen as bases in the design processes for two educational card games.

Both these educational games were to follow the same basic idea, based on the theoretical framework (Chapters 3 and 4) and the results of the empirical problem analysis (Section 6.1). Students are to apply the embedded information in the periodic table diversely and according to their age level (8th grade, 14-15 years) by comparing the properties and locations of the elements and presenting their reasoning to the other players with no separate adjudicator needed. All the players can give peer feedback and in this way support the learning of the player-learner by turns. All the in-game argumentation must be based on the long periodic table, which every player has in front of them during a game session.

6.2.1 Design process for *Periodical Domino*

*Domino* is a classical game, consisted of 28 tiles or cards with two numbers between 0–6 marked as dots in each of them. During play, each player in turn sets a tile in the tile line on the table, so that one or the other of the numbers on a piece matches one of the heads in the tile line. The winner is the player who first manages to set all of his/her tiles in the tile line.

6.2.1.1 The first version

For the first version of the *Periodical Domino* game, only the main group (1, 2, 13–18) elements were chosen, because basic chemistry at the lower secondary level is mainly focused on the general properties of the main elements, not the elements in the side groups, except when metals are discussed as a group of elements. Elements for the domino cards were chosen according to their familiarity in name and in appearance to the students from daily life and/or prior chemistry studies.

The game cards were developed in order that two elements from the same main group or the same period would correspond to the same number in classical domino tiles (Table 4). To increase the unpredictability of the game, an exception to that rule was made with the number 6, for which two familiar elements (He and Al) from different groups were chosen.

Every domino number is repeated eight times in the tiles. Unlike classical domino, the same facts about an element were not repeated from tile to tile, but four different facts were developed for every element.
in the game. These facts were relevant to either only this specific element, or several elements in the
game (Figure 12).

Table 4. The correspondence between the numbers in classical domino and the elements in *Periodical Domino*.

<table>
<thead>
<tr>
<th>Classical domino</th>
<th>Periodical Domino</th>
<th>Similarity criteria for the elements sharing the same domino tile number</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Blank Domino]</td>
<td>hydrogen (H)</td>
<td>Group 1</td>
</tr>
<tr>
<td></td>
<td>lithium (Li)</td>
<td></td>
</tr>
<tr>
<td>![Single Dot]</td>
<td>potassium (K)</td>
<td>3rd period</td>
</tr>
<tr>
<td></td>
<td>calcium (Ca)</td>
<td></td>
</tr>
<tr>
<td>![Two Dots]</td>
<td>sodium (Na)</td>
<td>2nd period</td>
</tr>
<tr>
<td></td>
<td>magnesium (Mg)</td>
<td></td>
</tr>
<tr>
<td>![Three Dots]</td>
<td>fluorine (F)</td>
<td>Group 17</td>
</tr>
<tr>
<td></td>
<td>chlorium (Cl)</td>
<td></td>
</tr>
<tr>
<td>![Four Dots]</td>
<td>neon (Ne)</td>
<td>2nd period</td>
</tr>
<tr>
<td></td>
<td>carbon (C)</td>
<td></td>
</tr>
<tr>
<td>![Five Dots]</td>
<td>oxygen (O)</td>
<td>Group 16</td>
</tr>
<tr>
<td></td>
<td>sulphur (S)</td>
<td></td>
</tr>
<tr>
<td>![Six Dots]</td>
<td>helium (He)</td>
<td>No shared group or period, but similarities with other elements in the game.</td>
</tr>
<tr>
<td></td>
<td>aluminum (Al)</td>
<td></td>
</tr>
</tbody>
</table>

All the clues in the game cards differ from each other: they can give information about the name, a
property, or the atomic structure of an element. These same facts can be read or derived from the
periodic table, if a player has sufficient usage skills for the periodic table.

Figure 12. The facts in the game cards corresponding with sulphur (S) in the first version of *Periodical Domino*.

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**S**

- **two** electrons are missing from the full outer shell
- similar properties with selenium (Se)
- a non-metal, **but not** a noble gas
The finalised facts were located into the cards similar to the tiles in classical domino (Figure 13). During the game, a player-learner must find a possible connection between the two different facts, as well as to argue and explain the connection to the other player both by using the periodic table and in a way that others will accept. During play, students can be seen constructing and justifying their own mental models of the periodic table while other players peer-assess them (Gilbert & Boulter, 2000) (see Section 4.2.3).

Figure 13. The correspondence of the tiles in classical domino (upper line) and the cards in *Periodical Domino* (lower line).

6.2.1.2 Testing on chemistry teachers

As stated in the study by Warren and Jones (2017), testing the usability of games and playing them are forms of educational game research. The first version of Periodical Domino was tested on 14th April 2009 with the science teachers participating in the workshop at the *Kemian opetuksen päivät* meeting in Helsinki. A total of 22 chemistry teachers around Finland tested the game. They played either *Periodical Domino*, *Collect a Triplet* (Section 6.3.2), or both, in groups of 2–4 players.

After the game session, the individual or group feedback was filled into the questionnaire, which included open and closed questions about the rules (additions, removals, changes), the cards (new clues, additions, removals, modifications), playing time (minutes, too short, suitable, too long) and difficulty level (too easy, suitable, too challenging). There was also space for general open feedback. Altogether, 20 players with three shared questionnaire forms gave feedback concerning *Periodical Domino*. Content analysis was built into the questionnaire’s construction, meaning that answers were post-coded into the same categories as in the questionnaire.

The playing time in the testing sessions was around 15–20 minutes and it was accepted by all the testers, with one exception. The players suggested to put more focus on the importance of in-game argumentation and explanation in the rules. They also asked for a short example about how to apply the
game rules to be embedded into the rules. Two of the testers suggested a rule change, in which only one card must be picked up instead of several, when none of the player's cards fit into the domino cards on the board. This would make each game session both smoother and quicker.

A joker-card for fitting as a pair regardless of what the fact might be was suggested for the game. Additionally, some useful corrections for the visual design and contents of the game material were suggested: electrons in the card drawings should be distinctively smaller than the nucleus; the clarity of the card drawings about outer electron shells without nuclei should be improved; and the facts targeting only one element were too restrictive and tended to stall the game, so they should be replaced with more permissive facts. For the same reason, the players asked for more cards. One of the testers wished that two facts, Cl and Group 17, would be removed from the game.

The difficulty level was mostly evaluated to be suitable for lower secondary level. Only two of the testers thought it was too challenging, whereas four of the testers did not mark their opinions into the questionnaire (too easy, suitable, too challenging).

Additionally, the playtesters suggested that the groups and periods be marked in the periodic tables which players would use as in-game information sources. During the testing session, the periodic tables were shared between pairs, but the testers hoped that all the players would have a periodic table of their own.

6.2.1.3 The second version

As a second design cycle for the Periodical Domino card game, it was modified according to the collected feedback from the chemistry researchers, teachers and pre-service teachers. Compared to the first version, the second version of the educational game included clearer drawings and more facts, which were targeted to be relevant to more than just one element. The rules changes were implemented, and in the present version, only one card must be picked up instead of several, when none of the player's cards fit with the domino cards on the board. A short, illustrated example about how to apply the game rules was embedded into the rules. The numbers for the groups and periods were added into the periodic table. It was decided to keep the number of playing cards the same as in classical domino.

6.2.2 Design process for Collect a Triplet

Another educational card game for learning and rehearsing the periodic table using skills at lower secondary level was based on Pekka-peli (en. Pekka Game, similar to en. Old Maid), which all Finnish adolescents are familiar with. The idea in this game is to collect as many four-card families as possible.
6.2.2.1 The first version

For the first version of the educational Collect a Triplet card game, 12 elements from the main groups (1, 2, 13–18) and two from the side groups were chosen (Table 5). Like Periodical Domino, the elements for the game cards were chosen according to their familiarity in name and in appearance to the students from daily life and/or prior chemistry studies, because basic chemistry at the lower secondary level is mainly focused on the general properties of the main elements. Additionally, two side group metals were chosen, because at lower secondary level metals are discussed as a group of elements with similar properties. Metals also have strong connections to everyone’s daily life.

Table 5. The elements chosen into the versions 1 and 2 of Collect a Triplet.

<table>
<thead>
<tr>
<th>Group</th>
<th>The first version</th>
<th>The second version</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>lithium (Li), sodium (Na)</td>
<td>lithium (Li), sodium (Na)</td>
</tr>
<tr>
<td>Group 2</td>
<td>magnesium (Mg), calcium (Ca)</td>
<td>magnesium (Mg), calcium (Ca)</td>
</tr>
<tr>
<td>Group 13</td>
<td>boron (B), aluminum (Al)</td>
<td>boron (B), aluminum (Al)</td>
</tr>
<tr>
<td>Group 14</td>
<td>carbon (C)</td>
<td>carbon (C), silicon (Si)</td>
</tr>
<tr>
<td>Group 15</td>
<td>phosphorus (P)</td>
<td>nitrogen (N), phosphorus (P)</td>
</tr>
<tr>
<td>Group 16</td>
<td>oxygen (O)</td>
<td>oxygen (O), sulphur (S)</td>
</tr>
<tr>
<td>Group 17</td>
<td>chlorine (Cl)</td>
<td>chlorine (Cl), jodi (I)</td>
</tr>
<tr>
<td>Group 18</td>
<td>helium (He), krypton (Kr)</td>
<td>helium (He), argon (Ar)</td>
</tr>
<tr>
<td>Side groups</td>
<td>iron (Fe), copper (Cu)</td>
<td>---</td>
</tr>
<tr>
<td>Groups 2 and 16</td>
<td>beryllium (Be), selenium (Se)</td>
<td></td>
</tr>
</tbody>
</table>

For every element in the game, three fact cards were created, such that some of these facts true for one element also fitted some other elements in the game. In this way the triplets formed in game session could be differentiated from those originally designed by the game developer. It was decided to create one shared triplet from calcium (Ca) and copper (Cu) despite the fact that they are situated in the side groups, and because they are very typical examples of metals in everyday life. One extra card was developed to replace one of the original fact cards in the triplet for chlorine (Cl). All these choices were made for to improve the playability and unpredictability of the game.
In the cards of *Collect a Triplet* facts similar to those on the cards of *Periodical Domino* (Section 6.3.1, Figure 13) were used. They were about the element's chemical symbol, electron structure, structure of outer electron shell in the atom, number of particles (electrons, protons), location in the periodic table (group, period), ionic charge or being metallic or non-metallic. As an example, the playing card for boron (B) in the first version of the game is presented in Figure 14.

![B card triplet](image)

*Figure 14. A card triplet for boron (B) in the first version of Collect a Triplet.*

6.2.2.2 Testing on chemistry teachers

*Collect a Triplet* was tested together with *Periodical Domino* (see Section 6.3.1.2). Altogether 16 testers gave feedback about *Collect a Triplet*. The testers liked the main idea of the game, but the students needed to concentrate while gaming, and there was too much unpredictability and too many luck elements in the game structure. The in-game requirement for argumentation and explanation divided the testers: some thought it was nice, while others thought it would reinforce the separation between the students in the class, because some are naturally better at argumentation than others. Similar comments were not found in the feedback for the similar *Periodical Domino* game.

Clarification and accuracy were suggested for the rules concerning the beginning of the game and the principles in collecting the triplets: what kind of triplets are players allowed to collect? In particular, it was mentioned that the criteria for approving the triplet must be tight enough. The testers made several suggestions for changing the rules or applying them in different ways. They also suggested that concrete sentences be added into the rules: Shuffle the deck of cards; it is then the next player's turn; when the triplet has been approved, the owning player picks it up and then starts the next turn with one card of a new triplet on the board. The comments for the contents in the cards were only about some minor errors. It was recommended to reduce the number of cards in play if there are only two players.
Contradictory feedback was given about playing time of the game. According to five of the testers, 20–30 minutes’ playing time was suitable, whereas six of the players did not manage to finish the game within this time limit. Four other testers had been playing for only 17 minutes, and one did not give any feedback about the playing time. Slightly over half of the testers shared the opinion that the game is suitable for upper secondary level, but too difficult and challenging for lower secondary chemistry education. Six testers had no opinion at all. The majority of the playtesters found the game rules to be too complicated for the lower secondary level.

6.2.2.3 The second version

As a second design cycle for the Collect a Triplet card game, it was modified according to the collected feedback from the chemistry researchers, teachers and pre-service teachers (see Section 6.3.2.2). Compared to the first version, in the second version of the educational game the rules are simpler and possibly more suitable for lower secondary students, and playing time is shorter when the rule for picking up several cards in turn has been removed. The visual design of the playing cards has also been improved to emotionally engage the students better (Hunicke et al., 2004), though function is more important (Warren & Jones, 2017).

Perhaps the most important change was applied to the cards. The elements were chosen again so that in the current version there are always two elements corresponding to one of the main groups, and the two side group elements have been removed (Table 5). This re-design was based on both the tester feedback and the national core curriculum (Finnish National Agency for Education, 2014), which puts the focus on the general properties of the elements and basic principles in the use of the periodic table. For every element in the game, a card with a name or a chemical symbol and two cards with linked properties exist in the pack of cards. In the second version of the game, there is a better chance for the players to create triplets different from the original ones and surpassing the limits of the elements, and in this way the construction of their own models of the periodic table can be even more creative, unpredictable and motivating. As an example, the clue cards for boron (B) in the second version of the game are presented in Figure 15. Two extra card triplets concerning beryllium (Be), selenium (Se), ions, ionic compounds and molecular compounds were added to the game to expand its content to cover the curriculum topic: types of compounds.
As in *Periodical Domino*, also in *Collect a Triplet*, the rules were modified and clarified according to feedback, in order to achieve better playability and to better match the skills of lower secondary students. It was particularly important that in the modified rules, the principles for collecting and approving the triplet would be clear to all the players from the beginning of the game. In this second version, a triplet can be started on the board only with a card on which either an element’s name or chemical symbol is mentioned. This new rule is stricter than before, but at the same time it makes playing and in-game decisions easier, as hoped for by the testers. The testers’ suggestion for rule improvements were also noted.

Despite the suggestion, it was decided to keep the number of divided cards the same as in the first version, because otherwise the reduced number of cards would diminish the options for cards in hand and thus the playability of the game. The requirement for argumentation and explanation were kept as an essential part of this educational game, because it is precisely active in-game processing of knowledge that provokes students to create their own mental models of the periodic table (Gilbert & Boulter, 2000) (see Section 4.2.3).

Different difficulty levels were taken into account in this second version. The rules for an easier and quicker way to play the game were developed. These rules can be applied in independent play or in parallel with the normal rules. In normal rules, all the three cards in the triplet must agree with each other, whereas in the easier rules, the first two cards of the triplet are stacked, and the third one must agree with the upper card.

### 6.3 Design solutions

In this section, the prescriptions of successful design solutions for two educational card games are presented. As design solutions in design challenge 1, the *Periodical Domino* and the *Collect a Triplet* educational card games were designed for lower secondary chemistry education to develop, support...
and enhance students’ periodic table usage skills. Both design solutions answered to RQ 2: which features of an educational game may support the development of skills to learn and use information included in the periodic table?

These educational games both (1) based on the theoretical framework about educational chemistry games, bring together all the clue types which have been used in the previous educational games developed for learning the periodic table; and (2) based on the theoretical framework about quality game elements, learning and the content of the national curriculum, make the students, with the help of the periodic table, argue and explain to each other why a specific card is set on the game table.

6.3.1 Design solution: Periodical Domino

The game mechanics in Periodical Domino are similar to those of classical domino, but the game dynamics differ: all the clues are different from each other and only one card will be picked up if none of the cards in a player’s hand fits on the game table.

The game material for Periodical Domino consists of 28 cards, the rules and one long periodic table for every player. Each card includes two parallel clues about the 14 main group elements in the game. All the clues differ from each other. Every player has their own long periodic table in front of them to help in play. Each of the players will get three cards. The rest of the cards are placed face down as a deck on the table. The player on the left of the card dealer starts the game. The players take turns clockwise. The first player sets one of the cards in his/her hand on the game table. At the same time, the player owns a duty to explain and reason to the other players, with the help of the long periodic table, why this card is the right choice. If the player has no suitable cards, then one card will be picked up from the deck and the turn changes. The next player tries to continue the card line on the table with a card which matches one of the clues on the heads of the card line on the table. The player also owns a duty to explain and reason to the other players, with the help of the long periodic table, why this card is the right choice. When the card deck runs out, the game continues, until none of the players can set a card on the table. The winner is the one with the smallest number of cards in hand.

The final version of the Periodical Domino educational game material (the cards and the guidelines) (Appendix 2) is available in the appendices of this thesis.

6.3.2 Design solution: Collect a Triplet

The game mechanics and dynamics in Collect a Triplet are loosely based on the mechanics of Pekka-peli (similar to Old Maid). In this game, the players collect card triplets on the table, whereas in Pekka-peli the card families of four are collected in the hand.
The game material for *Collect a Triplet* consists of 48 cards, the rules and a long periodic table for every player. For each of the elements in a game, there exist three cards: one with a name or a chemical symbol and two with clues. All the cards are different from the others. Every player has their own long periodic table in front of them to help in play. To begin, three cards are dealt to each of the four players. The rest of the cards are placed face down as a deck on the table. The player to the left of the dealer starts the game. This player sets one of the cards in their hand on the game table to start a triplet: only a card with a name or a chemical symbol is allowed. Then the player picks up one card from the deck. The turn moves on clockwise. Another card can be added to the triplet, if it fits together with the first card, and the player is able to explain the reason to the other players with the help of the periodic table. Otherwise the player fails, takes the card back into the hand, and picks an extra card. If a player successfully adds the third card into the triplet, the triplet is ready, removed from the table and the player gains a point. The game ends when none of the cards in hand fit on the table. The player with the highest score is the winner: the number of collected triplets minus cards in hand.

The final version of the *Collect a Triplet* educational game material (the cards and the guidelines) (Appendix 3) is in the appendices of this thesis.

### 6.4 Peer-evaluation concerning quality of the card games

The contents of *Periodical Domino* and *Collect a Triplet* card games were peer-evaluated using the first version of the CHEDU Game Design Tool (Table 18). Each evaluator filled in their own evaluation tool for each of the games evaluated. The evaluators circled those quality elements which they found to be present in the game. Cohen's kappa (Table 6) indicated substantial agreement among the evaluators. The results are presented in Table 7 for *Periodical Domino* and in Table 8 for *Collect a Triplet*.

<table>
<thead>
<tr>
<th>Peer-evaluated educational game</th>
<th>Cohen's kappa (κ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Periodical Domino</em></td>
<td>0.756</td>
</tr>
<tr>
<td><em>Collect a Triplet</em></td>
<td>0.718</td>
</tr>
</tbody>
</table>

*Table 6. Cohen's kappa for two educational card games, which were peer-evaluated by using the first version of the educational card and board game design and evaluation tool for lower secondary chemistry education.*
Table 7. Evaluation for *Periodical Domino* by using a criteria for quality educational chemistry card and board games presented in the first version of the CHEDU Game Design Tool.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>SUBCLASS</th>
<th>SUBCLASS DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEARNING OBJECTIVE</td>
<td>Game has a clear learning objective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
<td>remembering, concept or phenomenon</td>
</tr>
<tr>
<td></td>
<td>Skills</td>
<td>application of knowledge, social interaction</td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>Game materials</td>
<td>playable</td>
</tr>
<tr>
<td></td>
<td>Clear rules</td>
<td>easy to read, game goal is easy to understand</td>
</tr>
<tr>
<td></td>
<td>Playing time</td>
<td>15 min</td>
</tr>
<tr>
<td></td>
<td>Coherence between game’s outfit and context</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Availability (at the same time)</td>
<td>for all</td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td>school, home</td>
</tr>
<tr>
<td>PEDAGOGY</td>
<td>Making thinking visible</td>
<td>explanation and argumentation, evaluation</td>
</tr>
<tr>
<td></td>
<td>Suitable challenges (zone of proximal development)</td>
<td></td>
</tr>
<tr>
<td>CHEMISTRY AND NATIONAL CURRICULUM</td>
<td>Concept or topic is included in chemistry curriculum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chemistry triplet</td>
<td>submicro, symbolic</td>
</tr>
<tr>
<td></td>
<td>Application of knowledge</td>
<td></td>
</tr>
<tr>
<td>SOCIALITY ACTIVITY</td>
<td>Number of players</td>
<td>multiplayer</td>
</tr>
<tr>
<td></td>
<td>Nature of player interaction</td>
<td>competitive</td>
</tr>
<tr>
<td></td>
<td>Player involvement</td>
<td>continuous</td>
</tr>
<tr>
<td>INSTRUCTIONS SUPPORT FEEDBACK</td>
<td>Pregame</td>
<td>pregame instructions</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td>peer support, teacher support, in-game feedback</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
<td>discussion, postgame feedback</td>
</tr>
<tr>
<td>ASSESSMENT</td>
<td>In-game</td>
<td>self-assessment, peer assessment, teacher assessment</td>
</tr>
</tbody>
</table>
Table 8. Evaluation for Collect a Triplet by using a criteria for quality educational chemistry card and board games presented in the first version of the CHEDU Game Design Tool.

<table>
<thead>
<tr>
<th>CLASS</th>
<th>SUBCLASS</th>
<th>SUBCLASS DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEARNING OBJECTIVE</td>
<td>Game has a clear learning objective</td>
<td>remembering, concept or phenomenon, rules or principles application of knowledge, social interaction</td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skills</td>
<td></td>
</tr>
<tr>
<td>STRUCTURE</td>
<td>Game materials</td>
<td>playable, visual</td>
</tr>
<tr>
<td></td>
<td>Clear rules</td>
<td>easy to read, game goal is easy to understand</td>
</tr>
<tr>
<td></td>
<td>Playing time</td>
<td>30 min</td>
</tr>
<tr>
<td></td>
<td>Coherence between game’s outfit and context</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Availability (at the same time)</td>
<td>for all</td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td>school, home</td>
</tr>
<tr>
<td>PEDAGOGY</td>
<td>Multiple difficulty levels</td>
<td>different ways to play</td>
</tr>
<tr>
<td></td>
<td>Making thinking visible</td>
<td>explanation and argumentation, evaluation</td>
</tr>
<tr>
<td></td>
<td>Suitable challenges (zone of proximal development)</td>
<td></td>
</tr>
<tr>
<td>CHEMISTRY AND NATIONAL CURRICULUM</td>
<td>Concept or topic is included in chemistry curriculum</td>
<td>submicro, symbolic</td>
</tr>
<tr>
<td></td>
<td>Chemistry triplet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application of knowledge</td>
<td></td>
</tr>
<tr>
<td>SOCIALITY ACTIVITY</td>
<td>Number of players</td>
<td>multiplayer</td>
</tr>
<tr>
<td></td>
<td>Nature of player interaction</td>
<td>competitive</td>
</tr>
<tr>
<td></td>
<td>Player involvement</td>
<td>continuous</td>
</tr>
<tr>
<td>INSTRUCTIONS SUPPORT FEEDBACK</td>
<td>Pregame</td>
<td>pregame instructions</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td>in-game instructions, peer support, teacher support, in-game feedback, rewards</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
<td>discussion, postgame feedback</td>
</tr>
<tr>
<td>ASSESSMENT</td>
<td>In-game</td>
<td>self-assessment, peer assessment, teacher assessment</td>
</tr>
</tbody>
</table>
The game structure in *Periodical Domino* was stated to be of quality and to have a clear learning objective. It seemed to be in line with nearly all the quality criteria concerning chemistry curriculum and pedagogy. According to the evaluators, in-game chemistry learning is supported by making thinking visible, by application of knowledge and by providing suitable challenges in the zone of students’ proximal development. Instructions and support were found to be present in every phase of the game session, in the forms of rules, teacher or other players. In-game and postgame assessments in the forms of peer-feedback or feedback from a teacher existed. Partial disagreement appeared about the skills the game will teach to the players and the levels of chemistry triplet in the game. Disagreement was found in the cases of pregame and postgame assessment. According to evaluators, the weaknesses in the game material were playing cards' poor visual appeal, absence of connections to daily life, and a lack of support for critical thinking and multiliteracy.

The game structure in *Collect a Triplet* was stated to be of quality and to have a clear learning objective. Unlike *Periodical Domino*, the cards in this game were found to be visually appealing. Like *Periodical Domino*, *Collect a Triplet* seemed to be in line with nearly all the quality criteria concerning chemistry curriculum and pedagogy. According to evaluators, in-game chemistry learning is supported by making thinking visible, by application of knowledge and by providing suitable challenges in the zone of students’ proximal development. Instructions and support were found to be present in every phase of the game session, in the forms of rules, teacher or other players. In-game and postgame assessments in the forms of peer-feedback or feedback from a teacher existed. The evaluators partially disagreed about the skills that the game has potential to learn and about the levels of chemistry triplet appearing in the game. There was total disagreement between the evaluators concerning problem-solving challenges in the game and opportunities for pregame and postgame assessments. Both found that connections with daily life and support for learning critical thinking and multiliteracy were missing in the game.

**6.5 Summary: Students constructing their own in-game models of the periodic table**

In design challenge 1, both the guiding development models and the guiding models for learning have been developed as design solutions. The guiding development models are two prescriptions for potentially successful educational game design processes (Sections 6.3.1 and 6.3.2). The guiding models for learning are two educational chemistry card games that may support learning of periodic table usage skills: *Periodical Domino* (Section 6.4.1) and *Collect a Triplet* (Section 6.4.2).

The periodic table is an essential model in chemistry and an important teaching model in chemistry education. It has been noted that by structuring their own models the students enhance their understanding of the concept or phenomenon at hand (Saari & Viiri, 2003; Solomon 1995). According to Whitton (2014), behaviourist educational games focusing on memorization, recall and learning facts
are only the starting point, and it is the application of knowledge and skills in the constructivist educational games, that are important in processes underpinning learning. The two educational card games developed in design challenge 1 offer the students the opportunity as player-learners to construct both their own models of the periodic table, and to improve their knowledge, understanding and usage skills related to the periodic table in game sessions. Both games are based on the cognitive and the social constructivist learning theories (e.g. Palincsar, 1998; Piaget, 1951/1999; Powell & Kalina, 2009; Vygotsky, 1978), and follow the criteria for quality educational games and the current national curriculum for basic chemistry education (Finnish National Agency for Education, 2014). The players own a duty to argue and explain their own models to the other players by using the long periodic table as a supportive in-game tool. The games were tested only on teachers, not students, who will be the actual players of these games.

Both Periodical Domino and Collect a Triplet satisfy the criteria for quality educational chemistry card games (Section 6.5), but lack the macroscopic level and connections to adolescents' daily life, as well as opportunities for students to develop their problem-solving skills and multiliteracy during play. Some of these requirements could possibly be filled by modifying the clues or adding new types of clues to the game. In Collect a Triplet, the playing cards are visual and different difficulty levels in game are possible, whereas in Periodical Domino, these are both missing (see Section 9.1). In both games, elements to improve their uncertainty and unpredictability could be added, for example by creating cards which allow the players to remove cards from the game table or remove cards from the hands of the other players.

The above-mentioned needs for improvements in the criteria for a quality educational chemistry card and board games, in challenges to embed these requirements into the educational chemistry games on design, and in authentic game testing on students, will be taken into account in design challenges 2 and 3.
7 DESIGN CHALLENGE 2: EDUCATIONAL CHEMISTRY CARD AND BOARD GAME DESIGN AND EVALUATION TOOL

Design challenge 2 has its roots in the general need to improve the quality of educational games (Qian & Clark, 2016; Warren & Jones, 2017; Wu et al., 2012) and in developing systematic quality criteria for them (Dondi & Moretti, 2007). Additionally, the challenges noted in the design process of two educational games in design challenge 1 (Chapter 6) have been taken into account. Hence an educational chemistry card and board game design and evaluation tool in lower secondary education (CHEDU Game Design Tool) was developed. During the design process, an answer to RQ 1 was sought: what kind of game design and evaluation tool for educational card and board games supports both teaching and learning in chemistry education? The aim was to develop a practical and high-quality tool for game-developers, teachers, educators and researchers (1) to design new educational card and board games for chemistry education purposes, and (2) to evaluate if an educational game is in line with a particular teaching approach, a chemistry curriculum and with quality criteria for educational games.

7.1 Theoretical problem analysis

This theoretical problem analysis was conducted both to structure and to broaden the theoretical framework about games and educational games (Chapter 3), and to determine the theory-driven central concepts in the classification, assessment and evaluation of games and educational games. This was done not just to assess sporadic quality game elements, but to review systematic ways to classify and evaluate games and educational games.

Digital games such as computer and video games are very popular and research in the field is wide and still increasing. Studies exist concerning the use of digital games in entertainment (e.g. Boyle, Connolly, Hainey, & Boyle, 2012), in education and in edutainment (e.g. Qian & Clark, 2016), which means the unification of entertainment and education in a same game (Charsky, 2010). Particularly for digital games, several different classification and evaluation systems or tools have been developed. Classification or evaluation has been done according to flow state, narrativity, engagement and immersion (e.g. Annetta, 2010; de Freitas & Oliver, 2006; Ke, 2009). Educational elements such as educational effectivity, instructions and support, have also been taken into account (e.g. de Freitas & Oliver, 2006; Dondi & Moretti, 2007; Virvou, Katsionis, & Manos, 2005). Despite the fact that card and board games existed a long time before the digital era, similar kinds of systematic and specific tools to classify, design or evaluate card and board games have not been developed in the research. For example, in a study by Kavak and Yamak (2016) the effectiveness of the Picture Chem game was evaluated with a
general SWOT analysis. However, some important, sporadic quality game elements were mentioned in the previous research articles.

7.1.1 Structure of integrative literature review

This theoretical problem analysis was executed at the beginning of 2015 as an integrative literature review in accordance with the criteria and models for integrative and systematic data collection (Salminen, 2011; Koskinen, Kangas, & Krokfors, 2014). Integrative literature review has the advantage when there is a need to produce novel knowledge and to broaden the picture inside a formerly studied research area (Salminen, 2011). It shares similar phases with systematic literature review, but the data is sifted more loosely, yet evaluated critically, and this permits a wider and more variable perspective compared to systematic review (Salminen, 2011).

In the integrative literature review for design challenge 2, the following seven phases were executed:

1. Defining the objective: To review the relevant literature relating to the classification and evaluation of educational games
2. Defining criteria for articles: Article includes a tool, framework or other relevant, research-based information for classifying or evaluating games or educational games; article does not include only simulations or commercial games; article presents general information and does not focus only on one game; exceptions to the previous rule are articles about educational chemistry games; entire article is available at no extra cost; the sources were published in the years 2000–2014
3. Defining keywords for articles: First search with "games and classification"; second search with "games and evaluation"; third search with "games and quality assessment"; and fourth search with "educational games and quality assessment"
4. Defining data sources: Nelli Search Portal (including databases, journals and e-journal sources in the Helsinki University Library and the National Library of Finland)
5. Literature search (see Section 7.1.2)
6. Data extraction: A directed content analysis with coding (see Section 7.1.3)
7. Data synthesis: A directed content analysis with clustering (see Section 7.1.4).
7.1.2 Literature search

In the phase (5) literature search, a total of 14 articles from the four searches were accepted into phase (6) data extraction of this literature review. The first search with the keywords “games and classification” yielded 132219 results. When sorted by relevance, none of the first ten articles were considered relevant for this research. These non-relevant articles classified different games for instance by violence or cheating, or their content concerned something other than playable games, like weakly acyclic games. The second search with the keywords “games and evaluation” yielded 339307 results, a number which was absolutely too high to wade through. The decision was made to include only the top 90 articles when sorted by relevance. Six of these articles were considered to comply with the default criteria (phase 2), and therefore accepted. This second search was then adjusted to only include articles from the year 2014, and in this way three more articles were accepted. The third search with the keywords “games and quality assessment” resulted in 126075 articles, the relevant top 30 of which were considered, from which two more articles were accepted. The fourth and last search with the keywords “educational games and quality assessment” yielded 51080 results. Two more articles were accepted from the top 30 of articles sorted by relevance for the topic of this literature review.

In total, the literature search yielded 14 articles, of which only one was about board games and the other 13 were about digital games. Therefore, 16 additional articles were chosen to complement the literature search described in the previous paragraphs. These additional articles had either been cited in the searched articles or addressed the development, evaluation or study of educational chemistry card and board games, or given some other relevant information about the quality of chemistry-related card or board games. Therefore, some of the articles were published before 2014. These articles are also used as references in Chapter 3: Educational games. Additionally, none of these articles came to the fore in the literature search, because their topics were not directly related to game classification or evaluation. In January 2015, it was decided to include one recent article, which fulfilled the criteria.

Thus, a total 31 relevant articles were include in the integrative literature review. One of the articles was a meta-analysis (Ke, 2009) and two of them were article reviews (Chin, Dukes, & Gamson, 2009; Li & Tsai, 2013). Digital game evaluation tools and frameworks were presented in eight of the articles (Annetta, 2010; de Freitas & Oliver, 2006; Hainey, Conolly, & Boyle, 2010; Mayer, Bekebrede, Hartevedl, Warmelink, Zhou, van Ruijven, Lo, Kortmann, & Wenzler, 2014; Mitgutsch & Alvarado, 2012; O’Neil, Wainess, & Baker, 2005; Reuter, Mehm, Göbel, & Steinmetz, 2013; Tsai, Tsai, & Lin, 2015). Alternative suggestions for classifying or assessing games or/and educational games were presented in seven articles, and one of these was specifically about board games directed to basic education (Dondi & Moretti, 2007; Ibrahim et al., 2012; Ke, 2008; Rego, Moreira, & Reis, 2010; Salmina & Tihanova, 2011; Wouters, van der Spek, & van Oostendorp, 2011; Zapata-Rivera & Bauer, 2012). Two of the articles were about game materials for chemistry education (Bayir, 2014; Costa, 2007). In five articles, games or
educational games as teaching approach were discussed and sporadic quality game elements were mentioned in the texts (Casbergue & Kieff, 1998; Galus, 2003; Lujan & DiCarlo, 2006; Nemerow, 1996; Owens & Sanders, 1998). In the last five articles, game or educational game research concerning teaching or learning with them were discussed (Barab, Scott, Siyahham, Goldstoe, Ingram-Goble, Zuiker, & Warren, 2009; Bornstein, Kugler, & Ziegelemeyer, 2003; Rastegarpour & Marashi, 2012; Tüysüs, 2009; Virvou, Katsionis, & Manos, 2005).

7.1.3 Data extraction

After the phase (5) literature search (Section 7.1.2), the phase (6) data extraction was executed with a directed content analysis, which is typically included in the literature review to both clarify and condense the data, improving its informational value and supporting or even extending existing theory (Hsieh & Shannon, 2005; Tuomi & Sarajärvi, 2006). In directed content analysis, the theoretical framework together with relevant previous research serve as a basis for initial coding (Hsieh & Shannon, 2005).

First, the information in the article texts was extracted by excerpting directly relevant terms and sentences from the texts. Then the gathered information was coded into descriptive words or collocations (Appendix 1).

7.1.4 Data synthesis

The last phase of the literature review was (7) data synthesis, in which codes from the data extraction phase were clustered and evaluated. Based on the results in phase (6), in the phase (7) data synthesis, 31 categories for describing central concepts in the field of quality games and educational games were formed (Table 9). These central concepts can be named quality game elements. Table 9 shows that, according to number of mentions in the reviewed articles, the top three quality game elements are: sociality (sociality, interactivity, group work, participation), learning objective (skills, knowledge, attitudes, values), and aesthetic, visuality, playability and usability of a game. Number of mentions may not necessarily indicate the importance of this game element in such a small-scale review as this, but it does provide an indication.
Table 9. Coding and clustering of central concepts in the field of game and educational game assessment and evaluation based on literature review (n\text{articles} = 31).

<table>
<thead>
<tr>
<th>Central concepts in the field of game and educational game classification, assessment and evaluation</th>
<th>Number of mentions (n\text{article} = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sociality (sociality, interactivity, group work, participation)</td>
<td>17</td>
</tr>
<tr>
<td>Learning objective (skills, knowledge, attitudes, values)</td>
<td>17</td>
</tr>
<tr>
<td>Aesthetic, visuality, playability, usability</td>
<td>13</td>
</tr>
<tr>
<td>Feedback</td>
<td>10</td>
</tr>
<tr>
<td>Game linked to real life or context connected to players</td>
<td>9</td>
</tr>
<tr>
<td>Cooperative or competitive</td>
<td>9</td>
</tr>
<tr>
<td>Immersion, engagement, feel of presence</td>
<td>8</td>
</tr>
<tr>
<td>Evaluation and assessment (self-, pregame, in-game, postgame)</td>
<td>8</td>
</tr>
<tr>
<td>Rewards</td>
<td>7</td>
</tr>
<tr>
<td>Guidance and support (teacher, peer)</td>
<td>7</td>
</tr>
<tr>
<td>Content connected to players’ grade or age</td>
<td>7</td>
</tr>
<tr>
<td>Clear and explicit rules</td>
<td>7</td>
</tr>
<tr>
<td>Clear game goal (NB! can be different from a learning objective)</td>
<td>7</td>
</tr>
<tr>
<td>Curriculum or pedagogy</td>
<td>6</td>
</tr>
<tr>
<td>Problem-solving</td>
<td>5</td>
</tr>
<tr>
<td>Multiplayer (vs. single player)</td>
<td>5</td>
</tr>
<tr>
<td>Connection between game structure/content and topic</td>
<td>5</td>
</tr>
<tr>
<td>Game identity or customisable characters</td>
<td>5</td>
</tr>
<tr>
<td>Narrativity or richness of storyline</td>
<td>4</td>
</tr>
<tr>
<td>Different difficulty levels or increasing complexity</td>
<td>4</td>
</tr>
<tr>
<td>Uncertainty or surprise</td>
<td>3</td>
</tr>
<tr>
<td>Preknowledge</td>
<td>3</td>
</tr>
<tr>
<td>Flow state</td>
<td>3</td>
</tr>
<tr>
<td>Correctness (language, content)</td>
<td>3</td>
</tr>
<tr>
<td>Sense of control / balance between structure and agency</td>
<td>2</td>
</tr>
<tr>
<td>Portability or mobility</td>
<td>2</td>
</tr>
<tr>
<td>Conflicts and challenges</td>
<td>2</td>
</tr>
<tr>
<td>Zone of proximal development</td>
<td>1</td>
</tr>
<tr>
<td>Number of attempts</td>
<td>1</td>
</tr>
<tr>
<td>Easiness in navigation</td>
<td>1</td>
</tr>
<tr>
<td>Alternating feelings of pleasure and frustration</td>
<td>1</td>
</tr>
</tbody>
</table>
7.2 First design process

The results from the theoretical problem analysis (Section 7.1) were critically evaluated. It was decided to discard those central concepts (quality game elements) (Table 9) that were evaluated to be irrelevant or difficult to implement in card and board games, though they are indeed typical for digital games. Therefore, the following four quality game elements were excluded from the design process for a novel educational game design and evaluation tool: ease of navigation, number of attempts, game-identity or customisable characters, and narrativity or richness of storyline.

Additionally, it was decided to exclude a quality game element of correctness (language, content), because it was assessed as being implicitly included in the category of aesthetic, visuality, playability, usability and partly in the category of explicit and clear rules (Table 9).

Flow state can be defined as a state in which a player becomes completely immersed in a game activity and feels at one with it (Annetta, 2010). It is possible to achieve a flow state by gradually increasing in-game complexity and challenges in accordance with the development of a player’s skills, and thus provoke alternating feelings of pleasure and frustration for a player (Annetta, 2010; Tüysüs, 2009). In-game rewards and timely feedback as well as competitions and conflicts similarly offer a player opportunities for achieving flow state, which for its part predicts improvement in the player’s motivation and active engagement. According to some research, engagement is one of the key elements in creating positive attitudes toward learning during play (e.g. Annetta 2010; Charsky 2010; Tüysüs, 2009). Despite the fact that this state has mostly been studied in the field of digital games and it is dependent on quality game elements, it was decided to include it as an additional postgame self-assessment in the novel educational game design and evaluation tool.

Requirements for lower secondary chemistry education were included in the novel educational game design and evaluation tool such that the words describing the main aims and contents of chemistry education in the Finnish National Core Curriculum for Basic Education (Finnish National Agency for Education, 2014) were subsumed into the novel tool. “Chemistry in the student’s daily life and living environment” and “macroscopic level, and submicroscopic and symbolic models” are examples.

Norman (1993) lists the general features for an effective learning environment:

- Continuity in interplay and feedback
- Specific objectives and defined methods
- Motivating
- Continuity in challenges: not so easy as to affect feelings of boredom, nor so difficult as to affect feelings of frustration
- Forming engagement with the task
• Offering suitable tools for the task
• Excluding elements that might interfere with the subjective experience.

Comparing these requirements with the results of the previous integrative literature review and the theoretical framework about learning, games and educational games, they match the requirements for quality educational game closely, except for the criterion on avoiding the feelings of boredom and frustration in learning. As mentioned earlier, one of the elements that motivate and engage players with the magic circle of the game is the alternating feelings of anxiety and boredom during play. When rewards and positive feedback alternate with challenges and conflicts in actual game situations, players will achieve alternating feelings of anxiety and boredom, which engage players to play and learn (Annetta, 2010). In-game challenges fulfill learning games (Annetta, 2010; Charsky, 2010; Tüysüz, 2009) and they possess a positive effect on learning both directly and via engagement (Hamari et al., 2016).

The learning theories of cognitive (or individual) and social constructivism are a basis for the Finnish National Core Curriculum for Basic Education: “The National Core Curriculum is based on a conception of learning that sees the students as active actors. They learn to set goals and to solve problems both independently and together with others.” (Finnish National Agency for Education, 2014, p. 17). The basic principles of the parallel theories of Piaget and Vygotsky (e.g. Eilks et al., 2013; Piaget, 1951/1999; Powell & Kalina, 2009; Vygotsky, 1978) have informed the design process for a novel educational game design and evaluation tool for educational chemistry card and board games on the lower secondary level. Although the quality game elements derived from the integrative literature review and the content of the Finnish core curriculum for basic chemistry education both explicitly express the same elements as these two learning theories, it was decided to add, for example, Vygotsky’s zone of proximal development (1978) into the tool as a quality element on its own.

7.3 First version: Educational card and board game design and evaluation tool for lower secondary chemistry education

According to Warren and Jones (2017), learning with an educational game should be connected to a definition that explains how learning principles are tied to playing that game. This is called a game learning mechanics. A novel educational card and board game design and evaluation tool for lower secondary chemistry education was designed (Table 10) based on the results of both the theoretical problem analysis (Section 7.1) and the design process (Section 7.2). Thus, it includes essential features of game mechanics for quality card and board games in lower secondary education. The contents of the tool are aligned with the criteria for quality games, digital games and educational games in general, but with an emphasis on the pedagogical point of view, chemistry education, and card and board games. To
use the tool, the game elements in the tool are read from top down. In the game design process, these elements (subclasseses) and their alternative options (subclass details) are carefully considered and included in the game as well as possible (see Chapter 8 as an example). In the game evaluation process, these same game elements are soughting the game under evaluation (see Section 6.5 as an example).

The educational card and board game design and evaluation tool for lower secondary chemistry education consists of classes and subclasses that should be included into a quality educational chemistry card or board game for lower secondary purposes (Table 10). The purpose of the detailed subclasses is to guide and support game developers in the processes of evaluating and designing an educational chemistry game. Details in subclasses ease interpretation by showing alternative possibilities. Alternatives in bold are the best choices, according to the research literature. Additionally, a flow state self-assessment test is situated in the bottom of the tool.

The features of the educational game design and evaluation tool have been designed to be in line (1) with the criteria for a quality game in general (see Section 7.4.1). In order to achieve the aim for design challenge 2, the features also are in line (2) with cognitive and social constructivist perspectives for learning and teaching in general (e.g. Eilks et al., 2013; Powell & Kalina, 2009); (3) with demands for an effective learning environment (Norman, 1993); and (4) with demands in the national Finnish chemistry curriculum for basic education (Finnish National Agency for Education, 2014).
**Table 10. First version of the educational card and board game design and evaluation tool for lower secondary chemistry education**

<table>
<thead>
<tr>
<th>CLASS</th>
<th>SUBCLASS</th>
<th>SUBCLASS DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LEARNING OBJECTIVE</td>
<td>an option for best learning results in <strong>bold</strong></td>
</tr>
<tr>
<td></td>
<td>Game has a clear learning objective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
<td>remembering or repetition, concept or phenomenon, rules</td>
</tr>
<tr>
<td></td>
<td>Skills</td>
<td>motor skills (dexterity, accuracy), application of knowledge, decision making or problem solving, social interaction, self-assessment emotional, moral (values)</td>
</tr>
<tr>
<td></td>
<td>Attitudes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PREREQUISITES</td>
<td>What pre-knowledge is the student required to have?</td>
</tr>
<tr>
<td></td>
<td>STRUCTURE</td>
<td>playable, visual</td>
</tr>
<tr>
<td></td>
<td>Game paraphernalia</td>
<td>for one, for one group, <strong>for all</strong></td>
</tr>
<tr>
<td></td>
<td>Coherence between game’s look and context</td>
<td>school, home</td>
</tr>
<tr>
<td></td>
<td>Availability (at the same time)</td>
<td><strong>15 min, 30 min, 45 min</strong></td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Playing time</td>
<td>easy to read, explicit, goal is easy to understand</td>
</tr>
<tr>
<td></td>
<td>Clear rules</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PEDAGOGY</td>
<td>Unpredictability and uncertainty</td>
</tr>
<tr>
<td></td>
<td>Multiple difficulty levels</td>
<td>different ways to play, increasing difficulty within game event</td>
</tr>
<tr>
<td></td>
<td>Making thinking visible</td>
<td>discussion, explanation, argumentation, evaluation</td>
</tr>
<tr>
<td></td>
<td>Suitable challenges (zone of proximal development)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problem-solving</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CHEMISTRY CURRICULUM FOR LOWER-SECONDARY LEVEL</td>
<td>Concept or topic included in chemistry curriculum</td>
</tr>
<tr>
<td></td>
<td>Representational levels</td>
<td>macro, sub-micro, symbolic</td>
</tr>
<tr>
<td></td>
<td>Connection to the living environment and everyday life</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application of knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical thinking and multiliteracy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SOCIALITY ACTIVITY</td>
<td>Number of players</td>
</tr>
<tr>
<td></td>
<td>Student interaction</td>
<td><strong>single player, multiplayer</strong></td>
</tr>
<tr>
<td></td>
<td>Student involvement</td>
<td>competitive, co-operational, <strong>collaborative</strong></td>
</tr>
<tr>
<td></td>
<td>Possibility of assessment</td>
<td>rare, <strong>continuous</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>self-assessment, peer assessment</td>
</tr>
<tr>
<td></td>
<td>INSTRUCTIONS SUPPORT FEEDBACK</td>
<td>Pregame</td>
</tr>
<tr>
<td></td>
<td>Instructions, discussion</td>
<td>instructions, discussion</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td>in-game instruction, peer support, teacher support, discussion, feedback, rewards</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
<td>discussion, feedback</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASSESSMENT</td>
<td>Pregame</td>
</tr>
<tr>
<td></td>
<td>Preconceptions</td>
<td>in-game assessment self-assessment, peer assessment, teacher assessment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>questionnaire, self-assessment</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FLOW-STATE can be evaluated after playing</td>
<td>Feeling of being present during playing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-5 (0 = not at all, 5 = continuous)</td>
</tr>
<tr>
<td></td>
<td>Feeling of being able to achieve the goal</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Interest in playing</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Alternation between feelings of frustration and satisfaction</td>
<td>0-5</td>
</tr>
<tr>
<td></td>
<td>Engagement for playing (intrinsic or extrinsic motivation)</td>
<td>0-5</td>
</tr>
</tbody>
</table>
7.4 Testing on chemistry pre-service teachers

The aim in this test was to evaluate how well the educational card and board game design and evaluation tool for lower secondary chemistry education supports pre-service teachers in their educational chemistry game design process, and what improvements should be made in the first version of the educational game design and evaluation tool.

The first version of the educational card and board game design and evaluation tool for lower secondary chemistry education was used to guide and support pre-service teachers’ board game design processes, in which chemistry game ideas were developed. A qualitative content analysis was applied to six game design diaries of pre-service teachers.

7.4.1 Data collecting

The data for the research was collected in 2015 as part of a university course, Chemistry in Living Environment for chemistry teacher students. A total of 25 pre-service teachers participated in the course (22 females and 3 males). The 22 students were chemistry teacher students at the bachelor level and the other three had home economics as their major subject. The students worked in groups of four or five students and in six groups. An introductory session (3 h) was held at the beginning of the course to give basic information about educational games and playing sessions. First, the students were told about the aims and assessment for the task. The aim was to design a food- or environment-related educational game for lower secondary chemistry education. Secondly, they were briefly informed about games and educational games. Thirdly, students were provided with instructions about the nature of quality educational card and board games, during which the first version of the educational card and board game design and evaluation tool for lower secondary chemistry education was presented as a framework for upcoming game designs (Table 10). They were also given instructions on how to keep a game design diary in groups. At the end of the workshop, students played and evaluated different educational card and board games for chemistry education purposes, trying to find different quality game elements in them, which were mentioned in the first version of CHEDU Game Design Tool (see Chapter 7 and Table 10). The last part of the game tool, Self-evaluation for flow-state, was excluded from the teaching session and the study. Afterwards, all the groups were instructed first to play the Terra board game together and then start to design games themselves. The Terra game gave students an example of a collaborative and environmentally themed game for upper secondary level. This game was designed in Finland specifically to educate upper secondary students, who collaboratively take care of an imaginary planet in order to prevent climate change.
During the course, the students, among their other tasks, developed educational game ideas, not necessarily completed games, and wrote game design diaries in groups (6 h–). A total of six digital game design diaries were created. At the end of the four-month course, a game workshop (3 h) was held during which the students presented their designs for food- or environment-related educational chemistry games to each other and these ideas underwent peer assessment. In the short peer assessment session, other groups suggested improvements for the games, based on the game design and evaluation tool.

7.4.2 Data analysis

The data in the game design diaries was examined with content analysis, carried out with the help of ATLAS.ti 7, a software for qualitative analysis (Archiv für Technik, Lebenswelt und Alltagssprache 1993–2017).

Coding was applied using analytical coding, in which codes were derived from the theme and theoretical background (Cohen et al, 2011), meaning that the subclasses in Table 10 were used as pre-existing codes and the classes in Table 10 were used for code categorization. In this way it was possible to code the data consistently (Cohen et al, 2011) and only one new code, game type, was generated. Coding requires reading and rereading: therefore both initial coding and later coding were implemented (Cohen et al, 2011). Another researcher in the field of chemistry education was first introduced to the educational card and board game design and evaluation tool for lower secondary chemistry education, after which the researcher first pilot coded and then peer-coded the game design diaries.

For transparency and illumination of the coding, three coding examples from game design diary 3 (GD3) are provided:

A branching model [to play a domino], for example on colored joint, you can add a third [domino] piece, like for a new slough. (GD3, S3.1, coded: PEDAGOGY: multiple difficulty levels, STRUCTURE: game paraphernalia)

The [domino] game could be diversified with this branching model, and if you could combine two branches [with your domino piece], then you will get a bonus award or a bonus task. (GD3, S3.4, coded: INSTRUCTIONS/SUPPORT/FEEDBACK: in-game)

The basic tiles will be developed, but also a tile layout for the new tiles. In this way a teacher can easily modify the content and difficulty of the game depending on the situation and players. The game could be played using an explanation version, in which a player should reason with the other players as to two [domino] tiles will fit together (GD3, S3.5, coded: PEDAGOGY: multiple difficulty levels, PEDAGOGY: making thinking visible, SOCIALITY/ACTIVITY: player involvement).
7.4.3 Results and discussion

The results of the testing with pre-service teachers revealed that the use of the educational card and board game design and evaluation tool for lower secondary chemistry education supported pre-service teachers especially in adding different pedagogical elements to their (ideas for) board games. On the other hand, the pre-service teachers had difficulties in including elements for pregame and postgame assessment into their ideas for educational chemistry board games.

Similarities with the quality game elements included in pre-service teachers’ games can be seen between this and previous studies. Curriculum goals and game structure were covered well both in this and previous studies about educational games made by pre-service teachers (Artym et al., 2016; Sardone & Devlin-Scherer, 2016; Tokmak, 2015). Embedding multiple difficulty levels and in-game assessment into the educational board (or digital) games seemed to be easy for pre-service teachers, but they had difficulties with adding pregame or postgame assessment into the games (Sardone & Devlin-Scherer, 2016; Tokmak, 2015). Similar success by pre-service teachers in including player interaction in educational games was reported in a study by Sardone and Devlin-Scherer (2016), whereas in the case of digital games results concerning player interaction were unexpectedly low (Artym et al., 2016) and digital games were mostly designed for single-player purposes (Tokmak, 2015). Pre-service teachers mentioned the latter as a weakness of their games (Tokmak, 2015). The nature of player interaction in all board games was either competitive or cooperative, both in this study and in the study by Sardone and Devlin-Scherer (2016). None of the games was designed to implement collaborative interaction between players against the game.

In these card or board games ideas designed by pre-service teachers, multiple difficulty levels were mostly about different ways to play. These results are similar to the study concerning board games (Sardone & Devlin-Scherer, 2016), whereas in the study concerning digital games (Artym et al., 2016) 40% of pre-service teachers designed a game in which challenges get harder as the game progresses, but multiple ways to play were not mentioned in the study. Hence, it is possibly easier to add different ways to play a game into board games than challenges that will incrementally increase as the game progress.

7.4.3.1 Pre-service teachers’ ability to apply the educational game design tool

The pre-service teachers took the quality requirements given in the tool into account during the game development sessions, especially the elements involving pedagogy, chemistry curriculum and sociality/activity. For instance, multiple difficulty levels and player interaction were taken into consideration in the game design diaries. The support offered by the subclass details in the game design tool was variously used in the game design diaries.
The numerical results are counted instances of the game design tool subclasses found in the six game design diaries (GD1–GD6) and they are presented in Table 11. The column marked “Peer Revision” on the right includes the results from the peer assessment session during the workshop held at the end of the course. Based on the game design diaries, the pre-service teachers seemed to discuss the elements for a quality educational game implicitly or explicitly in their game design processes, and how to add these elements into their own games. A specific element in the tool was sometimes explicitly mentioned in the game diary.

All the classes offered by the first version of the educational game design and evaluation tool emerged, when the whole group of students and all the six game design diaries are taken together. In their entirety, the subclasses were used widely in the processes of game design. But despite the extensive use of different quality educational game elements, distinctive differences between game design diaries can be seen: in four game design diaries (GD2–GD5) out of six, more than 20 elements related to quality educational game and the CHEDU Game Design Tool (see Table 10) were mentioned, but in the last two (GD1 and GD6) only 8 or 9. Only in game design diary 3 (GD3) were all the classes covered well, aside from Prerequisites. In this diary, the pre-service teachers also made a similar table as in the game design tool, and filled it with the elements of their own Kemino domino game.

Table 11. The results of content analysis for six game design diaries, classified according to the educational game development and evaluation tool for lower secondary chemistry education.
7.4.3.2 Learning objectives, Prerequisites and Structure in game design diaries

Understanding of pre-knowledge that players should have before the game session was mostly missing from the game design diaries. Similarly, a clear learning objective for the game was missing from half of the game ideas, although it was clear that the games did support mostly learning of declarative knowledge, meaning that they rarely had skills or attitudes as learning objectives. One of the game design diaries (GD6) had a shortcoming with discussions about the learning objective for its game, even though the game idea seemed to work otherwise. The students apparently placed more emphasis on game structure, such as game paraphernalia, clear rules and, within the rules, clear aims for the game itself. It can also be seen (Table 11) that during the peer assessment session, ideas for revising the games mainly involved game paraphernalia (8) and multiple difficulty levels (3). The peer review did not provide suggestions for improving learning objectives or assessment in the games.

7.4.3.3 Pedagogy, Chemistry curriculum and Sociality/Activity in game design diaries

Elements in the tool’s classes for pedagogy, chemistry curriculum and sociality/activity were mentioned often. Despite the plentiful use of pedagogical elements in the game design diaries, the use of problem-solving as a game element was absent.

In the subclass of multiple difficulty levels, pre-service teachers mostly discussed different ways to play the game rather than increasing difficulty within the game event. In the subclass of making thinking visible, opportunities for argumentation and/or explanation were the most used options in the game design diaries, whereas opportunities for evaluation during a game were absent.

7.4.3.4 Instruction/Support/Feedback and Assessment in game design diaries

The class instruction/support/feedback and assessment were the least employed of the classes in the tool. Assessment elements were evident in the diaries only to a small degree. Still, some opportunities for in-game assessment were included organically into game mechanics and game rules. The class of instructions/support/feedback appeared only in the cases of in-game instructions, support of feedback. In one of the game design diaries (GD1), assessment was not mentioned at all. Some explicit but general mentions about the importance of self and peer assessment in games were found in the game design diaries.
7.5 Second design process

The empirical problem analysis (Section 7.4) yielded information on how well the educational game development and evaluation tool for lower secondary chemistry education supported chemistry pre-service teachers in the educational game design process. Based on its results, a need for improvements in the tool emerged, hence a second design cycle with a design process and revised design solution was applied.

Game paraphernalia, clear game rules, concepts or topics included in chemistry curriculum, multiple difficulty levels and player interaction were thought out well, whereas the class of assessment was evident only to a slight degree (Table 10). Findings in the empirical problem analysis indicated that some adjustments should be made to minimize ambiguities in the classes of the tool and to enhance its support capability.

Based on the coding in the empirical problem analysis, the tool’s contents in the classes of assessment, instructions/support/feedback and sociality/activity need to be revised to avoid repetition and overlapping. For example, peer and self-assessment are mentioned in two of the classes.

Based on the previous research about pre-service teachers as game developers (Section 3.3.5) and the results of the integrative literature review in the theoretical problem analysis (Section 7.1), the tool needs the additional subclasses of characters and narrativity/storyline. Game characters basically affect game structure, but also the pedagogy and sociality/activity of a game. It had been decided to exclude the subclasses of characters and narrativity from the first version of the tool (see Sections 7.1. and 7.2). Using characters is indeed typical in digital games, but as the studies of Sardone and Devlin-Scherer (2016), and Zagal and Hsi (2016) show, they fit very well into board games too, and according to previous research, narrative and game characters are engaging elements in games (e.g. Dickey, 2005; Ermi & Mäyrä, 2003). Although in board games, in-game progression of character and opportunity to immerse in the story might be challenging or even inapplicable, a game expansion called "Expeditions" with characters and storyline was published in 2014 for a very popular and traditional Finnish board game, Afrikan Tähti (en. Star of Africa), which was originally designed in 1951.
### 7.6 Design solution: CHEDU Game Design Tool

The second design cycle for the educational card and board game design and evaluation tool for lower secondary chemistry education was implemented, based on the empirical problem analysis (Section 7.4). As a result, the revised educational card and board game design and evaluation tool for lower secondary chemistry education (CHEDU Game Design Tool) was developed (Table 12).

The tool's actual name, *the educational card and board game design and evaluation tool for lower secondary chemistry education*, were found to be informative, but too long. Therefore, a still informative, yet slightly more general abbreviation was created: CHEDU Game Design Tool. The word “chedu” addresses both chemistry and education(al). This abbreviation can be used in parallel with the actual name.

Compared with the first version of the tool, the classes of assessment, instructions/support/feedback and sociality/activity were revised and clarified so that peer and self-assessment are mentioned only in the class of assessment in this second version of the tool. By embedding two novel subclasses into the tool, a novel class of engaging elements was created. Both two new subclasses, storyline/narrative and characters, were added into the class of engaging elements, but based on previous research, the subclasses of unpredictability/uncertainty and multiple difficulty levels were moved there from the class of pedagogy.
Table 12. Second and final version of the educational card and board game design and evaluation tool for lower secondary chemistry education (CHEDU Game Design Tool). In the tool, elements for quality educational chemistry game are listed in classes and subclasses.

<table>
<thead>
<tr>
<th><strong>CHEDU GAME DESIGN TOOL</strong></th>
<th><strong>EDUCATIONAL CARD AND BOARD GAME DESIGN AND EVALUATION TOOL FOR LOWER-SECONDARY CHEMISTRY EDUCATION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLASS</strong></td>
<td><strong>SUBCLASS</strong></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LEARNING OBJECTIVE</strong></td>
<td>Game has a clear learning objective</td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
</tr>
<tr>
<td></td>
<td>Skills</td>
</tr>
<tr>
<td></td>
<td>Atitudes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PREREQUISITES</strong></td>
<td>What pre-knowledge is the student required to have?</td>
</tr>
<tr>
<td><strong>STRUCTURE</strong></td>
<td>Game paraphernalia</td>
</tr>
<tr>
<td></td>
<td>Coherence between game’s look and context</td>
</tr>
<tr>
<td></td>
<td>Availability (at the same time)</td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
</tr>
<tr>
<td></td>
<td>Playing time</td>
</tr>
<tr>
<td></td>
<td>Clear rules</td>
</tr>
<tr>
<td><strong>PEDAGOGY</strong></td>
<td>Making thinking visible</td>
</tr>
<tr>
<td></td>
<td>Suitable challenges (zone of proximal development)</td>
</tr>
<tr>
<td></td>
<td>Problem-solving</td>
</tr>
<tr>
<td><strong>ENGAGING ELEMENTS</strong></td>
<td>Unpredictability and uncertainty</td>
</tr>
<tr>
<td></td>
<td>Multiple difficulty levels</td>
</tr>
<tr>
<td></td>
<td>Storyline or narrative</td>
</tr>
<tr>
<td></td>
<td>Game characters</td>
</tr>
<tr>
<td><strong>CHEMISTRY CURRICULUM IN</strong></td>
<td>Concept or topic included in chemistry curriculum</td>
</tr>
<tr>
<td><strong>LOWER-SECONDARY</strong></td>
<td>Representational levels</td>
</tr>
<tr>
<td><strong>EDUCATION</strong></td>
<td>Connections to daily life and the living environment</td>
</tr>
<tr>
<td></td>
<td>Application of knowledge</td>
</tr>
<tr>
<td></td>
<td>Critical thinking and multiliteracy</td>
</tr>
<tr>
<td><strong>SOCIALITY ACTIVITY</strong></td>
<td>Number of players</td>
</tr>
<tr>
<td></td>
<td>Player interaction</td>
</tr>
<tr>
<td></td>
<td>Player involvement</td>
</tr>
<tr>
<td><strong>INSTRUCTIONS SUPPORT</strong></td>
<td>Pregame</td>
</tr>
<tr>
<td><strong>FEEDBACK</strong></td>
<td>In-game</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ASSESSMENT</strong></td>
<td>Pregame</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>FLOW-STATE can be</strong></td>
<td>Feeling of being present during playing</td>
</tr>
<tr>
<td><strong>evaluated</strong></td>
<td>Feeling of being able to achieve the goal</td>
</tr>
<tr>
<td><strong>after playing</strong></td>
<td>Interest in playing</td>
</tr>
<tr>
<td></td>
<td>Alternation between feelings of frustration and</td>
</tr>
<tr>
<td></td>
<td>satisfaction</td>
</tr>
<tr>
<td></td>
<td>Engagement for playing (intrinsic or extrinsic</td>
</tr>
<tr>
<td></td>
<td>motivation)</td>
</tr>
</tbody>
</table>

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7.7 Summary: Quality game elements for guiding educational game developers

In design challenge 2, two guiding development models, describing theory and guiding theory, were developed as design solutions. The first guiding development model, the CHEDU Game Design Tool (Table 12), was designed to describe features for quality educational card and board games (Sections 7.3 and 7.6). In the CHEDU Game Design Tool, the contents of evaluation tools and frameworks from the previous game and educational game studies are combined in an explicit 2-dimensional table. The tool is not only a guiding development model, but it also serves guiding theory about games and educational games in a concise and simple manner. The tool may be used in guiding and supporting educational game developers to evaluate games and to design research-based, quality educational chemistry games, according to the principles from previous research. Another guiding development model designed herein is a prescription of successful design and evaluation tool design process (Sections 7.1, 7.2 and 7.4).

The describing and guiding theories were developed in the field of educational games simultaneously with the design process for the CHEDU Game Design Tool. Findings in the literature review in the theoretical problem analysis (Section 7.1) demonstrated agreement between digital game developers, card and board game developers, and educational games developers about the central and important quality features in games. The results support and fill out the theoretical framework about games as a suitable teaching method, particularly in lower secondary chemistry education.

The usability of the CHEDU Game Design Tool has been tested only on a small scale. Its capacity in guiding an educational game design process has been tested with 25 pre-service teachers (Section 7.4) and its capacity in supporting the quality evaluation of an educational game has been tested with the two card games developed in design challenge 1 in this thesis (Chapter 6 and Section 9.1).

The need for improvement in the contents in the CHEDU Game Design Tool and in challenges to embed these requirements into the educational chemistry will be taken into account in design challenge 3.
8 DESIGN CHALLENGE 3: AN EDUCATIONAL GAME ABOUT CHEMISTRY IN COOKING AND DAILY LIFE CONTEXTS

In design challenge 3, an educational game for learning chemistry both in the food and cooking context and in other familiar daily life contexts was designed and tested. The learning approach for the Proteins in the Backyard board game is to support lower secondary student in learning protein chemistry in order to enhance transfer of knowledge and relations to daily life. The design process sought to address RQ 3: how does an educational game in the food and cooking context help students with development and transfer of knowledge between theory, everyday life contexts and hands-on activity? Design challenge 3 consists of two empirical problem analyses, a design process and a design solution. The two separate empirical problem analyses were implemented to gather information concerning adolescents’ interest in and attitudes towards chemistry, food and cooking (Section 8.1) and to record pre-service teachers’ ideas about game mechanics and dynamics in food-related educational card and board games (Section 8.2).

8.1 Empirical problem analysis 1: Adolescents’ interest for chemistry, food and cooking

The aim of this empirical problem analysis was to gather information about Finnish adolescents’ interest and attitudes toward chemistry, food and cooking, and molecular gastronomy. A small-scale e-questionnaire was used as a data collection method.

8.1.1 Method

In this empirical problem analysis, a questionnaire for measuring adolescents’ attitudes and interest towards cooking, chemistry and their interface, molecular gastronomy (MG), was developed, tested and executed. The students’ personal interest in food and cooking, chemistry and the relationship between these two, as well as the most interesting topics in the field of MG, were the focus of the questionnaire.

The semi-structured questionnaire was tailored to first year students on the upper secondary level who had chemistry as a major subject and who participated in a course in the MG context. There were four parts in the questionnaire: background information, food and cooking, chemistry and science, and molecular gastronomy.
Existing questionnaires (Cheung, 2009; Coll et al., 2002) and theories about small-scale research (Denscombe, 2010) and approaching questionnaires (Cohen, Manion, & Morrison, 2011) were used as the basis for the planning process. Some of the statements concerning an individual interest in chemistry were taken directly from the CAEQ (Coll et al., 2002; Dalgety, Coll, & Jones, 2003), but semantic differential scales were modified into Likert scales. For this study, wider and more detailed attitudinal perspectives were chosen to measure interest and attitude toward MG (see Figure 16).

![Figure 16. Variables for attitudes and interest according to the latent process perspective for attitudes (Oskamp & Schultz, 2005) and the theory of interests (e.g. Palmer, Dixon, & Archer, 2017; Schraw & Lehman, 2001).](image)

The section of the questionnaire concerning food and cooking was constructed in the same manner as the chemistry section. For molecular gastronomy there was one earlier questionnaire available (Västinsalo et al., 2010), in which lower secondary students were asked about their interest toward MG in general, and as a learning context.

Hence this part of the questionnaire was constructed to include statements about cooking claims and beliefs, also called culinary precisions or kitchen stories (Fooladi & Hopia, 2013; Vartiainen, Aksela, & Hopia, 2013); about chemical phenomena related to cooking; and about the topics of the students’ own MG projects both in relation to chemistry content and finding out the most interesting topics of the course.
The relations between the MG questionnaire, MG course, adolescents’ everyday life and theories about attitude and interest are described in Figure 16. It follows the latent process perspective for attitudes (Oskamp & Schultz, 2005) and the theory of interests (e.g. Palmer, Dixon, & Archer, 2017; Schraw & Lehman, 2001).

8.1.2 Data collection

The questionnaire data was gathered from two different groups in May 2015 (n = 8, age 15–17, 6 boys and 2 girls) and in January 2016 (n = 14, age 16–17, 4 boys and 10 girls). Before answering the questionnaire, students had been participating in a MG course, which consisted of lessons (4 x 75 min) about claims and phenomena related to cooking, and getting information on how to carry out a study. In a workshop (1 x 75 min, held by the researcher) students prepared different types of fudge, in which sucrose and fructose were used as sugars, and molecular gastronomic eggs, which were prepared by keeping them in a pot of water at 69 degrees Celsius in the oven for an hour. During the course, students also executed a small MG study in small groups. First they made a research plan (3 x 75 min) for their topic, and then applied experimental work, wrote a theory framework, and presented the results to the others in a two-day camp. After the camp, a short feedback session (30 min) was held at school. The course was graded on a pass/fail basis.

All the students were asked to fill in and return a consent form concerning the research, and the teacher gave a link to an e-questionnaire to those who had permission. The e-questionnaire was kept open for two weeks after the end of the MG course.

8.1.3 Data analysis

The qualitative data analysis was organized by the research question (RQ 3). The multiple types of content in the questionnaire made it necessary to use both by-individual and by-issue methods in the analysis (Cohen et al., 2011). In the by-individual method, the questionnaire data was analyzed in order to find similar and shared responses, small-scale patterns of responses and agreement/disagreement between the answers of the students and thus summarize the data (Cohen et al., 2011) and find the relations between the variables (Figure 16).

The by-issue method concentrates on information about a relevant issue for which the data was gathered (Cohen et al., 2011). In this analysis, the data was relevant to chemistry, food and cooking, and MG issues. This analysis method revealed important results concerning the contents of these topics.
Students’ answers concerning topics of discussions at home were first roughly grouped to find general categories and then subcategories were formed inside these categories (Tables 13 and 14). Students’ answers concerning MG topics were categorized according to the topics presented in the questionnaire (Table 15).

8.1.4 Results

8.1.4.1 Interest and behaviors related to food and cooking

The results concerning food and cooking revealed the interest toward cooking and other food-related activities among the adolescents. The majority, meaning 15 to 16 of 22 students, reported that they cooked and discussed topics related to food at home at least a few times a week. Interest in talking with friends about food, cooking or baking showed similar results. In this small sample there was no clear difference between boys and girls, nor relation between the frequency of cooking and discussions. With two exceptions, all the students who share an interest in talking with friends about food-related topics also discussed food and cooking at home weekly or daily.

The topics concerning food-related discussions at home can be divided into three main categories: food quality and processed food (4), recipes and ingredients (6) and food preparation (18) (Table 13). The last category had three subcategories: daily meals (4), techniques and methods (8), and modifying taste or structure (6).

Half of the adolescents shared an interest (answered “quite interesting” or “interesting”) in TV or internet shows and a majority toward web pages related to food and cooking. Approximately half of the students liked both ways of getting information equally. In both cases three of the students felt that type of information to be boring. Almost half of those students who cooked weekly or daily were also interested in food-related TV or internet shows. Similarly, those students who discussed food and cooking at home weekly or daily were quite or really interested in TV or internet programs concerning food and cooking.
Table 13. The classification of the topics that adolescents on upper secondary level (age 15–17) had in food and cooking-related discussions at home.

<table>
<thead>
<tr>
<th><strong>CATEGORIES</strong></th>
<th><strong>SUBCATEGORIES</strong></th>
<th><strong>detailed topics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>FOOD QUALITY AND PROCESSED FOOD (4)</td>
<td>FOOD QUALITY (2)</td>
<td>quality of food, is outdated food still edible</td>
</tr>
<tr>
<td></td>
<td>PROCESSED FOOD (2)</td>
<td>convenience food, school lunch</td>
</tr>
<tr>
<td>RECIPIES AND INGREDIENTS (6)</td>
<td>RECIPES (3)</td>
<td>Baltic herring recipes, how to replace all animal-based ingredients with plant-based ingredients, recipes</td>
</tr>
<tr>
<td></td>
<td>INGREDIENTS (3)</td>
<td>yeast, salt, ingredients</td>
</tr>
<tr>
<td>FOOD PREPARATION (17)</td>
<td>DAILY MEAL (4)</td>
<td>what to eat, meal at the moment, planning a day’s meal and dishes, planning a day’s meal: what would be nice to cook</td>
</tr>
<tr>
<td></td>
<td>TECHNIQUES AND METHODS (8)</td>
<td>omelet, grilling, sauces for the rice, frying a chicken, baking, roasting a beef, making ice-cream, different cooking methods</td>
</tr>
<tr>
<td></td>
<td>MODIFYING TASTE OR STRUCTURE (5)</td>
<td>improving the structure of falafels, taste combos, how to make food as tasty as possible, tenderness of a meat stew, the taste</td>
</tr>
</tbody>
</table>

8.1.4.2 Interest and behaviors related to chemistry and science

When asked about their interest in chemistry and science, almost half of the adolescents shared an interest in scientific programs. 2/3 of the students showed interest in web pages about chemistry. Two of the students who were interested in scientific programs, felt web pages about chemistry were boring.

According to 2/3 of the adolescents, talking with friends about topics related to chemistry was interesting. At home almost half of the students discussed topics related to chemistry daily or a few times a week and six students reported discussing them a few days a month. Four of those, two boys and two girls, who thought that talking with friends about chemistry topics was interesting also discussed chemistry at home daily or weekly. All the students discussed chemistry topics at home at least a few times a year. The chemistry topics (20) discussed at home are listed in Table 14.
Table 14. The classification of the topics that adolescents on upper secondary level (age 15–17) had in chemistry-related discussions at home.

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SUBCATEGORIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMISTRY STUDIES (3)</td>
<td>chemistry home works, a chemistry test, a lack of mathematics in chemistry education on upper secondary level</td>
</tr>
<tr>
<td>CHEMISTRY AT HOME (5)</td>
<td>COOKING AND BAKING (4)</td>
</tr>
<tr>
<td></td>
<td>chemistry related to cooking, topics related to baking, uses of baking soda and baking powder, whisking a cream foam</td>
</tr>
<tr>
<td></td>
<td>DOMESTIC WORK (1)</td>
</tr>
<tr>
<td></td>
<td>chemistry related to cleaning</td>
</tr>
<tr>
<td>GENERAL CHEMISTRY (12)</td>
<td>HISTORY OF CHEMISTRY (1)</td>
</tr>
<tr>
<td></td>
<td>the discoveries of the Curies</td>
</tr>
<tr>
<td></td>
<td>ATOMS AND ELEMENTS (4)</td>
</tr>
<tr>
<td></td>
<td>atomic structure, periodic table and atoms, the chemical symbols of the elements and their changes of phases, metals reactivity,</td>
</tr>
<tr>
<td></td>
<td>COMPOUNDS (2)</td>
</tr>
<tr>
<td></td>
<td>nitroglycerin, sulphuric acid</td>
</tr>
<tr>
<td></td>
<td>CHEMISTRY APPLICATIONS (5)</td>
</tr>
<tr>
<td></td>
<td>halogen lights, the composition of a liquid coolant, plastic polymers, plant alkaloids, chemical properties of medicines</td>
</tr>
</tbody>
</table>

At home, discussions concerning topics in the field of general chemistry (12) were dominant (Table 14). But when the topics were classified in more detailed groups, it was noticed that topics concerning chemistry applications and chemistry at home were of the same interest (5). In the context of chemistry at home, interest towards cooking and baking related topics in particular (4) can be seen, e.g. leavening agents and cream foaming. Chemistry studies, elements, compounds and different kinds of everyday applications of chemistry were also discussed at home. All the students with interest in chemistry of cooking and baking also discussed daily or weekly topics concerning food and cooking at home, and took an interest in web pages related to chemistry and to food and cooking. Despite the discussions at home, talking with friends about similar topics was not of interest to these students.

8.1.4.3 Attitudes toward food and cooking, and chemistry related knowledge
The results concerning knowledge in the areas of food and cooking and chemistry revealed that the majority of the students totally agreed that chemistry-related knowledge is scientifically certified. Although only three students agreed that knowledge related to food and cooking is scientifically
certified, the majority of the students partially agreed with the statement: ‘Knowledge related to food and cooking is scientifically certified’. They all argued their choice quite coherently by saying that the research concerning the chemistry of cooking lives side by side with old lore and myths, which seem to work:

Some are old lore, which just seem work, but they all can be scientifically verified. (G2-2015)

Despite the research concerning cooking, old and false myths still exist. (B10-2016)

Even those three who neither agreed nor disagreed made similar arguments. Four students with total agreement gave arguments related to the preparation of perfect food, but also arguments similar to those who expressed partial agreement. The one who totally disagreed with the statement criticized the simplification of food chemistry:

The chemistry related to cooking is so simplified, that you can’t call it chemistry. (B4-2015)

In turn, almost all partially or totally agreed that knowledge related to chemistry is scientifically certified. None of the students disagreed and only one student neither agreed nor disagreed, saying:

Knowledge is dependent on a source. (G3-2016)

The arguments indicating total agreement were about chemistry being a science and/or about all the scientific knowledge being (empirically) testified or about the existence of scientific research:

Chemistry is science. (G1-2015; G2-2015; B7-2016)

Chemistry belongs to natural sciences, where all the knowledge has been attested. (B4-2015)

Chemistry-related knowledge is based on research results and theories, which will be updated, whenever more legitimate ones appear. (B8-2016)

8.1.4.4 Interest toward molecular gastronomy (MG) topics

The food-related topics from the two MG courses are listed in Table 15. This shows which topics were the favorite among the students and what kind of chemistry they think they learned during their own MG projects under the listed topics. In this study, students’ self-reports about chemistry contents were not compared to the teachers’ views, because the MG topics were chosen by the students themselves and the MG projects were inquiry-based.
Table 15. Food related topics on the two MG courses, 1st year high school students’ interests toward them and chemistry their think they learnt under their own MG project topics.

<table>
<thead>
<tr>
<th>FOOD RELATED TOPIC on the MG courses</th>
<th>INTERESTED THE MOST</th>
<th>LEARNT CHEMISTRY according to the students, who owned the topic in their MG project</th>
</tr>
</thead>
<tbody>
<tr>
<td>68-degree egg</td>
<td>2</td>
<td>(General topic in a workshop for all the students)</td>
</tr>
<tr>
<td>Cakes</td>
<td>3</td>
<td>concentration, water and its properties, combustion reaction, comparing speeds of reaction, fats, carbohydrates, proteins</td>
</tr>
<tr>
<td>Chocolate</td>
<td>3</td>
<td>fats, something else: crystal structure</td>
</tr>
<tr>
<td>Coffee</td>
<td>3</td>
<td>types of chemical reactions, amount of substance, concentration, different mixtures, water and its properties</td>
</tr>
<tr>
<td>Cream foam</td>
<td>4</td>
<td>chemical bonds, different mixtures, water and its properties, fats, carbohydrates, proteins, other organic compound groups</td>
</tr>
<tr>
<td>Finnish bun (fi. pulla)</td>
<td>2</td>
<td>chemical bonds, types of chemical reaction, water and its properties, properties of the elements, comparing speeds of reaction, alcohols, carbohydrates, proteins, reaction equations, something else (a weight difference between a yeasted and a non-yeasted bun, a chemical function of a yeast)</td>
</tr>
<tr>
<td>French fries</td>
<td>2</td>
<td>types of chemical reaction, water and its properties, combustion reaction, fats, carbohydrates</td>
</tr>
<tr>
<td>Fudges</td>
<td>9</td>
<td>(General topic in a workshop for all the students)</td>
</tr>
<tr>
<td>Gelling agents</td>
<td>3</td>
<td>chemical bonds, types of chemical reaction, concentration, different mixtures, water and its properties, acidity and basicity, comparing speeds of reaction, fats, carbohydrates, proteins, other organic compound groups</td>
</tr>
<tr>
<td>Meringues</td>
<td>4</td>
<td>chemical bonds, types of chemical reaction, amount of substance, concentration, water and its properties, fats, carbohydrates, proteins</td>
</tr>
<tr>
<td>Microwave muffins</td>
<td>3</td>
<td>chemical bonds, types of chemical reaction, concentration, different mixtures, water and its properties, comparing speeds of reaction, fats, carbohydrates, proteins</td>
</tr>
<tr>
<td>Smashed sweet potatoes and minced meat sauce</td>
<td>4</td>
<td>(General topic in a workshop for all the students)</td>
</tr>
<tr>
<td>Thin pancakes</td>
<td>3</td>
<td>types of chemical reaction, different mixtures, proteins, reaction equations, something else: organizing a research and blind tasting</td>
</tr>
</tbody>
</table>

The results in Table 15 reveal that the Fudges workshop interested the students the most. They prepared fudges with sucrose and fructose. The theory touched on Maillard reaction between proteins’ amino acids and certain sugars, and on caramelization of sugars. Two of the other popular topics, cream foam and meringues, focused on chemistry and knowledge of chemical bonds, proteins, fats, carbohydrates, and water and its properties.
The students were also asked if there were any other topics related to cooking, baking or chemistry they were especially interested in. Six of the answers (6/11) revealed an interest in the chemistry of food: perfect meals, cooking an egg, roasting (meat), darkening of egg yolk, fermentation and why thawed food cannot be frozen again.

The results of this empirical problem analysis provided new information and knowledge about adolescents’ interests and attitudes toward food, cooking, chemistry and MG. Their interest in chemistry is apparent, because the students had already chosen chemistry as their major subject, but the affective and behavioral attitudinal responses revealed in this research indicate positive attitudes towards food and cooking as well. At home the students were especially interested in discussing food preparation, and when discussions were about chemistry, general chemistry was at the top. This study also revealed which detailed topics in the context of MG were particularly popular among the students: fudges, cream foam and meringues. In the following sections, the qualitative results are presented, followed by numerical data.

8.1.5 Discussion

One of the main findings of this empirical problem analysis and case study was that the majority of 22 first year chemistry major students at the upper secondary level cooked weekly or daily and/or discussed topics related to chemistry, as well as topics related to food and cooking, weekly or daily at home and willingly with friends. Approximately 2/3 of the students showed an interest in web pages concerning chemistry and concerning food and cooking. Approximately half of the students were interested in science programs on TV and TV or internet shows related to food and cooking. According to previous research (Palmer, et al., 2017; Schraw & Lehman, 2001), these adolescents can be identified as having an individual interest in chemistry and food and cooking. Their interest in chemistry is obvious since the students have already chosen chemistry as their major subject. Based on the results of previous studies (Cheung, 2009; Eagly & Chaken, 2005; Nieswandt, 2007; Oskamp & Schultz, 2005; Palmer et al., 2017), the affective and behavioral attitudinal responses revealed in this research (Figure 1) indicates positive attitudes towards food and cooking. The cooking frequency among these students was greater than reported in earlier research by Utter et al. (2016), in which half of the adolescents said that they cooked monthly. Contrary to that research, here high cooking frequency was not clearly related to high levels of family connections, which in this case were discussions at home. The results about adolescents’ interest in food- and cooking-related TV programs and web pages are in line with the previous research by Worsley et al. (2014), in which the most preferred ways to learn more about food and cooking were watching TV programs or YouTube videos, and reading magazines. In contrast, discussions with family or friends were not as popular as they were in Worsley et al. (2014).
Another main result of this study concerns the students’ cognitive attitudinal responses to the knowledge of chemistry and the knowledge of food and cooking. Most of the students partially agreed with the statement that ‘knowledge related to food and cooking is scientifically certified’, whereas the statement ‘knowledge related to chemistry is scientifically relevant’ received partial or total agreement from all the students. The argument against knowledge concerning food and cooking being scientifically correct was that it lives side by side with old lore and myths, which just seem to work. In their study, Västinsalo et al. (2010) noticed that some students were especially interested in these myths (aka kitchen stories or culinary precisions) and these has already been collected and applied in different sessions to teach and learn chemistry and its disciplines, like home economics (Fooladi & Hopia, 2013; Vartiainen, 2013). The agreement for the scientific basis of chemistry knowledge was that chemistry is science, with existence of scientific research and/or with all the scientific knowledge being (empirically) tested. The last argument is in line with prior research in which one of the two main features that explained scientific knowledge among high school students was: “Science can generally produce definitive knowledge through testing as that provides proof of the truth (or otherwise) of scientists’ ideas” (Taber, Billingsley, Riga, & Newdick, 2015, p. 382).

Molecular gastronomy (MG) has already been shown to have the potential to be an interesting and relevant context for teaching and learning chemistry for university students (Miles & Bachman, 2009) and for students at the lower secondary level (Västinsalo et al., 2010). This case study supported earlier studies, but also expanded the results on a small scale to cover students on the upper secondary level as well.

At home the students were especially interested in discussing food preparation (daily meals, techniques and methods, modifying taste or structure) within the area of food and cooking (Table 13). When the discussions were about chemistry, general chemistry (history of chemistry, atoms and elements, compounds, chemistry applications) was on the top, but chemistry at home (cooking and baking, domestic work) was also of particular interest (Table 14). The subclass of cooking and baking included chemistry related to cooking, topics related to baking and whisking a cream foam. These results match the results of Västinsalo et al. (2010), in which the adolescents answered that the scientific background for cooking would apparently be the most interesting area in the context of MG. Miles & Bachman (2009) discovered that a compulsory chemistry course applied in the context of food and cooking inspired university students with non-science majors, like arts and humanities. The course topics covered multiple food and ingredient groups, for example eggs, meat, herbs and spices, and sugars.

This study revealed which detailed topics in the context of MG were particularly popular among the students. This kind of context-based interest can be classified as situational interest (Schraw & Lehman, 2001) (Figure 16). Fudges, cream foam and meringues were associated with the highest interest among the students (Table 15). Both cream foam and meringues include chemistry and knowledge about
chemical bonds, proteins, fats, carbohydrates and about water and its properties. Many of the results about topics of interest concern the chemistry of proteins: omelets, grilling, roasting beef, frying chicken (in the class of Techniques and methods, Table 13); how to make food as tasty as possible, tenderness of a meat stew, the taste, how to replace all animal-based ingredients with plant-based ingredients (in the class of Modifying taste or structure, Table 13); chemistry related to cooking, topics related to baking, whisking a cream foam (in the class of Chemistry at home, Table 14).

The results of this case study are not generalizable, but it supplied in-depth descriptions, as well as new information and knowledge both about MG and adolescents’ attitudes and interests toward chemistry, food and cooking, and about topics used in the context of MG. The results also partly confirmed or broadened the results of previous research in the same research areas. For example, it strengthened the status of MG as an interesting context for teaching and learning chemistry.

8.2 Empirical problem analysis 2: Pre-service teachers as game developers

The aim of this empirical problem analysis was to evaluate pre-service teachers’ game design processes and to map out their ideas for game mechanics and game elements in board or card games related to food chemistry and the environment. In this empirical problem analysis, the first version of the CHEDU Game Design Tool (Section 7.3 and Table 12) was used to guide and support pre-service teachers’ board game design processes, in which chemistry game ideas were developed. For the analysis, a qualitative content analysis was applied in the study of six game design diaries of pre-service teachers.

8.2.1 Data collection and data analysis

Qualitative content analysis was applied in the study of six game design diaries of pre-service teachers. The data collection and data analysis in this empirical problem analysis is described in detail in the previous sections of this thesis: data collection (Section 7.4.1) and data analysis (Section 7.4.2).

8.2.2 Results

8.2.2.1 Ideas about game mechanics in game design diaries

Half the game ideas lacked clear learning objectives, although it was clear that the games did support mostly learning of declarative knowledge, meaning that they rarely established skills or attitudes as learning objectives. The students apparently put more emphasis on game structure, such as game paraphernalia, clear rules and a clear aim for the game as such.
Ideas about game mechanics in the pre-service teachers’ game design diaries were mostly based on well-known existing games. Educational game ideas were based on bingo, dominos, Afrikan Tähti (en. Star of Africa), Labyrinth, Snakes and Ladders, Treasure Island or Trivial Pursuit or a combination of these games. One of the domino-based games (GD3) was named Kemino.

In game design diary 1 (GD1) the students created a version of bingo in which every card is one element or a covalent bond. During a bingo game, a pair or group of students attempts to construct a named organic compound (a component of food) as quickly as possible.

In game design diary 2 (GD2) the students discussed a dominoes game, in which two parallel tiles portray a certain food or its components in everyday life at macroscopic, sub-microscopic or symbolic level, for example a picture of glass of milk and the atomic structure of calcium.

In game design diary 3 (GD3) the students designed Kemino, a domino game quite similar to the one in GD2. It uses parallel tiles in the food chemistry context in formula–formula, formula–word and word–word forms. For example, the clues for glucose in the game design diary were: C₆H₁₂O₆–glucose–grape sugar–monosaccharide.

In game design diary 4 (GD4) the students generated an idea for a board game which combines ideas from Treasure Island, Labyrinth and Trivial Pursuit. Players collect ingredients for a baked good, which differs from player to player. The ingredients are situated around the board, where players both move towards the ingredients and answer chemistry-related questions. Correct answers will release the food ingredients. The questions can be either short and easy factual, difficult factual or analytical questions with source materials.

In game design diary 5 (GD5) the students shared design ideas about a board game which mixes the classic Finnish board game Afrikan Tähti (en. Star of Africa) and Trivial Pursuit. By travelling on a world map board and answering questions, players collect resources from different areas: kitchen chemistry (food ingredients), biomolecules (proteins, lipids, carbohydrates), energy (CO₂, climate change, etc.) and sustainable development in daily life (waste, recycling, use of water, etc.). Like Afrikan tähti, the players also turn up chips on the board. These chips can be phenomena or chemicals, which might destroy collected resources. For example, resources such as baking soda or sensitive indicator species can be destroyed by the acid rain chip.

In game design diary (GD6) the students designed a board game similar to Snakes and Ladders. Players move on the board by answering questions about different chemical phenomena in cooking and baking. Easier questions will move a player or group of players a shorter distance forward or backward on the board than more challenging questions. One example of question cards suggestions in the GD6 is presented in Figure 17.
8.2.2.2 Ideas about game dynamics and game elements in game design diaries

There were plenty of ideas for game dynamics and game elements in the pre-service teachers’ game design diaries. Some of them, like general rules for the game(s), were copied directly from the game(s) that the pre-service teachers’ own game ideas were based on. But the diaries also contained novel ideas for game dynamics or game elements (Table 16).

The class of pedagogy was the most widely acknowledged of the classes in the first version of CHEDU Game Design Tool. A total of 27 novel ideas for using game dynamics in the game design tool’s class of pedagogy were found in the game design diaries. The results in Table 16 declare how multiple ways one subclass of the game design tool can be embedded into the games.

In the subclass of multiple difficulty levels, the pre-service teachers mostly discussed different ways to play the game rather than increasing difficulty within the game event. In the subclass of making thinking visible, opportunities for argumentation and/or explanation were the most used options in the game design diaries, whereas possibilities for evaluation during a game were absent.
Table 16. The ideas for game dynamics in the class of pedagogy (n = 27). Chemistry pre-service teachers designed these elements in their game design diaries to be included into the educational card or board game for chemistry education purposes.

<table>
<thead>
<tr>
<th>THE CLASS: THE SUBCLASS</th>
<th>IDEAS FOR GAME DYNAMICS IN THE GAME DESIGN DIARIES OF THE PRE-SERVICE TEACHERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedagogy: multiple difficulty levels (14)</td>
<td>Different ways to play</td>
</tr>
<tr>
<td></td>
<td>- a tile layout for new tiles, which can be used by the teacher to modify a game for different levels (domino)</td>
</tr>
<tr>
<td></td>
<td>- players can decide, if only easy, only difficult or both tiles are used in the game (domino)</td>
</tr>
<tr>
<td></td>
<td>- different ways to form a pattern: a line, a circle, a branching model (domino)</td>
</tr>
<tr>
<td></td>
<td>- multiple fitting tiles (domino)</td>
</tr>
<tr>
<td></td>
<td>- a game can be shortened by counting who has the fewest tiles when time is up (domino)</td>
</tr>
<tr>
<td></td>
<td>Increasing difficulty within the game</td>
</tr>
<tr>
<td></td>
<td>- easier tiles with a strong everyday life connections (e.g. biology, home economics) (domino)</td>
</tr>
<tr>
<td></td>
<td>- a player gets more points out from a more difficult tile (like a tile with molecular structure) (domino)</td>
</tr>
<tr>
<td></td>
<td>- a more difficult game: if different chemical reactions and bondings are added into the game (domino)</td>
</tr>
<tr>
<td></td>
<td>- instead of answering the questions, a player can throw a dice (Labyrinth/Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- by giving a correct answer to a difficult question, a player can use a shortcut on the board (Snakes and Ladders)</td>
</tr>
<tr>
<td></td>
<td>- if a player answers correctly three resources will be earned, if they need one tip, two resources and if they need two tips, only one resource (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td></td>
<td>- in 2/5 categories in a game a tip can be earned by answering easy question (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td></td>
<td>- in 2/5 categories in a game a tip can be used (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td></td>
<td>- a player can choose easy or difficult question, which directly affects the length of movement forward or backward on the board (Snakes and Ladders)</td>
</tr>
<tr>
<td>Pedagogy: unpredictability and uncertainty (5)</td>
<td>- a chance to change a tile with another player (domino)</td>
</tr>
<tr>
<td></td>
<td>- a chance to steal a missing ingredient from another player (Labyrinth/Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- jumping from one part of a game board onto another (Labyrinth/ Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- changing ingredients, depending on the pastry to be baked in a game (Labyrinth/ Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- a thief tile can be turned up instead of mineral tile or a new environment technology tile (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td>Pedagogy: making thinking visible (2)</td>
<td>Argumentation</td>
</tr>
<tr>
<td></td>
<td>- a player must explain to other players, why the two tiles fit together (domino)</td>
</tr>
<tr>
<td>Explination</td>
<td>- a player must answer a question to get resources or to move forward on the board (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td>Pedagogy: problem solving (0)</td>
<td>-</td>
</tr>
<tr>
<td>Pedagogy: suitable challenges (6)</td>
<td>- some of the tiles make it easier to keep up motivation (e.g. salt, sugar) (domino)</td>
</tr>
<tr>
<td></td>
<td>- a tip list for all the tiles, where you can read a tip for a tile, if it otherwise would be too difficult for a player to fit it onto the table; and the user loses some points (domino)</td>
</tr>
<tr>
<td></td>
<td>- the rules for the game are easy to understand and a teacher can modify suitability for different groups and topics (domino)</td>
</tr>
<tr>
<td></td>
<td>- instead of answering a question, a player can throw a die (this way skilled players have a chance to answer, but low-achievers can choose a die roll instead) (Labyrinth/ Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- when answering questions instead of throwing a die, a player can possibly go forward with more precision (for example to the goal) (Labyrinth/ Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- it might be easier for a player explain only to other players than to a whole class of students, why two tiles fit together (domino)</td>
</tr>
</tbody>
</table>
The classes of instruction/support/feedback and of assessment were the least employed in the game design diaries. Assessment elements were evident only to a small degree in the diaries, earning three mentions. Still, some opportunities for in-game assessment were included organically into game mechanics and game rules. Examples of the ideas concerning these two classes in the game designs are collected in Table 17. Some explicit but general mentions about the importance of self and peer assessment in games were found in the game design diaries.

Table 17. The ideas for game dynamics in the classes of Instructions/Support/Feedback and Assessment (n = 13). Chemistry pre-service teachers designed these elements in their game design diaries to be included into the educational card or board game for chemistry education purposes.

<table>
<thead>
<tr>
<th>THE CLASS: THE SUBCLASS</th>
<th>IDEAS FOR GAME DYNAMICS IN THE GAME DESIGN DIARIES OF THE PRE-SERVICE TEACHERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructions/Support/Feedback: pregame (1)</td>
<td>- the rules are introduced to all the players before a game session</td>
</tr>
<tr>
<td>Instructions/Support/Feedback: in-game (8)</td>
<td>- a tip list for all the tiles, where you can read a tip for a tile, if it would otherwise be too difficult for a player to fit it onto the table; the user loses some points (domino)</td>
</tr>
<tr>
<td></td>
<td>- a player gets more points out from a more difficult tile (domino)</td>
</tr>
<tr>
<td></td>
<td>- a player who manages to connect two branches rewarded (domino)</td>
</tr>
<tr>
<td></td>
<td>- a teacher can participate in play or listen carefully to what players are talk about (domino)</td>
</tr>
<tr>
<td></td>
<td>- the player will not be told the number of correct answers until all the questions has been answered, to avoid maneuvering (Labyrinth/Treasure Island)</td>
</tr>
<tr>
<td></td>
<td>- in 2/5 categories a tip can be used (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td></td>
<td>- if a player answers the question correctly, their token will be moved forward along a molecule; if incorrectly, backwards (Snakes and Ladders)</td>
</tr>
<tr>
<td></td>
<td>- a player can choose easy or difficult questions, which directly affects the length of movement forward or backward on the board (Snakes and Ladders)</td>
</tr>
<tr>
<td>Instructions/Support/Feedback: postgame (1)</td>
<td>- after a game session the whole class together with a teacher will have a session, in which the correct connections between the tiles are discussed (domino)</td>
</tr>
<tr>
<td>Assessment: in-game (2)</td>
<td>- after listening to the first group’s answer, all other groups can try to correct and fill out the answer, and a teacher judges (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td></td>
<td>- one player mimes and the others in the same group try to guess (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td>Assessment: postgame (1)</td>
<td>- after a game session the whole class together with a teacher will have a session, in which the correct connections between the tiles are discussed (domino)</td>
</tr>
</tbody>
</table>

According to the results, during their game design process the pre-service teachers took into account the contents of the first version of the CHEDU Game Design Tool (see Section 7.4). This empirical problem analysis focused on the concrete ideas about game mechanics and game dynamics in the pre-service teachers’ game design diaries.
8.2.3 Discussion

Similarities and differences can be seen between this and previous studies. Compared to the study by Sardone and Devlin-Scherer (2016), there were differences between the elements in the class of pedagogy. In the previous study (ibid., 2016), there were three ideas in eight board games on how to execute multiple difficulty levels in board games, consisting of question cards for different levels, more complex evaluation materials (e.g. maps) for more advanced players and the ability to expand a game from 4 to 17 characters. Whereas in this empirical problem analysis, 13 ideas in six game design diaries were created (see Table 17). These ideas were questions and questions cards or tiles for different levels. In addition, the game design diaries also mentioned options to use only easy or only difficult tiles in a game, use shortcuts on the board and get tips for questions (Table 16).

In total, pedagogical perspective and pedagogical game elements were more apparent in this study than in previous research, in which they were not mentioned as explicitly and widely as in the game design diaries of this study. In these diaries, a total of 44 specific elements concerning the class of pedagogy in the first version of the CHEDU Game Design Tool were explicitly discussed. Only the subclass of problem solving was absent. In a study by Tokmak (2015), student levels and complexity of game were mentioned, whereas problem solving opportunities and incrementally increasing challenges were part of the quality game criteria in Artym et al. (2016). In the descriptions of board games (Sardone & Devlin-Scherer, 2016), eight elements were observed, concerning multiple difficulty levels, unpredictability, making thinking visible and suitable challenges.

8.3 Design process

This section presents the prescriptions of successful design processes for an educational board game (Edelson, 2002). The design process included three cycles. The board game was designed to answer both the challenges noted in the two previous phases of this thesis (Chapters 6 and 7), and to apply the results of two empirical problem analysis (Sections 8.1 and 8.2). The game was designed by following the requirements for quality educational chemistry games and to enable opportunities for students to transfer chemical knowledge between contexts.

In this educational Proteins in the Backyard board game, students apply basic knowledge about proteins according to their age level (9th grade, 15–16 years), with opportunities for interconnections with different daily life situations and contexts, and with a specific cooking chemistry hands-on activity.
8.3.1 The first version

According to Warren and Jones (2017), as a game developer it is necessary to explain how you think learning occurs within your game, because players need to know that. The first version of the Proteins in the Backyard board game was grounded on several demands. The most important of all was to follow the quality board game elements in the CHEDU Game Design Tool (Table 12) as well as possible. The match between the CHEDU Game Design Tool and the first version of the Proteins in the Backyard board game is presented in Table 18.

The game attempted to address the challenges defined during the previous design challenges 1 (Chapter 6) and 2 (Chapter 7). Specifically, the results of the two empirical problem analyses (Sections 8.1 and 8.2) were fully exploited.

The design process for the Proteins in the Backyard board game started with the decisions about game topics, other main contents and game mechanics. Based on the first empirical problem analysis (Section 8.1) and its theoretical framework (Chapter 5), it was decided to use ‘proteins’ as a food-related chemistry topic from the MG perspective as the theme of the game. The decision was made despite the fact, that in the current national chemistry curriculum for basic education, ‘proteins’ are not explicitly mentioned, but instead: “The pupils familiarise themselves with carbon and its compounds as well as nutrients” (Finnish National Agency for Education, 2014, p. 426). But it is also said that: "The task of instruction of chemistry is to support the of concepts related to chemistry and the understanding of phenomena” (ibid., p. 424). This decision was also necessary to keep the content of the game clear and simple and to follow the basic principles of MG in examining only one cooking-related phenomenon at a time.

The molecular gastronomic hands-on activity Fluffy Meringues (Vilhunen et al., 2013) was taken as a guiding idea for the whole game. In this game, students participate in a Top Chef competition, trying to develop the best possible recipe for meringues, based on the recipe for Italian Meringues, theoretical framework and empirical experiments. The winner is the group of participants who (1) make their meringues in the Home Economics classroom, (2) create a poster in which all the chemical secrets behind the fluffiness of meringues, meaning the factors affecting proteins' denaturation, are revealed; and (3) are evaluated in the blind test by the teacher to have the best structure, taste and fluffiness in their meringues. In the Proteins in the Backyard game, three game characters participate in a World’s best meringues competition in school and each has already developed their own, secret meringue recipe. To win the game, a game character must first collect all the ingredients needed, move to the school on the game board and then write down on a post-it note all those factors in the character’s meringue recipe that affect the denaturation of proteins. A teacher will evaluate whether an answer is correct or not.
In this board game, embedded hands-on activity is aimed to work like simulations: if particular inquiry-based hands-on activities are not possible to do in school because of lack of materials or limited time, simulations can be used (Lunetta & Hofstein, 1991). In simulations, instead of real substances and equipment, students engaged in action with meaningful representations of inquiry experiences (Hofstein & Lunetta, 2003). The inquiry-based Fluffy Meringues hands-on activity (Vilhunen et al., 2013) made with real materials would take 4 lessons (4 x 45 min), whereas World’s best meringues as part of the Proteins in the Backyard game is meant to take 45 minutes.

A backstory and game characters were added to the final version of the CHEDU Game Design Tool (Section 7.6), and therefore this game must now have a backstory and game characters as engaging game elements. Backstory is included in the rules to be read out loud before the game begins. The story establishes the meaning of the game board with its places, the three game characters, the chips and the playing cards, which share with the players a similar context of home street, neighborhood and/or backyard. The aim of the game and the learning objective are also provided during the story. The choice between two girls and one boy or two boys and one girl as game characters was evaluated. The names for the three game characters were taken from the list of most popular child names in Finland in 2016. In the end, two boy’s names, Onni (en. Taylor) and Elias, and one girl’s name, Sofia, were chosen.

Based on the researcher’s own wide playing experience of commercial card and board games, the game board and some of the game mechanics in the Bonnie and Clyde board game were used as a base for the Proteins in the Backyard game. Bonnie and Clyde is played on a rectangular game board consisting of different crime locations, among which players move by car. Only back and forth movements on the board are allowed. During the game, players pick up playing cards. This kind of game board structure made it possible to embed daily life into the Proteins in the Backyard game by using different, familiar places as spaces on the board. In the current national chemistry curriculum for basic education, adolescents’ everyday life plays an important role: “The instruction of chemistry helps the pupils understand the significance of chemistry and its application in daily life, the living environment, the society, and technology. The instruction supports the pupils’ ability to make choices and to use their knowledge and skills in different life situations.” (Finnish National Agency for Education, 2014, p. 423)
Table 18. The match between the CHEDU Game Design Tool and the first version of the *Proteins in the Backyard* board game. The specific, game-related additions have been marked in *italics*. The improvements made in the third version of the game are marked in *blue*.

### Game: The Proteins in the Backyard (1st Version and 3rd Version)

<table>
<thead>
<tr>
<th>Class</th>
<th>Subclass</th>
<th>Subclass Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning Objective</td>
<td>Game has a clear learning objective</td>
<td>pure basic proteins chemistry and its daily life applications, especially in the context of food and cooking</td>
</tr>
<tr>
<td></td>
<td>Knowledge</td>
<td>remembering or repetition, concept or phenomenon</td>
</tr>
<tr>
<td></td>
<td>Skills</td>
<td>application of knowledge, decision making or problem solving, social interaction</td>
</tr>
<tr>
<td>Prerequisites</td>
<td>What pre-knowledge is the student required to have?</td>
<td>basic knowledge of protein chemistry and especially denaturation (9th grade level)</td>
</tr>
<tr>
<td>Structure</td>
<td>Game paraphernalia</td>
<td>playable, visual</td>
</tr>
<tr>
<td></td>
<td>Coherence between game’s look and context</td>
<td>for all</td>
</tr>
<tr>
<td></td>
<td>Availability (at the same time)</td>
<td>school, home</td>
</tr>
<tr>
<td></td>
<td>Mobility</td>
<td>30–45 min, one lesson</td>
</tr>
<tr>
<td></td>
<td>Playing time</td>
<td>explicit, easy to read, game goal is easy to understand: to collect the specific ingredients for meringues, go to school and write on the post-it note all those factors affecting proteins denaturation in the game character’s own meringue recipe</td>
</tr>
<tr>
<td></td>
<td>Clear rules</td>
<td></td>
</tr>
<tr>
<td>Pedagogy</td>
<td>Making thinking visible</td>
<td>application of knowledge, which can be tackled by using basic knowledge of proteins</td>
</tr>
<tr>
<td></td>
<td>Suitable challenges (zone of proximal development)</td>
<td>discussion, explanation, argumentation, evaluation</td>
</tr>
<tr>
<td></td>
<td>Problem-solving</td>
<td></td>
</tr>
<tr>
<td>Engaging Elements</td>
<td>Unpredictability and uncertainty</td>
<td>different ways to play</td>
</tr>
<tr>
<td></td>
<td>Multiple difficulty levels</td>
<td>ability to choose a game character with specific features</td>
</tr>
<tr>
<td></td>
<td>Storyline or narrative</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Game characters</td>
<td></td>
</tr>
<tr>
<td>Chemistry Curriculum in Lower Secondary Education</td>
<td>Concept or topic included in chemistry curriculum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Representational levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connections to daily life and the living environment</td>
<td>In the curriculum (Finnish National Agency for Education, 2014): “The pupils familiarise themselves with carbon and its compounds as well as nutrients” (p. 426).</td>
</tr>
<tr>
<td></td>
<td>Application of knowledge</td>
<td>macro, submicro, symbolic</td>
</tr>
<tr>
<td></td>
<td>Critical thinking and multiliteracy</td>
<td></td>
</tr>
<tr>
<td>Sociality Activity</td>
<td>Number of players</td>
<td>multiplayer</td>
</tr>
<tr>
<td></td>
<td>Player interaction</td>
<td>competitive, co-operational, collaborative</td>
</tr>
<tr>
<td></td>
<td>Player involvement</td>
<td>continuous</td>
</tr>
<tr>
<td>Instructions Support Feedback</td>
<td>Pregame</td>
<td>instructions</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td>in-game instruction, peer support, teacher support, discussion, feedback, rewards, punishments</td>
</tr>
<tr>
<td></td>
<td>Postgame</td>
<td>discussion</td>
</tr>
<tr>
<td>Assessment</td>
<td>Pregame</td>
<td>preconceptions</td>
</tr>
<tr>
<td></td>
<td>In-game</td>
<td>self-assessment, peer assessment, teacher assessment</td>
</tr>
</tbody>
</table>
A home for each game character, a neighbor with a cat, a school (with chemistry and home economics classrooms), a bakery, a corner shop and a meadow were chosen as contexts (Figure 18). Here, the idea of careful selection of contexts was applied to facilitate players’ possible capacity of transfer of knowledge from one context to another during play (Gilbert et al., 2011). According to Aikenhead (2003), context-based learning is suited especially to lower secondary students.

![Figure 18. The first version (in Finnish) of the game board for the Proteins in the Backyard game.](image)

It is also important to “guide the pupils to think in a manner characteristic of science, to acquire and use knowledge, to form ideas, and to be interactive as well as to evaluate the reliability and significance of knowledge in different situations” (Finnish National Agency for Education, 2014, p. 424). The playing cards in the game were designed to challenge players to use and apply basic knowledge, to solve contextual problems, to search and to evaluate information, and to form ideas. The essential supplementary material for the game is mentioned in the game guidelines: a smartphone, a tablet or a computer with internet connection, three post-it notes and pencils.

For the first version, a total of 28 playing cards were designed. Ideas for the mission contents in the playing cards were partly taken from the results in the first empirical problem analysis (Section 8.1). The topics that interested students were: how to replace all animal-based ingredients with plant-based ingredients, recipes and ingredients, meal at the moment, baking, chemistry related to cooking, topics related to baking, whisking cream foam, and periodic table and atoms. The following topics were excluded from the first version, because of limited number of playing cards and time: whether expired food is still edible, school lunch, planning the day’s meal and dishes, omelet, grilling, frying a chicken, tenderness of a meat stew and 68-degree egg. Also, sustainable choices and the future, as an important part of the national curriculum for basic education (Finnish National Agency for Education, 2014), were implicitly embedded into the challenges of the playing cards. Possible aids, like use of the internet or a textbook, are mentioned in missions, if they are acceptable. With these aids, the missions are situated in the 9th grade students’ zone of proximal development, based on the researcher’s experiences as a chemistry teacher at lower secondary level (12 years) and as an author of chemistry learning material for lower secondary education (11 years).
To fulfill the requirements for visuality and coherence between the game’s look and context in the game materials (Table 12), much attention was paid to the visuality of the playing cards, as well as coherence between the contexts on the game board and the contexts in the playing cards (Figure 19). The idea for the look of the cards was taken from game design diary 3 (GD 3), which presented the results of the second problem analysis (Section 8.2.2.1, Figure 17).

Figure 19. An example of the playing cards in the first version of the Proteins in the Backyard board game.

The cognitive perspective for game mechanics in this game was based on the four-phase criteria for the use of context in chemistry education (Gilbert, 2006; Pilot & Bulte, 2006) and the idea that contexts in the game must provide a broader perspective, but within a coherent structural meaning (Gilbert, 2006).

Additionally, the second empirical problem analysis (Section 8.2) yielded information on what kinds of game mechanics and dynamics the chemistry pre-service teachers created in their educational game ideas through the game design diaries. This provided another guiding idea for the Proteins in the Backyard game. Like the idea in game design diary 4 (GD4) (Section 8.2.2.1), in this game, the players collect ingredients for meringues by completing missions – challenges or questions – presented in the playing cards. But, in contrast to GD4, here all the challenges and questions are related to proteins, the main topic of the game. Collectable ingredient chips in the game are: a bottle of water, a can of chickpeas, berry juice, egg, granulated sugar, icing sugar, lemon and vinegar (Appendix 4). To provide some unpredictability and different ways to collect the ingredients, 2€ chips and the opportunity to buy several ingredients from the corner shop were included in the game.

To add even more unpredictability and uncertainty to the game, each game character has a secret ability to suddenly change the balance of rewards in the game. Similar elements of uncertainty are also embedded into a few of the playing cards.
The game is mostly based on competition between three game characters and three players. However, it can also be played with two players acting as a single character, meaning six players can play and each pair must collaborate to achieve their game objectives. Opportunities for cooperation are available during play: whenever two characters appear at somebody’s home at the same time, they are allowed to exchange a chip with each other. Similar elements are also embedded into the playing cards.

The game rules were constructed to be easy to read. First the backstory is presented, then the actual rules in the following order: before gaming, starting the game, playing and winning the game. All the rules fit on a single sheet of A4 paper. Many rules in this game are based on the ideas presented in the results of the second problem analysis (Section 8.2 and Table 19). The game rules for the final version of the game are presented in Appendix 4.

Table 19. The ideas for game dynamics in chemistry pre-service teachers’ game design diaries, which were on some level applied in the first version of the Proteins in the Backyard board game.

<table>
<thead>
<tr>
<th>THE CLASS: THE SUBCLASS</th>
<th>IDEAS FOR GAME DYNAMICS IN THE GAME DESIGN DIARIES OF THE PRE-SERVICE TEACHERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedagogy: multiple difficulty levels (4)</td>
<td>Different ways to play</td>
</tr>
<tr>
<td></td>
<td>- a game can be shortened by counting who has the fewest tiles when the time is up (domino)</td>
</tr>
<tr>
<td></td>
<td>- increasing difficulty within the game</td>
</tr>
<tr>
<td></td>
<td>- easier tiles with a strong everyday life connections (e.g. biology, home economics) (domino)</td>
</tr>
<tr>
<td></td>
<td>- a player gets more points from playing a more difficult tile (like a tile with molecular structure) (domino)</td>
</tr>
<tr>
<td></td>
<td>- if a player answers correctly three resources will be earned, if they need one tip, they earn two resources and if they need two tips, only one resource (Trivial Pursuit/Star of Africa)</td>
</tr>
<tr>
<td>Pedagogy: unpredictability and uncertainty (3)</td>
<td>- a chance to change a tile with another player (domino)</td>
</tr>
<tr>
<td>Pedagogy: making thinking visible (2)</td>
<td>- a chance to steal a missing ingredient from another player (Labyrinth/Treasure Island)</td>
</tr>
<tr>
<td>Pedagogy: suitable challenges (6)</td>
<td>- changing ingredients, depending on the pastry to be baked in a game (Labyrinth/Treasure Island)</td>
</tr>
<tr>
<td>Argumentation</td>
<td>Explanation</td>
</tr>
<tr>
<td>- a player must answer a question for to get resources or to move forward on the board (Trivial Pursuit/Star of Africa)</td>
<td></td>
</tr>
<tr>
<td>Pedagogy: suitable challenges (6)</td>
<td>- some of the tiles are easier to keep up motivation (e.g. salt, sugar) (domino)</td>
</tr>
<tr>
<td>Pedagogy: suitable challenges (6)</td>
<td>- the rules for the game are easy to understand and a teacher can modify suitability for different groups and topics (domino)</td>
</tr>
<tr>
<td>Pedagogy: suitable challenges (6)</td>
<td>- it might be easier for a a player to explain only to other players than to a whole class of students, why two tiles fit together (domino)</td>
</tr>
</tbody>
</table>
8.3.2 Testing on chemistry educators

The first version of *Proteins in the Backyard* was tested by two chemistry educators and one masters-level chemistry teacher student. The test version of the game was in Finnish. Testing the first version of a game with trusted friends or colleagues is recommended (Warren & Jones, 2017), because even an experienced game developer cannot predict what will work without testing a prototype (Salen & Zimmerman, 2004). By observing the gaming session and by including some specific questions about playability, ease of play and possible problem areas, important feedback can be received (Warren & Jones, 2017).

8.3.2.1 Method: Video recording of educational gaming

The game testing by the chemistry educators was video recorded to test the video camera settings and the best perspective for videotaping gaming sessions. It was also an opportunity to observe a game session and receive feedback about the game.

Detailed structure of learning and teaching can be learnt by watching video recordings of people in action (Hall, 2000). The advantages of video recording include unfiltered data, repeatability (also in slow motion) and the ability to watch multi-party interactions and share these authentic moments with other observers (Cohen et al., 2011; Hall, 2000). Because we cannot directly observe what is in the human mind (Warren & Jones, 2017), video recording learners in action is a good way to analyze possible moments for learning.

Almost every time, the perspective recorded is one that no individual participant in the recorded activity could have had. This is one reason why claims about objectivity and realisticity of records must be considered carefully (Hall, 2000). At the same time, this perspective gives the researcher the opportunity to access things and moments that participants might miss (Hall, 2000).

When using video recordings as research data, four set of problems must be addressed (Derry et al., 2010):

1. Selection: Which elements should be recorded in a complex environment?
2. Analysis: Which analytical practices are valid and appropriate for the given research questions?
3. Technology problems: Which technological tools are available to support collecting, analysing and reporting video?
4. Ethics: How can be the rights of the human subjects represented in the recordings be protected?
Selection problems appear when video is a major data source, as particular elements, clips, are removed from the complex environment for further examination (Derry et al., 2010). The video clips selected for further analysis, are called events, time-analogues of objects (Derry et al., 2010; Zacks & Tversky, 2001). One event can first be divided into subevents, which represent or indicate, for example, agreement or period of negotiation (Derry et al., 2010). These subevents can be decomposed into smaller events, like speech, tool use and gestures.

The specific interests of the researcher determine which events are selected and how they are decomposed (Derry et al., 2010). These events are called critical events and they should be reasonably selected and appropriate for a given research question (Powell, Francisco, & Maher, 2003). Hence, the selection problem is related to analysis problems, in the sense that analysis practices or methods are also dependent on a given research question. According to Hall (2000), primary video data is always both technology- and theory-laden, because these constraints drive data recording and arrangements toward those parts of action and interaction which have already been found to be interesting. For example, once can choose video screen views with people or without people (Hall, 2000). In a video recording with people the way in which a group of people organize their actions can be seen, but from a wide perspective, details about using tools or pointing objects on the screen will be missed. In the video recording without people, detailed actions on the board or on the screen can be followed and they can be linked to indexial talk like "You can’t do it like this". Though it is not possible to set a single standard practice for video data collection (Hall, 2000), combining video data with other forms of data for triangulation is recommended (Derry et al., 2010). In this problem analysis, the video data is combined with a questionnaire and observational data.

Technological problems concerning data collection are about technical skills: how to choose and place cameras and microphones, when to start and end recording, whether to use wide-angle or close-up shots, and whether or not to use zoom while recording (Derry et al., 2010). As said by Hall (2000), "production values that are preserved in technical arrangements for collecting video become a permanent part of the 'data' one is recording" (p. 647). How the primary video data has been approached shapes what is later available for analysis (Hall, 2000).

Analysis problems concerning data analysis are about different purposes in making video selections. In an inductive approach, video data is investigated with broad questions and without a strong theoretical framework, whereas a deductive approach is guided by a strong theory framework and clear research questions. (Derry et al., 2010) A researcher using a narrative approach selects themes with thick and rich descriptions, aiming to make the complex understandable with aesthetically pleasing images, not to simplify it (Derry et al., 2010; Tobin & Hsueh, 2007).
According to Derry et al. (2010), there are various ways to develop representations of video records, but in general, it is important to allow the researcher to identify which segments to analyze and to see patterns within and across these segments. Usually, the chosen method depends on the research question. For example, time-indexed field notes can be made to give a basic outline of the events simultaneously with an actual video recording. Narrative summaries give long descriptive accounts of a video recording. Transcription is time consuming, because typically both talk and nonverbal information are transcribed. The initial transcription may include only some segments of video and it can be iteratively revised until the transcription provides a reliable record and relevant aspects for the research question(s). The transcription thus becomes a key piece of data, though describing the full complexity of authentic verbal and nonverbal actions in transcription is impossible. (Derry et al., 2010)

Coding of transcription is normally a process in which a coding schema is iteratively build up and it often focuses on rich examples with non-counting types of events preferred (Derry et al., 2010).

For the first game test, it was decided to use a stationary video camera and without-people perspective. Oral and written in-game feedback about the game was collected from the players.

8.3.2.2 Data collection and data analysis

Game materials were set on the table and three test players were gathered around the table. A video camera was set up so that only the game board and the players’ hands were in view. The recorded gaming session lasted 46 minutes, and within this time the players managed to finish the game. It was decided to zoom out the view after 15 minutes of play, because gestures and glances were found to play an important role in the gaming action.

During the session, the researcher performed unstructured observation, and oral and written feedback was collected from the players. Oral feedback from the players was immediately written down by the researcher. If the players noticed anything odd or incorrect in the game material, they wrote specific corrections or suggestions for improvement directly onto the game paraphernalia in question.

Immediately after the gaming session, the video data was briefly watched and analyzed to evaluate whether the quality of footage and voice was sufficient and whether a with-people view would be more suitable for collecting video data about board gaming than the view without people. Written feedback and game materials with corrections and improvement suggestions were analyzed and decisions made regarding improvements for the second design cycle for the Proteins in the Backyard game.
8.3.2.3 Results

As a result of the game testing with chemistry educators, it was decided to make six improvements to the game materials. Additionally, one of the test players suggested that more characters could be included into the game, because once someone has played the game, they know all the character secrets. It would have taken too much time to implement this suggestion, so it was decided not to.

New decisions were made about the video recording during the next testing with 9th grade students (Section 8.3.4). It was decided to change the screen view from without-people to with-people perspective, to record authentic gaming moments as best as possible with one camera. It was also decided to keep the camera still, without any zooming during the recording.

8.3.3 The second version

Based on the testing with the chemistry educators, the following six improvements for the Proteins in the Backyard game were decided upon:

- The name of game character Elias was changed to be neuter, Puro (en. Indigo). This solved the problem of uneven numbers of boy and girl characters in the game.
- The contents of three playing cards were corrected, modified or clarified.
- The rules were corrected regarding picking up a card only at a character’s own home and the chance to exchange chips at someone’s home. A rule concerning turning round at the ends of the game board was written into the rules.
- The number of chips were increased to 36, because some of the ingredients almost ran out during the test gaming.
- A granulated sugar chip and egg chips were added to the corner shop’s selections in addition to water, lemon, and a can of chickpeas.
- The game board was modified to be more visual and playable than the first version, and to include places for the playing cards and the chips (Figure 20).
Figure 20. The second version (in Finnish) of the game board for the Proteins in the Backyard game.

8.3.4 Testing on 9th grade students

The second version of Proteins in the Backyard was tested in 2018 on authentic, likely users (Warren & Jones, 2017), in this case meaning 9th grade students (age 15–16 years) at the lower secondary level. The testing was performed with Finnish game material. According to Warren and Jones (2017), usability and play testing are forms of research.

8.3.4.1 Method

A deductive approach to collecting video data was used in this testing, as well as a piece of advice for beginning researchers, that good research literature-based orienting questions prevent a researcher getting lost in the details of video data (e.g. Derry et al., 2010; Goodwin, 1994). The players also answered a post-game questionnaire.

Determination of the critical subevents of in-game discourse in the video data was based on the principles of conversation analysis, which focuses on language in action and interaction, rather than language as action orientation (Cohen et al., 2011; Denscombe, 2010; Wooffitt, 2011). A conversation analysis method makes it possible to embody human social action and activity, such as learning, through use of the language and body (Sahlström, 2011). Features of conversation can be investigated, for
example its generation and construction and its distinctive features (Cohen et al., 2011). Sequential patterns of interaction were sought and each particular utterance was examined in the turn-by-turn development of interaction, not isolated from its context (Wooffitt, 2011). It was also kept in mind that "turns at talk are built to display how they ‘fit’ with prior turns” (Wooffitt, 2011, p. 10).

8.3.4.2 Data collection

Video data about the Proteins in the Backyard board game was collected in the upper-secondary chemistry classroom. A total of 17 9th grade students (5 boys and 12 girls, ages 15–16) participated in the gaming session in the chemistry classroom. One randomly chosen group of six players (3 boys and 3 girls) was video recorded with a stationary camera and microphone using a compromise between with-people and without-people perspectives (Hall, 2000), which focused on the game board, players’ hands, actions, and interactions concerning in-game situations. These six students had received parental permission to undergo in-game video recording. The other three gaming groups were not recorded, because they did not have permission to participate in video or audio recording. A total of six students answered a postgame questionnaire, and two of these students had also been recorded on video.

During the same day’s lesson before the game session (10:00-10:45), all the students studied basic knowledge about proteins. A teacher gave them a list of questions:

- Which elements do proteins consist of?
- Which smaller molecules do proteins consist of?
- What is the same in every protein’s structure?
- Why must proteins be eaten every day?
- What does protein denaturation mean and what factors affect it?
- What are proteins’ purposes in our body? And the purposes of hemoglobin?
- What is a peptide bond?
- How many different amino acids do the proteins in the human body consist of?
- How much protein do we need every day?
- How is cheese produced?

The students answered these questions either independently or in groups of 2-3 students. Each student wrote the answers into their own Chromebox laptop (provided by the school). The teacher walked around and observed the work. The answers were not checked together, neither did the teacher ask how many questions the students had managed to answer before the end of the lesson. Hands-on activities or demonstrations about the topic were not used during the lesson.
After the lunch break, the gaming session was held (11:15-12:00). The games were already set up on three tables when the students arrived in the classroom. Game materials on the tables consisted of the game board, playing cards, the chips, the rules sheet, the clue booklet, three game character cards, three tokens, and a die. One of the game tables was equipped with a stationary video camera. Based on the first test (Section 8.3.2), the stationary camera was adjusted so that both the game board and students around the table were visible (Figure 21).

First, the researcher told the students briefly about the game testing. Second, she read out the aim for the game, the background story, and then explained the game rules as shortly and as clearly as possible (10 min). Video recording was started when the actual gaming began and it was stopped when the lesson reached its end (36 min). The session was continuously recorded and zooming was not used during recording (Derry et al., 2010).

Because of the lesson’s time limit, none of the playing groups managed to complete the game. At the end of the session, the teacher handed postgame questionnaires to the students with permissions, and they filled in their responses before leaving the classroom (3–5 min). Six questionnaires in all were completed.

During play, the researcher and the teacher walked around the classroom and answered students’ questions or gave clues, if needed. At the same time, they made unstructured observations in addition to the video data. Unstructured observation is usually qualitative, natural, and participatory (Cohen et al., 2011). After the lesson a short discussion session was held between the researcher and the teacher to share the results of their observations.
8.3.4.3 Video data analysis

For the video data, a deductive approach, guided by a strong theory framework and clear research questions (Derry et al., 2010), and conversation analysis with an understanding of learning as situated and constituted in interaction (Sahlström, 2011), were used. Also in the field of digital game research, analysis of communication transcripts in a way of evaluating in-game learning is suggested (Whitton, 2014). The original plan was to perform a light transcription of the collected video data (36 min) in order to find segments (Derry et al., 2010), but after watching the first two turns of play and noticing that several possibly important subevents were already embedded into these two segments, the researcher decided to transcribe the whole video data in detail.

It was decided to include in the transcription both verbal and nonverbal actions: talk and other sounds, such as laughter, and other in-game interactions, such as gestures and glances (Derry et al., 2010). This capitalized on the advantages of video recording over audio recording, and a sufficient description of in-game events on a turn-by-turn basis was captured for the purposes of conversation analysis.

During transcription, the video data was divided into the natural events (Derry et al., 2010): 1st playing turn, 2nd playing turn, …, 27th playing turn and end of the game. It was decided to color code two repeating occurrences:

- The content of a specific playing card is read out loud
- Unclear talk

And two typical transcription notations were used:

- ( . ) = a short break
- [ = simultaneous talking.

The specific interest of the researcher determined which subevents were sorted out from the events (Derry et al., 2010) for deeper analysis. Based on the research question, possible subevents including remarking for transfer of knowledge were sought, but two other types of relevant situations also emerged from the video data. These three critical subevents were color-coded in the transcription:

- Indicating in-game transfer of knowledge between contexts
- Indicating in-game problem with rules or contents
- Indicating non-chemical in-game relation to everyday life.
8.3.4.4 Questionnaire data and observation data analyses

The questionnaire was filled in by two of the video recorded players and four of the other players. These six postgame questionnaires from one boy and five girls were qualitatively analyzed. Content analysis was built into the questionnaire's construction, meaning that answers were post-coded into the same categories as in the questionnaire (Cohen et al., 2011): sex, age, likes gaming, types of games usually played, favourite game, learn something new about chemistry or everyday life while gaming (if yes, what), pros of the game, cons of the game. Preliminary coding was not applied, nor checking the validity by using the same coding system for another sample.

8.3.4.5. Results of video data

Testing Proteins in the Backyard with 9th grade students revealed three types of results: problems with the game, indications of transfer of knowledge and indications of non-chemical connections with daily life. The detailed results are presented in the next sections on the perspective of video data. The postgame questionnaires and the in-game observations, for their parts, were found to support the video data, but also provided some additional information.

8.3.4.5.1 In-game problems with rules or contents

A total 18 subevents concerning in-game problems with rules or contents were found in the video data. These subevents are listed and classified in Table 21.

<table>
<thead>
<tr>
<th>GAME MATERIAL</th>
<th>DETAILED DESCRIPTION ABOUT THE PROBLEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chips (4)</td>
<td>- when the exchange of the chips between the players is possible (1)</td>
</tr>
<tr>
<td></td>
<td>- from which pile are reward chips picked up (CORNER SHOP or FREE CHIPS' PILE) (1)</td>
</tr>
<tr>
<td></td>
<td>- what to do, when a chip is received, that is not needed (2)</td>
</tr>
<tr>
<td>Game character card (3)</td>
<td>- should a secret in the game character card be read out loud, when it has been decided to use (1)</td>
</tr>
<tr>
<td></td>
<td>- what ingredients are necessary to collect (or word in the game character card of SOFIA) (2)</td>
</tr>
<tr>
<td>Moving on the game board (2)</td>
<td>- is it allowed to go to SCHOOL (1)</td>
</tr>
<tr>
<td></td>
<td>- where to move, when the token arrives on the end of the street on the game board (1)</td>
</tr>
<tr>
<td>Playing cards (8)</td>
<td>- there exist playing cards without a reward in the game (1)</td>
</tr>
<tr>
<td></td>
<td>- when picking up the HOME playing card is allowed (2)</td>
</tr>
<tr>
<td></td>
<td>- should the text in the playing card read out loud (1)</td>
</tr>
<tr>
<td></td>
<td>- where should the used playing cards be placed on the game table (2)</td>
</tr>
<tr>
<td></td>
<td>- exhaustion of cards in some destinations on the game board (CORNER SHOP, HOME) (1)</td>
</tr>
<tr>
<td></td>
<td>- difficult/incomprehensible question/task in the card about wool yarn for a pair of wool socks (1)</td>
</tr>
<tr>
<td>The clue booklet (1)</td>
<td>- are the correct answers in the clue booklet (1)</td>
</tr>
</tbody>
</table>
Most of the in-game problems (11) were apparent during the first ten turns of play, and especially during the beginning of the game in the 1st (3) and the 3rd (3) turns. Whereas the problems concerning the placement of used playing cards (2), what ingredients are necessary to collect (2) and when picking up the HOME playing card is allowed (2) came up in different phases of the game session. The problems concerning exhaustion of cards at some destinations on the game board (1), and what to do when a player receives a chip which is not needed (2) appeared in the back end of the game session. Similar problems were mentioned in the postgame questionnaires and in-game observations (see Section 8.3.4.4). The situation concerning reading the text in the playing card is presented here as an example of this type of subevent in the transcription (Excerpt 1). Both voices and gestures can be seen supporting the emergence of a problematic subevent.

Excerpt 1. An example about in-game problems with rules or contents: Should the text in the card to be read out loud?.

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:07</td>
<td>G2</td>
<td>should you read out loud</td>
<td>G3 and B3 picked up a card and read it silently</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>should these questions to be read out loud?</td>
<td>G2 turns to look at G3 and B3</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>yes, it is best to read both the story and the task</td>
<td>R arrives</td>
</tr>
</tbody>
</table>

According to the results of the shared observation of the researcher and teacher, there were some difficulties among the students in answering the challenges or questions given in the playing cards. One arose because the student had not managed to reach the question concerning factors for denaturation in the previous (study) session and two others because of the way that the questions were written (e.g. Excerpt 5). Some students needed the teacher or researcher to prompt them to the right answer. On the contrary, the questions concerning pure protein chemistry (SCHOOL) were answered well, perhaps because this kind of information was studied right before the gaming.

Bogging down was one of the very visible problems during play. The researcher observed it while she was walking around the classroom, but the problem was also apparent in several subevents in the video data. The reasons for this sticking was most certainly the die, which in the second version of the game allowed only 1, 2 or 3 steps in movement on the game board, and the game rule prevented moving around on the game board.

The written answers in the questionnaires (Table 20) gave similar feedback to the video data about in-game problems concerning movement on the game board: “You could move around on the game board”; and problems with the number of playing cards: "Perhaps more questions, and less searching for information in them" and “more cards".
8.3.4.5.2 Visible engaging game elements in gaming

Engaging game elements play an important role in gaming (see Section 3.2.2.4). The video analysis revealed that at least the following engaging game elements were experienced during the game session: backstory and game characters, enjoyment and excitement, frustration and boredom, unpredictability, rewards and feedback.

The *Proteins in the Backyard* game is based on a backstory about a meringue making competition at school for 9th graders. The backstory was read to the students just before the game began to move them inside the magic circle of the game and into the daily life of the three game characters. According to Namkee et al. (2010), both a visual video backstory and a non-visual backstory text are able to improve students’ positive attitudes toward a game to be played. According to analyzed video data, the students were absorbed in the game and adopted the roles of the game characters, some better than the others. Only the game characters’ names were used in the act of play, instead of the students’ real names. The game character cards were scanned a total of 32 times during play and the personal secrets of each character seemed to be very important to the players. According to Qian & Clark (2016), while playing roles, students are able to explore social roles. These game characters gave students only a slight opportunity to explore social roles, because characters were also 9th graders and giving opinions in character was not needed during play.

Laughing, smiling and joking about game-related topics were analyzed as indicating in-game joy and enjoyment. Comments like “Ah. (G3)”, “Why are we always getting such difficult questions? (B3)” and “We don’t even need a lemon chip (the disappointment in his voice). (B3)” were analyzed as indicating in-game frustration. The moment in the 19th turn of play, when the players (G3 and B3) became stuck on one part of the game board for several turns, describes the feeling of frustration well in both voice and gesture: “This is depressing. (G3)” (G3 is leaning tiredly on her arms.).

Another moment in the 8th turn of play, when the secret of one game character (B1 and B2) was revealed and because of that, another game character (G1 and G2) lost her icing sugar chip, was indicated to typify frustration. However, there was also laughter in that moment. This moment also included an element of unpredictability, because *Indigo* was then using the character’s secret. According to previous studies, there should be a degree of tension, meaning uncertainty, unpredictability and unexpected events in every game (Gredler, 2004; Huizinga, 1949/1998; Knudtson, 2015; Salen & Zimmerman, 2004) to engage players.

In the video data, boredom was expressed both mostly with gestures. One moment in the 17th turn of play is very descriptive of in-game boredom: “B1 and B2 are reading the text. Others are starting to behave restlessly: glancing elsewhere, hitting the table with fingers, snapping a pencil.” Emotions of anxiety and boredom have been shown to engage students in play and in learning during play (Annetta,
According to Chanel et al. (2008) maintaining the same level of difficulty for a long time elicits only boredom. Based on this observation, overly long periods of silence reading and solving the problem bog the game down and therefore elicit boredom. Perhaps this mission was a little too challenging for 9th graders to be in their zone of proximal development (Vygotsky, 1978), or at least the text was slightly too long for this game.

In this game, chips are counted as rewards, and collecting them is one of the main goals of the whole game. Feelings of happiness and satisfaction were observed in the video when a player received the needed rewards. However feelings of frustration, disappointment and disbelief were noticed when the reward was something other than the needed one, or when there was no reward mentioned in the playing card: "Is it possible that we are not getting any reward? (B2)"; "B2 is looking at the researcher." Feedback from the researcher or from the peer players played an important role in the game, whenever the correctness of an answer was evaluated. The supportive feedback together with the well-earned reward usually inspired the players. At least once during this session, a player gave supportive feedback for himself: " [...] I think it is quite well explained. (B3)". According to the postgame questionnaire answers (Table 20), the best aspects of the game were the questions and accomplishing tasks in groups. "The game was well developed" and "It was not boring" were two other comments from the students that supported the observations from the video data.

8.3.4.5.3 In-game competition, cooperation and collaboration

The Proteins in the Backyard game is based on both competition, cooperation and also collaboration, if it is played in pairs or small groups. In this video analysis it was played in pairs. Similarly to Nemerow’s study (1996) in this study students were noted to have a positive attitude towards performance anxiety during a play session. Collaboration between the players sharing the same game character was visible, but there were also moments and playing turns, where another of the players took a main responsibility of the mission to solve, or it was given to this player, when his/her player partner remained silent. In this study it was not possible to compare, if competition between groups rather than individuals has potential to support learning (Johnson & Johnson, 1999). Competition between three game characters were apparent during the whole game session, but based on the collected data it is impossible to say, if competitiveness hindered any player’s in-game learning (Harviainen et al., 2012).

A cooperative game can be described as a game in which it is possible, for example, to buy something from other players, whereas collaborative game is a game in which all the players play together against a shared opponent (Zagal, Rick, & Hsi, 2006). In cooperative or collaborative play, students focus on a shared aim and because of that, they play more rationally and more quickly, and make fewer mistakes than in competitive play (Bornstein, Kugler, & Ziegelmeier, 2004; Zagal, Rick, & Hsi, 2006). Decision-
making in cooperative or collaborative play often differs from individual play (Bornstein, Kugler, & Ziegelmeyer, 2004; Ke, 2008). It also seems that boys engage in cooperative game and in-game problem-solving better than girls (Ke, 2008). When university students were encouraged to engage in peer-to-peer discussion during play to help each other in problem-solving, it was noticed that in order to win, players did not give peer-to-peer support to others, but attempted to solve the in-game problem by themselves (Knudtson, 2015).

Winning the game should depend both on skills and on luck, and every player should learn something (Gredler, 2004). The most skilled student should not be the evident winner, nor should wrong answers be penalized by loss of points (Gredler, 2004).

8.3.4.5.4 In-game transfer of knowledge

A total of six subevents indicating in-game transfer of knowledge were found in the video data. These subevents are presented in Excerpts 2–7, but not in playing turn order. The critical moments (interactions, talk and gestures) in these subevents are colored orange. Questionnaire answers partly supported the this video data with one statement concerning learning about why eggs can be whipped and another about denaturation in general.

In Excerpts 2 and 3, basic knowledge about protein denaturation is transferred to daily life contexts. Both these missions are about an everyday material, wool, and two everyday subjects, socks and a ball (Childs, 2015). Excerpts 2 and 3 most clearly indicate transfer of knowledge as it has been defined by Gilbert (2006). In Excerpt 2, the player immediately answers the question about felting wool, and gets confirmation of the right answer from the player of another game character. This subevent presents direct application of basic chemistry knowledge about protein denaturation. In Excerpt 3, the basic knowledge about protein denaturation should be applied in reverse. In this subevent, a player answers the question how to prevent wool socks from becoming felted or shrinking. First the player seems confused, even about the word ‘denaturation’, but then she comes up with a correct answer, being first supported by herself and two other players, and then also a third player.

Because the students had not explicitly studied protein-based materials, but only basic protein chemistry before gaming, these questions could have been impossible to answer without the tips in the playing card missions to connect protein chemistry to wool. When comparing Excerpts 2 and 3, it can be seen that direct transfer of knowledge about protein denaturation in Excerpt 2 seems to be much easier for the students than the reversed application of the same knowledge in Excerpt 3. Hesitation and uncertainty are visible, and support from the other players was needed.
**Excerpt 2. Indicating in-game transfer of knowledge: Felting wool.**

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>05:54</td>
<td>B2</td>
<td>(is reading aloud the content of the card)</td>
</tr>
</tbody>
</table>

**TIME**

**5TH PLAYING TURN [INDIGO]**

**NON-VERBAL ACTIONS**

- Others concentrate in listening

B2 is holding the card in his hands

B2 (is reading aloud the content of the card)

**VERBAL ACTIONS**

- Other s concentrate in listening

**NON-VERBAL ACTIONS**

B2 is holding the card in his hands

B2 (is reading aloud the content of the card)

**VERBAL ACTIONS**

- Other s concentrate in listening

B2 is holding the card in his hands

**NON-VERBAL ACTIONS**

**Excerpt 3. Indicating in-game transfer of knowledge: Washing the wool socks.**

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>21:06</td>
<td>G3</td>
<td>(is reading aloud the content of the card)</td>
</tr>
</tbody>
</table>

**TIME**

**13TH PLAYING TURN [TAYLOR]**

**NON-VERBAL ACTIONS**

- Also B3 is glancing at the card

G3 looks at B3

B2 looks at B3

**VERBAL ACTIONS**

- B2 looks at B3

**NON-VERBAL ACTIONS**

- B2 looks at B3

B2 looks at B3

**VERBAL ACTIONS**

B1 if it’s too warm

**NON-VERBAL ACTIONS**

B1 looks at B3 and B2

B1 looks at B3 and B2

In Excerpt 4, an information search for a new food product and application of both general and chemical information about the product is needed. Now, the mission is about everyday issues and advertisements as another area of interest (Childs et al., 2015). In this subevent, first one player answers the given challenge to come up with a witty banner for the Härkis product. There is joking about the banner, especially about the absence of chemical information in it. Two players in turn are able first to find a connection between Härkis and meat and then a connection between Härkis, meat and proteins. The difficulty of creating a truly witty banner in a short time is explicitly visible in Excerpt 4.
In this example of transfer of knowledge, at first the players only needed to find the connection between proteins and vegetable proteins in the new Härkis (made of oat and broad beans) on the internet. But the players were also asked to demonstrate application of knowledge about proteins for commercial purposes and in a creative way. According to Excerpt 4, this kind of transfer of knowledge was slightly too difficult for the students. Perhaps one reason was that during play, quick reactions are normally what is needed, but creating something might take time. It can also be seen that new vegetable-based protein products inspired joking and discussion between the players.

In Excerpt 5, the basic knowledge about proteins’ appearance in the human body is applied and transferred. The mission in this playing card is about everyday activity and objects (Childs et al., 2015). In this subevent, the player at first struggles and mixes up proteins with their elements and amino acids.
### Excerpt 5. Indicating in-game transfer of knowledge: Proteins in a cat.

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:16</td>
<td>TG2</td>
<td>(is reading aloud the content of the card)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3, B2 and B1</td>
<td>(start to laugh)</td>
<td>P3 leans on his knees</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>err</td>
<td>G1 is smiling</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>wow ( . ) you have to know all that</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>in cat, proteins (fi. proteiineja) are at least its proteins (fi. valkuaisaineet) ( . ) muscles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>tell a composition of a cat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1 ja B3</td>
<td>(start to laugh)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>basic knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>amino acids</td>
<td>G2 points at B1 with her hand</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>err… e-e-err…</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>proteins (fi. proteiinit) and proteins (fi. valkuaisaineet) are the same thing</td>
<td>B2 is waving his hand back and forth on horizontal plane</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>and then ( . ) err well ( . )</td>
<td>G3 stands up for a while and then sits again</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>and then cream proteins</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>(says something)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>nitrogen ( . ) yes a cat is consisted of it</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>oh what are you thinking ( . ) no but four things that in a cat which are consisted of proteins ( . ) no you are going inside the protein molecules ( . ) think about cat so that which parts in a cat could be consisted of</td>
<td>R arrives</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>heart</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>heart, yea-ah</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>heart muscles, liver</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>yea-ah, I’m not sure about liver</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>the brain</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>(is laughing)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>there is too, yeah yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>how long is guessing allowed?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>a moment still, because this is a test so you may now think</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G1</td>
<td>the brain and</td>
<td>G1 starts to count with her fingers</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>heart, muscles</td>
<td>Others are looking at the pair (G1 and G2) in turn</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>what about outside of the cat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>blood</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>blood ( . ) yeah ( . )</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>well then ( . ) ooh, we are getting an egg</td>
<td>G2 is browsing a pile of free chips on the table, takes an egg chip and moves it beside the other chips on the character card</td>
</tr>
</tbody>
</table>

Perhaps a part of this confusion is due to the word ‘consisted of’ in the card text. They also did not realize that the cat’s exterior, like its fur and eyes, might also be composed of proteins. With the support of the researcher, transfer of knowledge happens for the player, but in this excerpt, similar transfer of knowledge cannot be indicated for any of the other players.
The mission in Excerpt 5 was meant to be easy, because only basic knowledge about proteins’ occurrence was needed. But this mission turned out to be difficult, perhaps because the students had studied only proteins’ occurrence in food before gaming. Also the player was only thinking about tissues inside the cat, not its fur, eyes or whiskers, despite the tip from the researcher. The student managed to construct a correct answer at last, possibly by using familiar context of food proteins, like in muscles and in liver, as a base for transfer of knowledge. This kind of daily chemistry knowledge is not necessarily very useful, except if it is used for example in choosing the best possible cat shampoo.

In Excerpts 6 and 7, the tasks in the playing cards ask a player to first read a news article and then find some specific protein-related information in the text. Both missions are about everyday issue, but Excerpt 6 is also about everyday materials and Excerpt 7 an everyday activity, eating.

**Excerpt 6.** Indicating in-game transfer of knowledge: Milk-based clothes.

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>16:30</td>
<td>G3</td>
<td>(is reading aloud the content of the card)</td>
<td>G3 looks tired</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>ah</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>why are we always getting so difficult questions</td>
<td>B3 takes the clue booklet in his hands</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>we always are getting difficult questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>milk-based clothes are there, in that title, they are in alphabetical order in there (. ) then you’ll read the news and tell, how it is related to proteins and what properties it is having</td>
<td>B3 is browsing the clue booklet</td>
</tr>
<tr>
<td></td>
<td>G1 and G2</td>
<td>(are silently discussing about the character card)</td>
<td>G1 and G2 are looking at their character card</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>shhh… (to G1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1 and B2</td>
<td>(are discussing about something)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>are you reading?</td>
<td>B3 gives the clue booklet to G3</td>
</tr>
<tr>
<td></td>
<td>B3 and G3</td>
<td>are reading the clue booklet together</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(others are talking something)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>are you reading?</td>
<td>others are waiting and are looking either their fingers or the game board</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>err…</td>
<td>B3 turns back to look at the clue booklet once more</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>fabrics made of milk fiber are promised to be sensitive on the skin, against the skin and long-lasting and they are like anallergic (. ) yes and they are water-repellent (. ) they are biodegradable (. ) drying faster than normal clothes (. ) casein is one of the milk proteins (is also reading about the manufacturing process) (. ) I think it is quite well explained</td>
<td>G3 gives the clue booklet to B3</td>
</tr>
</tbody>
</table>
Excerpt 7. Indicating in-game transfer of knowledge: Plant- or animal-based proteins.

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>23:34</td>
<td>B2</td>
<td>well (.) three</td>
<td>B2 throws a die</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>let’s go home (and something else)</td>
<td>B2 moves the token on the board from SCHOOL, to CORNER SHOP and CAKE SHOP, but then moves the token to INDIGO’S HOME</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>otherwise we can go one-two-three (.) let’s go home</td>
<td>B1 and B2 are both going to pick up a card, but B2 backs off</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>ummm</td>
<td>B1 shows the card to B2, who takes the card in his hand</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>(is reading aloud the content of the card)</td>
<td>B2 takes the clue booklet in his hand and starts to browse it</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>you’ll get a can of chickpeas or an egg chip</td>
<td>B2 finds a correct page from the clue booklet and organize it on the board in front of B1 and himself</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>huh</td>
<td>B1 moves the card from below the clue booklet</td>
</tr>
<tr>
<td>24:43</td>
<td>B1 and B2 are reading the text</td>
<td>others are starting to behave restlessly: glancing elsewhere, hitting the table with fingers, snapping a pencil</td>
<td></td>
</tr>
<tr>
<td>26:10</td>
<td>B2</td>
<td>yeah (.) so it does not much matter if you eat peanuts, seeds, soy and then you eat B12 vitamin (.) then this animal-based protein is quite even</td>
<td>B2 takes the clue booklet in his hands and points at various parts of it with his finger to B1</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>yeah</td>
<td>B1 picks up an egg chip from the pile of the free chips on the table</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>yeah</td>
<td>G1 and G2 are nodding</td>
</tr>
</tbody>
</table>

In Excerpt 6, the task is first considered difficult, but eventually the player manages to explain the chemistry behind the milk-based fiber and fabric to the other players so well that at the end of this subevent he is proud of himself. This is an important observation, because before this subevent, this player has mostly seemed to be more absent than present and expressed feelings of tiredness and boredom.

According to observations presented in Excerpt 6 and Chanel et al. (2008), engagement will occur if the skills of the player meet the challenge of a new task. This is in line with Vygotsky’s theory of zone of proximal development and indicates that the mission in the playing card was suitable for 9th graders. Excerpt 6 also indicates that interest and motivation in learning will be enhanced when a student experiences feelings of success (Nieswandt, 2007; Piaget 1951/1999; Rahayu, 2015; Vygotsky, 1978).
8.3.4.5.5 Non-chemical in-game relations to everyday life

Some non-chemical relations to daily life were revealed in the video data. All three were related to food and cooking or products (Excerpts 8, 9 and 10), in the areas of everyday objects, materials, activities and other areas of interest, like consuming. Excerpt 8 describes a subevent about Kiehu milk. While one of the players browses for information, three other players talk about Kiehu milk as a product and its availability in shops.

**Excerpt 8. Indicating non-chemical relations to daily life: Kiehu milk.**

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:18</td>
<td>G3</td>
<td>(is reading aloud the content of the card)</td>
<td>B3 is yawning</td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>do you have a smartphone?</td>
<td>G3 turns towards B3</td>
</tr>
<tr>
<td></td>
<td>B1 or B2</td>
<td>(is asking something about a reward)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G3</td>
<td>a water bottle ( . ) I have not even heard about of that kind of product ( . ) never heard that kind of product</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>I have, but</td>
<td>B3 is reading the card silently and keeping his smartphone in his hand</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>it was advertised a while ago, but now it cannot be find anywhere</td>
<td>P3 is browsing his smartphone others are talking something</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>if you are afforded</td>
<td></td>
</tr>
</tbody>
</table>

In Excerpt 9, the players taking their turn are buying an egg chip from the CORNER SHOP with the 2€ chip when another player suddenly starts to wonder about the egg’s high price in the game and compares it to the price of eggs in real life.

**Excerpt 9. Indicating non-chemical relations to daily life: Eggs.**

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>19:34</td>
<td>B1</td>
<td>let’s go to the shop</td>
<td>B2 moves the token to CORNER SHOP on the game board</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>well ( . ) let’s by an egg ( . ) is this an egg?</td>
<td>B2 takes a brown egg chip in his hand from the pile in the corner shop</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>you have a rattle</td>
<td>B1 drops 2 € chip back to the pile of free chips G3 is smiling</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>but what egg is costing two euros? ( . ) At least I suppose that with that money I will get more than one, get a whole package (laughs)</td>
<td>all are directing towards B1 G3 is smiling</td>
</tr>
</tbody>
</table>

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The third example, Excerpt 10, is about cooking salmon without an electric oven or an electric stove. Instead of using basic knowledge about the factors affecting protein denaturation, the player taking their turn is focused on grills and wonders if electricity is needed for a gas grill or not.

Excerpt 10. Indicating non-chemical relations to daily life: Salmon in the oven.

<table>
<thead>
<tr>
<th>TIME</th>
<th>PLAYER</th>
<th>VERBAL ACTIONS</th>
<th>NON-VERBAL ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>29:02</td>
<td>21ST PLAYING TURN [SOFIA]</td>
<td>was reading aloud the content of the card</td>
<td>B3 is leaning on his knees and looking at his legs, others are looking at the G2</td>
</tr>
<tr>
<td>G2</td>
<td>(is reading aloud the content of the card)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>what you mean by slower</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>that oven are not used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G3</td>
<td>you can use a candle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>err (...) so (...) we are using a candle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G3, G1, and R</td>
<td>(are giving a laugh)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>indeed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>perhaps not in real</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>not at all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>yes perhaps you could, if there would be on a metal plate, then you could get</td>
<td>R arrives</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>(something) light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>no no (...) no a smoker</td>
<td>G2 is looking at G1</td>
<td></td>
</tr>
<tr>
<td>G3</td>
<td>I do smoke</td>
<td>G1 is moving her hands wider and closer on horizontal plane</td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>such a gas barbeque (...) a small gas barbeque (...) an electric grill (...) a gas barbeque</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>yes I would accept that (...) that is now so imaginative (...) yea-ah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td>electricity is not needed for a gas barbeque, right?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>nope</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.3.4.6 Results of observation and questionnaire

In the postgame questionnaire, information about 9th grade students’ game activities and favorite games were first revealed. All of the students who answered, except one girl, liked to play games. The students usually played digital games only, role-playing games only, digital and board games, or digital, card and board games. Favorite games included Pokémon, Trivial Pursuit and role-playing games with friends.

In the second part of the questionnaire, questions about in-game learning were asked: did you learn something new about chemistry or did you find any connections to daily life during play? If yes, what?

Two of six answers had these connections:
I learnt more knowledge concerning denaturation. (G1)

I learnt more about proteins, like why eggs can be whipped. (G4)

In the third part of the questionnaire, students’ opinions about the Proteins in the Backyard game were revealed (Table 20). As can be seen from Table 20, they liked the questions/tasks in the playing cards a lot and the game was evaluated to be fun and not boring. Exhaustion of the playing cards at some destinations on the board was noted to be one of the weaknesses in the game, as well as the rule to move only back and forth on the board, not going around. They also wished for less searching for information in the tasks.

<table>
<thead>
<tr>
<th>WHAT WAS BEST IN THE GAME?</th>
<th>HOW WOULD YOU IMPROVE THE GAME?</th>
</tr>
</thead>
<tbody>
<tr>
<td>- the questions</td>
<td>- the questions could be even more challenging</td>
</tr>
<tr>
<td>- the questions, they were fun and easy enough</td>
<td>- perhaps more questions, and less search of information in them</td>
</tr>
<tr>
<td>- the game was well developed</td>
<td>- more cards</td>
</tr>
<tr>
<td>- solving the tasks was fun in groups</td>
<td>- you could move around on the game board</td>
</tr>
<tr>
<td>- it was not boring</td>
<td>- not in any way (2)</td>
</tr>
<tr>
<td>- eggs</td>
<td></td>
</tr>
</tbody>
</table>

Both the researcher and the teacher shared two similar in-game observation results: some of the tasks/questions in the playing cards were too challenging for some students or took too much time to solve; the students willingly helped each other or liked to answer the question instead of the player(s) taking their turn.

In addition to the shared observations, the researcher noticed some more:

- At least two of the missions in the playing cards must be modified to be more precise.
- One student said that he did not know the answer, because he did not reach the question concerning factors affecting denaturation in the previous session.
- Some students needed a teacher to prompt them to the right answer.
- The questions concerning pure protein chemistry (SCHOOL) were answered well, perhaps because this kind of information was studied right before the gaming session.
- The players got stuck in the HOME triplet (INDIGO’S HOME, SOFIA’S HOME, ONNI’S HOME) (see Figure 20), perhaps because of dice allowing only 1, 2 or 3 steps of movement and the board allowing only back and forth, not circular movements.
Based on the results of this educational game testing with 9th grade students, it can be said that the *Proteins in the Backyard* board game and its grouped elements influenced in-game transfer of knowledge, to a certain degree, in the different contexts of protein chemistry. It was noticed in particular that transfer of knowledge concerning protein chemistry was easier for students when it was applied directly than reversed. In methodological level this study offers one possible answer in solving an existing problem of absence of in-game assessment providing evidence of the transferability of learning to other contexts (Whitton, 2014).

The relationships between engaging game elements, in-game emotions and in-game learning were clearly visible in one of the seven excerpts presented in this study. This indicates the quality of this game, being in line with the given instructions for game quality: “One must also show that it was the game and its grouped or independent elements that were responsible, rather than the pedagogical method, practice and related time on task, and/or feedback from the [game] system on that practice that influenced learning” (Warren & Jones, 2017, p. 50).

It was also possible to identify engaging game elements from the data. According to previous research, rewards and positive feedback alternating with challenges and conflicts invoke alternating feelings of anxiety and boredom, which on their part engage players to play and learn (Annetta, 2010; Chanel et al., 2008; Hamari et al., 2016; Tüysüz, 2009). In this study, it was apparent that the players were engaged, but learning was studied only from the perspective of transfer of knowledge. The observed and engaged emotions are quite similar to the learning theories of cognitive and social constructivism, in which attitude and interest are seen as two affective factors in student’s learning motivation in addition to cognitive processes (Nieswandt, 2007; Piaget 1951/1999; Rahayu, 2015; Vygotsky, 1978).

Additionally, three non-chemical in-game relations to everyday life appeared. There were a few mentions about learning daily life chemistry during play, although it was visible in the video data and the excerpts presented in the previous sections. Perhaps this was due to the short time available to fill in the questionnaire (2-5 minutes), or lack of control over what students actually learned about protein chemistry before the game session.

Unfortunately, because of a lack of time, the game was not played to the end. Therefore it was impossible to observe or demonstrate the possible in-game linkages or bridging between the game content, contexts and the *World’s best meringues* hands-on activity. However, the in-game observations and suggest that instead of students only reading theory, it would be preferable to execute a hands-on activity concerning factors affecting protein denaturation. And as a postgame activity, the students could bake real meringues, based on the three different recipes in the game character cards (Lunetta & Hofstein, 1991; Hofstein & Lunetta, 2003).
This testing also revealed a valuable amount of written and video-based information about problems in game mechanics and dynamics during play. These problems appeared despite the fact that the challenges faced in the previous design challenges 1 and 2 had already been taken into account in the first version of Proteins in the Backyard. This information about the problems was crucial when the game was improved in a third design cycle producing the third version of the game (Section 8.3.5).

8.3.5 The third version

Based on the second testing of the Proteins in the Backyard game with the 9th graders, the third design cycle for the game was applied. All the results that emerged from the data were taken into account as the game was developed. In particular the game board, rules and playing cards were modified.

The game board was modified to be more informative by first removing the spaces for the playing cards away from the board. The cards were too large to fit into their spaces. Instead, three supplemental game rules were embedded into the board, ditto the new rule allowing the circular movements at the ends of the final game board (Appendix 4). These same rules are also printed in the rules sheet. The game die was normalized, now allowing movements between 1 and 6 steps.

The prerequisites were added into the general game information in the guideline sheet: “Basic knowledge about protein chemistry has been learnt and preferably also hands-on activity concerning denaturation has been applied.” The backstory text was shortened and finalized. The rules were also edited for the greatest possible clarity, with additions regarding:

- which chips are included in the corner shop’s selection
- where the piles of the unused playing cards and used playing cards, as well as unused and collected chips are to be situated on the table.
- to read out loud the playing cards that are picked up
- to read out loud the character’s secret, whenever it is used
- who is the winner, if the game has not been played all the way
- a teacher-led postgame discussion (Table 18).

Three playing cards were corrected, based on observations during the second test gaming. To substantially shorten playing time and to increase the pace of the game dynamics, some of the original playing cards were converted to true-or-false questions and more ingredients were added into the corner shop’s selection. It was verified that the missions on the playing cards covered everyday objects, materials, issues, activities and other areas of interests, like consuming (Childs et al., 2015; see Figure 11). Rewards in the playing cards were adjusted so that there were alternative chips for students to choose as rewards.
Multiple difficulty levels were embedded into the game in the form of different ways to play (Table 18). The rules for short and long games were created and the character cards and the playing cards were modified to follow these new rules. In short play three ingredients and in long play four ingredients are collected.

8.4 Design solution: Proteins in the Backyard

The design process for the Proteins in the Backyard educational board game was applied in three design cycles. The game mechanics in Proteins in the Backyard is loosely similar to those of Bonnie and Clyde, but it also includes game elements from other games, such as Treasure Island. The game material for Proteins in the Backyard consist of the game board, a die, 36 playing cards, 36 chips, 3 tokens, 3 game character cards, the clue booklet and guidelines (general information and the rules). A smartphone, a tablet or a laptop, a chemistry textbook (and a notebook) and three post-it notes and pencils are needed as essential supplementary material for gaming. One game is played by 2–3 individuals or pairs of players.

During the gaming, the players act as game characters who compete against each other, collecting ingredients for their own secret meringue recipes by answering different questions and challenges in different contexts on the game board. After collecting all the necessary ingredients (3–4), the player must go to the School space and write down on a post-it note all those factors in the meringue recipe that affect protein denaturation. A teacher will check if the answer is right or wrong. In the postgame session, a teacher can lead a discussion about the game and meringue recipes. The Proteins in the Backyard educational game material is attached as an appendix to this thesis (Appendix 4).

The cognitive perspective for game mechanics in this game is based on the four-phased criteria for the use of context in chemistry education (Gilbert, 2006; Pilot & Bulte, 2006). Here, a neighborhood is a valuable setting as a social, spatial and temporal framework for a community of practice. Different places on the game board act as contexts within the neighborhood, offering focal events. Missions in the playing cards bring the behavioral environment into focus with problems that offer examples of chemically important concepts, even if only in the context of protein chemistry. In answering and solving these missions, the player-learners use specific chemical language, where relevant background knowledge is especially valuable.

The design values of the researcher as a game designer of the Proteins in the Backyard game can be explicit evaluated by using Table 1 (Kultima & Sandovar, 2016). Based on the researcher’s self-evaluation and the content of CHEDU Game Design Tool (Table 12), collection of design values from all the categories, except of values of commercial, have been emphasized during the game design process:

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Accessibility and simplicity, challenge and competition, visual design and aesthetics, experimentation, value of game mechanics, impactful games, open source ideology, and autonomy and artistic freedom. There could have been more of emphasis on the development culture, like collaboration between peers.

8.5 Summary: Quality board game enabling engagement and in-game transfer of knowledge

In this design challenge 3, the guiding development model and the guiding model for learning and describing theories have been developed as design solutions. The guiding development model is a prescription for successful educational game design processes (Sections 8.3). The guiding model for learning is an educational chemistry board game for supporting the learning of protein chemistry in different contexts of daily life and thus a transfer of knowledge, and also for bridging theoretical knowledge to the molecular gastronomic Fluffy meringues hands-on activity (Section 8.4.). Descriptive theories were developed in two areas of research: students’ interest and attitudes towards food and cooking, chemistry and food-related molecular gastronomic chemistry (Section 8.1) and pre-service teachers as game developers (Section 8.2).

In this board game an inquiry-based MG hands-on activity was embedded into a game as an essential part of the game mechanics and winning the game. Embedding a hands-on activity into a card or board game is unique and has not been reported in previous studies concerning the design of educational chemistry card and board games. Its function is similar to chemistry simulations, which are used, for example, if actual practical work is difficult to execute at school (Lunetta & Hofstein, 1991). Like educational games, in hands-on activities collaboration has been noted to be more effective in learning than competition (Okebukola & Ogunniyi, 1984) because it gives students the opportunity to construct knowledge together and form a “classroom community of scientists” (Hofstein & Lunetta, 2003). In this study, students played the game in pairs and based on video data, peer support and collaboration were important.

The Proteins in the Backyard board game is based on the cognitive and the social constructivist learning theories (e.g. Palincsar, 1998; Piaget, 1951/1999; Powell & Kalina, 2009; Vygotsky, 1978), as well as the CHEDU Game Design Tool (Chapter 7). It also follows the current Finnish national core curriculum for basic chemistry education (Finnish National Agency for Education, 2014). Contextual perspectives like students’ everyday life, previous experiences and observations, different life situations mostly at the macroscopic level, as well as ability to make choices, evaluate the reliability and significance of knowledge in different situations, scientific and creative thinking are in focus. And it covers all the possible areas for everyday chemistry contexts (Childs et al., 2015, Figure 11).
The game fully meets the requirements for a quality board game (Table 18), which are listed in the CHEDU Game Design Tool. Only postgame assessment, attitudes as learning objective and increasing difficulty within a game session are missing from the *Proteins in the Backyard* game. Some of these quality educational game elements are considered engaging game elements and based on the video data, these elements appeared during play. The elements of backstory and game characters are typical for digital games, but rare in educational card and board games, and absent in research-based educational card and board games directed at chemistry education (see Chapter 3 and Table 2). Increasing difficulty within the game session is difficult to embed into board game mechanics, whereas in digital games it is a typical engaging element, like game characters and backstory.

The usefulness of the *Proteins in Backyard* game in the students' process of in-game transfer of chemistry knowledge was apparent in the applied case study (Section 8.3.4.5). In these sessions it was observed that direct transfer of chemistry knowledge from context to another was easier for students than transfer of reversed knowledge. The relationship between engaging game elements, in-game emotions and in-game learning were clearly visible in one of the seven excerpts presented in this study concerning in-game transfer of knowledge. This indicates the quality of this game, being in line with given instructions for quality game elements and their meaning in a successful in-game learning process (Warren & Jones, 2017).

In two empirical problem analyses applied to design challenge 3, descriptive theories were developed. In the first empirical problem analysis, a descriptive theory about students' interest toward food, cooking, chemistry and molecular gastronomy was articulated. This case study among students in upper-secondary education supported earlier studies among students at the lower secondary level (Västinsalo et al., 2010) and at the university level (Miles & Bachman, 2009) in establishing molecular gastronomy (MG) as an interesting and relevant context for teaching and learning chemistry. In this study, fudges, cream foam and meringues were found to be particularly popular among the students as topics in the context of MG. New knowledge was revealed about students' cognitive attitudinal responses to the knowledge of chemistry and the knowledge of food and cooking, as well as adolescents’ cooking frequencies and discussions about food, cooking and chemistry at home and with friends.

In the second empirical problem analysis, a descriptive theory about chemistry pre-service teachers' game developing processes was revealed. Similarities and differences in creating and using different elements in game mechanics and game dynamics were found between this case study and previous research (Artym et al., 2016; Sardone & Devlin-Scherer, 2016; Tokmak, 2015).

The need for improvements in embedding game elements in design challenge 3 must be taken into consideration in further research in the field of educational board and card games, and possible further design cycles for this game or other similar games.
9 VALIDITY AND RELIABILITY

In this thesis, three design challenges with their design solutions were executed. In Table 22, the three phases of this design-based research and the data collection and analysis methods used are presented. The validity and reliability of these three phases – design challenges 1, 2 and 3 – are presented in the following sections one challenge at the time.

Table 22. Phases of the design-based research, data collection and analysis methods within, and documenting design challenges.

<table>
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<td>One lesson in the Central areas of chemistry education course in the Unit of Chemistry Teacher Education, University of Helsinki, 2015–2017</td>
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<td>Empirical problem analysis 1</td>
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<td>Testing on chemistry educators</td>
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<td>3rd design cycle</td>
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<tr>
<td>Documenting</td>
<td>E-discussions and feedback from the supervisors 2018</td>
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<td>&lt;the challenge was applied 2018, no other documenting yet&gt;</td>
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According to the quality criteria for design-based research (The Design-Based Research Collective, 2003), validity and reliability of a design-based research can be evaluated by using five perspectives: holisticity, cyclicity, mobility, testing and documenting (see Section 2.2). Clear reporting of the design and explanations using coherent learning theories are suggested for educational game development processes (Warren & Jones, 2017).

Across the study, qualitative approach with qualitative methods for collecting and analysing data were applied. The validity and reliability of these qualitative methods have been evaluated according to criteria for qualitative research in the research method literature (e.g. Cohen et al., 2011; Denscombe 2010; Schofield, 2002), as presented in the next sections. Altogether six separate case studies were executed in this study. Case studies provide an in-depth description about a phenomenon in a specific instance (Cohen, Manion, & Morrison, 2011), possibly supporting trends found in previous studies and giving some new knowledge, ideas and new perspectives for research in the field.

9.1 Design challenge 1: Educational games for learning the periodic table

In design challenge 1, two educational card games, Periodical Domino and Collect a Triplet, were designed to promote the development of lower secondary students’ skills in learning and using information included in the periodic table. The following phases were included in the design process: Empirical problem analysis, 1st design cycle, testing on chemistry teachers, 2nd design cycle and evaluation (Table 22).

From the five given criteria for a quality design-based research, the design solutions in design challenge 1 partially or entirely fulfill the criteria for cyclicity, testing, mobility and documenting, but not sufficiently the criteria for holisticity. To fulfill the criteria for cyclicity, two design cycles were executed for each of the games, which is the minimum, because the first design solution is rarely fully fit for use (Juuti & Lavonen, 2006). The criteria for testing was partially fulfilled, because the games were tested once each with teachers, but not in authentic classroom situations, as they should be tested in design-based research (Juuti & Lavonen, 2006). The game materials were first developed in Finnish and they are known to be in use in several schools in Finland. It is normal for mobility to be first local and later widescale and according to Barb and Squire (2014), it also indicates that a design solution is valid and reliable. Therefore, mobility for these card game materials is apparent in lower secondary education at the national level, but whether they are also valid in upper-secondary education and at international level must be studied in the future. Table 22 shows that design challenge 1 has been documented several times in conferences and in the courses for chemistry teachers and pre-service teachers. Two peer-reviewed articles have been published on it in Finnish (Tuomisto & Aksela, 2007; 2009). In this thesis, game design processes have been described in detail for transparency, though only some examples of
game materials in the first version are included in the thesis. Guiding or descriptive theories were not
developed during the design process, only a prescription of design processes in which the game
mechanics of two classic games were used as bases for developing educational card games for chemistry
education purposes.

9.1.1 Small-scale questionnaires and content analyses

When testing on 8th grade students (n = 38) in the empirical problem analysis, two different small-scale
questionnaires were used for triangulation of data. Only the students with permission from their
parents were allowed to anonymously answer the questionnaire. Validity of the results was good,
because similar answers were collected in both, though the questions in the questionnaires were
different: the first was developed to collect data about relations of concepts in the periodic table in
general, and the second to collect similar data, but from one element’s (Mg) perspective. Based on the
data collection, the first questionnaire was found to be slightly too long, including perhaps too many
questions concerning only atomic structure, not relations to the periodic table. Data in the
questionnaires were analyzed with content analysis, using one answer as a unit of analysis (Cohen et al.,
2011). First, categories based on general themes in the topic field were formed, and then descriptive
subcategories were extracted from the data in each category. In the end, the collected information was
reduced to eight descriptive sentences.

When testing the games on teachers (n = 20), a small-scale questionnaire was used as the data collection
method and content analysis as the analysis method. The questionnaire, with ten open and four closed
questions, was pilot tested with two chemistry teachers to check the clarity of the questions (Cohen et
al., 2011). Mostly word-based data was collected, in which there is always possibility for the researcher
to interpret the information wrongly (Cohen et al., 2011). Three questionnaires were filled in by two
teachers each, and it is possible that only shared opinions, suggestions and feedback had been written
in these questionnaires. For better reliability and triangulation, interviews, for example, should have
been applied in addition to the questionnaire.

Content analysis was built into the questionnaire’s construction, meaning that answers were post-coded
into the same categories as in the questionnaire (Cohen et al., 2011): rules (additions, changes,
removals), cards (new clues, additions, removals, modifications), playing time (minutes, too short,
suitable, too long), difficulty level (too easy, suitable, too challenging) and open feedback. The same
categories were used for both games. It was thus possible to analyze all the information in the
questionnaires. Preliminary coding was not applied, nor checking of validity by using the same coding
system for another sample.
Participating in the workshop and responding to the questionnaire was voluntary and the anonymity of the respondents was guaranteed. They were also informed that only the researcher and the supervisors would be allowed to see and analyze answered questionnaires.

9.1.2 Peer-evaluation

To improve reliability, both games were evaluated using the first version of the CHEDU Game Design Tool (Table 10). Two evaluators, a chemistry teacher and a researcher in chemistry education, independently evaluated the games. For these parallel evaluations Cohen’s kappa (κ) was calculated. It describes an inter-rater reliability by measuring the agreement (%) between two raters. Cohen’s kappa indicated that interrater reliability, meaning consistency between the evaluators, was substantial (Periodical Domino κ = 0.756; Collect a Triplet κ = 0.718). According to the peer-evaluation, the Periodical Domino game and the Collect a Triplet game included multiple quality game elements and fulfilled satisfactorily the criteria for a quality educational chemistry game (see Table 7 and Table 8).

9.2 Design challenge 2: Design and evaluation tool for educational chemistry

In design challenge 2 the CHEDU Game Design Tool was designed in order to support game developers in designing and evaluating quality educational card and board games for chemistry education purposes. The following phases were included into the design process: theoretical problem analysis, 1st design cycle, testing on chemistry pre-service teachers, 2nd design cycle, use in design challenge 3 (Table 22).

Of the five criteria for a quality design-based research, the design solutions in design challenge 2 partially or entirely fulfilled the criteria for cyclicity, testing, holisticity, mobility and documenting. To fulfill the criteria for cyclicity, two design cycles were executed on the tool, which is the minimum, because the first design solution is rarely fully fit for use (Juuti & Lavonen, 2006). The tool’s capacity to guide the educational game design process of chemistry pre-service teachers was tested (Section 7.4), as well as its evaluation of the two educational games designed in design challenge 1 (Section 9.1.2). Holisticity is evident, because both a guiding model and descriptive theory were developed during the design process. In this thesis, the tool design process has described in detail for transparency and thus record a prescription of successful design and evaluation of the tool design process. The tool is mobile, at least at local level in Finland, and it has already been applied successfully three times in this thesis, the first version in Section 7.4 and in Section 9.1.2 and the final version in Chapter 8. Table 22 shows that design challenge 2 has been documented several times in conferences and courses for chemistry teachers and pre-service teachers. One peer-reviewed article has been published on it (Tuomisto, Aksela, & Fooladi, 2014).
9.2.1 Integrative literature review and directed content analysis

The integrative literature review in the theoretical problem analysis of design challenge 2 followed the procedure presented in the study of Koskinen, Kangas and Kroksfors (2014). During the phase of literature search, a total 31 relevant articles were included in the integrative literature review and in the phase of data synthesis, 31 categories for describing central concepts in the fields of quality games and educational games were formed. During the literature search phase, more advanced ways to filter the large number of returns could have been used: for example, using the reference list in the latest articles as guidelines for finding other relevant articles.

Directed content analysis was applied to the data. It typically is included in the literature review to both clarify and condense the data, improving its informational value and supporting or even extending existing theory (Hsieh & Shannon, 2005; Tuomi & Sarajärvi, 2006). In directed content analysis, the theoretical framework together with relevant previous research serve as a basis for initial coding (Hsieh & Shannon, 2005). Peer coding was not implemented, but for transparency, the results of coding are documented in this thesis (Appendix 1).

9.2.2 Game design diaries and content analysis

The testing of the first version of the tool on chemistry pre-service teachers in design challenge 2 was designed to be a qualitative case study because of the exploratory nature of the study and the small number of pre-service teachers involved (n = 25). Therefore, the study suffers from the limitation of generalizability. To improve the validity of the study, a strong focus was placed on the thick and clear description of the method and results (Schofield, 2002). All the students were informed about the data gathering at the beginning of the course and participation in the case study was voluntary. For the research data, all the students were anonymous and only game diary-based codes were used.

The data in game design diaries were analysed by using content analysis. Coding was applied using analytical coding, in which codes were derived from the theme and theoretical background (Cohen et al, 2011), meaning that the subclasses in the first version of the CHEDU Game Design Tool (Table 2) were used as pre-existing codes and the classes were used for code categorization. The last part of the game tool, Self-evaluation for flow-state, was excluded from the teaching session and the study, because the games developed here were not played or was played only partly, and therefore evaluating players’ flow state would have been either insufficient or impossible.
By using the subclasses of the tool it was thus possible to code the data consistently (Cohen et al., 2011) and only one new code, *game type*, was generated. The fact that the game design diaries were written precisely for the purposes of this study improved reliability, although there may have been ambiguous words in the diaries that created misunderstandings for the researcher (Cohen et al., 2011). Also, coding may have lost some of the richness of the contents of the game diaries. The problem of category overlap was apparent in the tool, creating the same problem in parallel peer coding. In retrospect, parallel interviews would supposedly have increased validity.

The parallel peer coding for the data was implemented as triangulation. To enhance the reliability of the results, after pilot coding, the researchers discussed the disagreements in coding. Cohen’s kappa for cohesion about the actual coding data was 0.79, meaning substantial consistency (Landis & Koch, 1977).

9.2.3 Peer-evaluation

To improve reliability and test the usability of the CHEDU Game design Tool as an evaluation tool, the first version of the CHEDU Game Design Tool (Table 18) was used in the game quality evaluation process described in detail in Section 6.5. For the parallel evaluations of two card games, Cohen’s kappa (κ) was calculated. Cohen’s kappa indicated interrater reliability, meaning consistency between the evaluators, as substantial (*Periodical Domino* κ = 0.756; *Collect a Triplet* κ = 0.718).

9.3 Design challenge 3: An educational game about chemistry in cooking and daily life contexts

In design challenge 3, a board game for learning chemistry both in food and cooking context and in other familiar daily life contexts aimed to help students to learn protein chemistry in order to enhance transfer of knowledge between theory, daily life and hands-on activity. The following phases were included in the design process: empirical problem analysis 1, empirical problem analysis 2, first design cycle, testing on chemistry educators, second design cycle, testing on 9th grade students and third design cycle (Table 22).

Of the five criteria for quality design-based research, the design solutions in design challenge 3 partially or entirely fulfill the criteria for cyclicity, testing, holisticity and mobility, but documenting weakly (see Table 22). Three iterative design cycles were executed, in which both teacher educators and students were operating as testers. This means improvement in the design solutions’ validity and usability, as well as validity and reliability in testing (The Design-Based Research Collective, 2003). Holisticity is evident, because both a guiding model, and guiding and descriptive theories were developed during the
design process. In this thesis, the phases of game development are described in detail for transparency and to generate a prescription for successful game design process. The game is mobile, at least at local level in Finland, but further research regarding wider use must be conducted. Table 22 shows that design challenge 3 was conducted in the beginning of 2018, and therefore it is publicly documented only in this thesis. More documenting, for example peer-review articles, needs to be published.

9.3.1 Small-scale e-questionnaire and content analysis

The first empirical problem analysis of design challenge 3 (Section 7.1) was applied on a small scale, because the sample was known to be small, only two separate groups of students in a special course. Therefore this study was considered a case study, ergo mostly giving an in-depth description about the phenomena in a specific instance (Cohen, Manion, & Morrison, 2011), possibly supporting trends found in previous studies and providing some new knowledge, ideas and new perspectives for research in the field.

In the small-scale e-questionnaire, straightforward and clear information, like facts and opinions, was collected (Denscombe, 2010). Rating scales, namely Likert scales, were included in the questionnaire because of their unidimensionality, as well as the sensitivity and differentiation of response they offered to given questions and statements (Cohen et al., 2011). The statements and questions consisted of short and simple sentences in clear language (Salta & Tsougraki, 2004). "I don’t know" was added as one choice in the answers for better validity (Coll, Dagely, & Salter, 2002). The three problems with Likert scales were addressed (Salta & Tzougraki, 2004). Fakability was minimized by the anonymity of participants and by using non-normative questions in the questionnaire. The items within each scale were related only to a single attitude or the object of interest, which reduced criterion inadequacy.

The content and clarity of the research instrument were first constructed and discussed with an expert in chemistry and home economics education, and then the first version of the questionnaire was tested with a group of three experts in the area of chemistry education (Coll et al., 2002; Munby, 1997). Based on the test, some small revisions for clarity of the questionnaire were made.

The e-questionnaire was delivered via a link, which the teacher gave in the final session to all those students who participated in the research. Because the participating students were underage persons, permission to collect research data was requested beforehand from both the Educational and Cultural Services of the city and the students’ parents. Only the students who received permission were allowed to participate. All answers were collected anonymously over a period of one week after the last course session. In the first case, only 8/14 students who had received permission filled in the questionnaire.
This perhaps was due to the placement of the questionnaire at the end of the period and the whole school year. In the second case, all the students with permission filled in the questionnaire.

9.3.2 Game design diaries and content analysis

The second empirical problem analysis in design challenge 3 was part of a case study, which was executed during the testing of the CHEDU Game Design Tool on chemistry pre-service teachers in design challenge 2. Therefore the problem analysis shares the same validity and reliability evaluation with the testing, which has been described in detail in Section 9.2.2.

9.3.3 Video recording, observation, small-scale questionnaire and conversation analysis

In the second testing of the game, a multi-method approach was applied, which is recommended particularly for research in the social sciences (Cohen et al., 2011). In the testing on 9th grade students, six students were video recorded while gaming. Before data collection, official permission was requested from the underage students, the head of the school and the head of education in the city. According to Warren and Jones (2017), "Your player-learner comes to no harm should be the first concern" (p. 56). Especially in the case of video recording, ethical issues must be considered very carefully (Derry et al., 2010). These six students had received their parents’ permission to participate in video recording. The other three gaming groups were not recorded. In the permission document the purpose of the study was described and three different permissions were requested (video recording, audio recording, filling the questionnaire). They were also told that the students’ anonymity would be protected, the video data was for research use only and only the researcher and the supervisors would be allowed to see it. This video data will be stored only in one memory stick for the next 5 years.

One stationary camera was used and the perspective on the video screen was mid-way between with-people and without-people perspectives (Hall, 2000), so it focused both on the game board, players' hands, actions, and interactions concerning in-game situations. A problem of selection was faced (Derry et al., 2010), because it would have been preferable to record in without-people perspective, but during the pilot testing with chemistry teacher educators it was noticed that essential data and nonverbal information would be missed.

It is said that good research literature-based orienting questions prevent a researcher from getting lost in the details of video data (Derry et al., 2010), and collecting this testing data was directly based on one of the research questions of this study. In analysing the data, the analysis problem was addressed in choosing the most suitable analysis method between discourse and conversation analysis (Derry et al.,
Conversation analysis was chosen because it focuses on language in action and interaction, whereas discourse analysis focuses on language as action orientation (Cohen et al., 2011; Denscombe, 2010; Wooffitt, 2011). Technological problems were also faced during data analysis. Because only one microphone was used, in some parts of the video data it was impossible to hear what the students were saying.

Unstructured and shared observation was applied together with the teacher and researcher for triangulation and to improve the validity of video data and the results derived from it. A questionnaire was also used, but only six of the students had received permission to fill it in. Content analysis was built into the questionnaire’s construction, meaning that answers were post-coded into the same categories as in the questionnaire (Cohen et al., 2011): sex, age, like gaming, types of games usually played, favorite game, learned something new about chemistry or everyday life while gaming (if yes, what), pros of the game, cons of the game. Preliminary coding was not applied, nor was validity checked by using the same coding system for another sample.

This testing was a case study, giving deep and descriptive data about verbal and nonverbal action during play. Generalization is a key issue in social and educational research, and while this case was unique, it is also one example of a broader class of its type (Denscombe, 2010). The collected video data is not unusual, but can likely be repeated whenever this game is played by Finnish 9th grade students. Of course, it depends on what students have studied before the gaming. As in every case study, some responsibility falls on the person reading the results and conclusions, but the reader must be provided with the necessary information (Denscombe, 2010).

Because of a lack of time, the game was not played to the end. Therefore it was impossible to observe or demonstrate the possible in-game linkages or bridging between the game content, contexts and the World’s best meringues hands-on activity. Therefore, all the events and playing turns during the possible game session were not documented and it is impossible to say, if there would have appeared data to give supportive or dissimilar results as the data presented in this case study.
10 DISCUSSION AND CONCLUSIONS

In this chapter, the discussion and conclusion are made for the whole study. In the first three sections, the results are discussed one research question (RQ) at the time. In Section 10.4, the significance of this study is discussed, and future research possibilities in this area are considered in Section 10.5.

The main research problem in this design-based research was: how do we support the design and evaluation of educational chemistry card and board games and in-game learning using them? Three research aims and three research questions (RQ1–RQ3) were derived from the research problem.

For the answer to the main research problem, quality game elements for chemistry card and board games were revealed and based on them, different design solutions were developed in the field of educational games research and chemistry education. Periodical Domino and Collect a Triplet card games, Proteins in the Backyard board game and the CHEDU Game Design Tool are the four guiding development models created, and in their design processes, descriptive and guiding theories, as well as prescriptions for successful design processes were developed.

The results of this thesis provided a new theory about quality educational card and board games by revealing elements that play an important role in giving quality to non-digital educational games, particularly those used in chemistry education. Simultaneously, the need to develop tools to systematically assess the quality of educational games was answered. A theory about using educational game design as a part of chemistry teacher education was developed, which supported previous studies and also provided new information about the quality game elements in games designed by pre-service teachers. Also, a new theory about developing educational games to support chemistry learning and about in-game chemistry learning, particularly engagement and in-game transfer of knowledge, was developed.

10.1 Research question 1

The first research question (RQ 1) was: what kind of game design and evaluation tool for educational card and board games supports both teaching and learning in chemistry education? Based on RQ1, a design decision was made to develop a practical and high-quality tool for designing and evaluating educational card and board games for chemistry education. As a result, the CHEDU Game Design Tool was designed and guiding theory about educational games was developed.

In the design process of the CHEDU Game Design Tool (Chapter 7), background theory about games, especially digital games, and to some extent about educational card and board games, was gathered in order to find out the game elements that are important and necessary in engaging and motivating
players (Section 7.1). The tool was developed based on these features, cognitive and social constructive learning theories (e.g. Piaget 1951/1999; Powell & Kalina, 2009; Vygotsky, 1978), and the current Finnish national core curriculum for basic chemistry education (Finnish National Agency for Education, 2014). The literature review by Wu et al. (2012) revealed that playing educational games tended to provoke positive learning outcomes if learning theories were used as the basis of game design. Additionally, Warren and Jones (2017) have suggested that learning with an educational game should be connected to a definition that explains how learning principles are tied to playing that game.

Comparing important game elements with cognitive and social constructivist perspectives of learning (e.g. Eilks et al., 2013; Piaget, 1959/1999; Powell & Kalina, 2009; Vygotsky 1978), and the content of the Finnish national core curricula for basic education (Finnish National Agency for Education, 2014), similarities can be found: for example, sociality, feedback, guidance and support, daily life connections or contexts, evaluation and assessment, and problem solving all belong both to quality game elements and to the subject curriculum of chemistry for 7th–9th graders. Also, game elements, such as providing players with adaptive challenges, immediate feedback, curiosity, variable rewards or low-stake failures can be linked directly to 21st century skills, but also to a concept of flow (Qian & Clark, 2016).

These connections support previous research about the effectiveness of well-designed educational games as teaching tools. In the CHEDU Game Design Tool (Chapter 7), all three aspects mentioned above are combined into a simple and explicit framework for expanding the existing culture of quality game assessment within the educational game band (Dondi & Moretti, 2007). The CHEDU Game Design Tool consists of research-based quality educational game elements, working as a guiding model, and promotes new guiding theory precisely in the field of educational card and board games. In this thesis, the tool was tested three times and its ability to support both evaluation of ready-made educational card and board games and educational game design processes was evaluated to be good.

Only a few research articles have considered educational games from the perspective of pre-service teachers as game developers. In the testing phase of the first version (Section 7.4), chemistry pre-service teachers applied the CHEDU Game Design tool in order to design educational games related to food and cooking or environment themselves. As a result, ideas concerning game mechanics and dynamics in card and board games were revealed and classified according to the tool’s subclasses. Similarities in the quality game elements included in pre-service teachers’ games can be seen between this and previous studies. Embedding multiple difficulty levels and in-game assessment into educational board (or digital) games seem to be attainable for pre-service teachers, but they have difficulties with adding pregame or postgame assessment into the games (Sardone & Devlin-Scherer, 2016; Tokmak, 2015). This result indicates that this design tool might be useful in teacher education, for example in Finland, where autonomous teachers are educated achieving the skills to explore and make own decisions about versatile and useful teaching methods (Sardone & Devlin-Schere, 2016; Tryggvason, 2009). However,
more research is needed concerning this tool’s usability in other school subjects than chemistry and at different levels of education.

10.2 Research question 2

The second research question (RQ 2) was: which features of an educational game may support the development of lower secondary students’ skills in learning and using information included in the periodic table? Based on RQ 2, a design decision was made to design two educational card games to promote the development of lower secondary students’ skills in learning and using information included in the periodic table, and to construct their own models of the periodic table.

*Periodical Domino* and *Collect a Triplet* (Chapter 6) are examples of concept-driven educational games and their design process was based on general research literature about games and educational games, which was thinner than the theoretical framework about games and educational games presented in Chapter 3 and in the CHEDU Game Design Tool. The aim for these educational games was based on the empirical problem analysis concerning 8th grade students’ lack of understanding of the information in the periodic table and related concepts (Section 6.1). Of the previously developed educational games on this topic, only a few shared the idea of promoting the periodic table using skills in relating elements’ properties to their locations in the table (e.g. Bayir, 2014).

Argumentation and construct-your-own-model were taken as two guiding features for the game design process, because argumentation was absent in the previously developed games. Even though in the *Groupica* game (Bayir, 2014) students practiced their use skills, it only asked for elements by name. In the *Periodical Domino* and *Collect a Triplet* games, students have to explain to other players, with the help of the periodic table, why they are playing a specific card. Other players accept or reject the explanation. The games thus follow the social constructivist idea of whole group learning, a meaningful learning, in which knowledge is constructed together for understanding the whole, not just remembering individual facts (Eilks et al., 2013; Lujan & DiCarlo, 2006; Powell & Kalina, 2009). This makes thinking visible. It is not necessary to remember the information in the periodic table, but learn to use it. Naturally, in-game support and feedback from the teacher is needed, but it has already been shown to be included among the features of quality educational games (see Table 18).

According to previous research, teachers should use several different models in teaching to describe the same phenomenon (Gilbert et al., 2000a; Harrison, 2000; Saari, 2000, Saari & Viiri, 2003). But it is also important to let the students build their own models, which makes learning interesting and student-centred (Saari & Viiri, 2003). According to Warren & Jones (2017), students’ in-game interactions should allow exploration of models for learning to happen. In the games developed here, independent facts
about embedded information in the periodic table are presented in the playing cards. While gaming, students independently and together construct a model of the periodic table, linear in *Periodical Domino* and series of three in *Collect a Triplet*. The first version of the CHEDU Game Design Tool was used in quality evaluation of *Periodical Domino* and *Collect a Triplet*. Both evaluators filled in an evaluation tool for each game evaluated. The evaluators circled those quality elements that they evaluated to be present in the game. Cohen’s kappa (Table 6) indicated substantial agreement among the raters, which indicates that the CHEDU Game Design Tool is possibly useful in evaluating ready-made games.

Even though *Periodical Domino* and *Collect a Triplet* card games were research-based and based on theoretical framework developed to support learning, they have not yet been tested with students. Therefore it was not possible to present evidence about their actual ability to support lower secondary students’ learning and using skills of the periodic table in this study.

### 10.3 Research question 3

The third research question (RQ 3) was: how does an educational game in food and cooking context help students with development and transfer of knowledge between theory, everyday life contexts and hands-on activity? Based on RQ 3, two design decisions were made: (1) to design research-based educational games for chemistry education in order to support both learning of central chemistry concepts and use of this knowledge and skills, and (2) to achieve understanding of relationship between educational games and students’ concept development and transfer of knowledge in context-based learning.

First, the *Proteins in the Backyard* board game was designed (Chapter 8). This game is an example both of a context-base-driven educational game and of a board game that has an inquiry-based hands-on activity embedded in its game mechanics. In the design process, the CHEDU Game Design Tool was used as a base. The game was designed to support lower secondary students both in learning protein chemistry and in enhancing transfer of knowledge in daily life contexts.

*Periodical Domino* and *Collect a Triplet* (Chapter 6) were designed without the use of the CHEDU Game Design Tool. Comparing the quality game elements in *Proteins in the Backyard* with these two (see Tables 18, 7 and 8), the positive effect of the CHEDU Game Design Tool for the educational game design process can clearly be seen. This game laudably fulfills the criteria for quality educational games, whereas the other two only do so satisfactorily. Only postgame assessment, attitudes as learning objective and increasing difficulty within a game session are missing from the *Proteins in the Backyard* game. Some of these quality educational game elements are called engaging game elements, which appeared in the video data during play. The elements of backstory and game characters in particular are
typical for digital games, whereas they are rare in educational card and board games, and absent in research-based educational card and board games directed to chemistry education (see Chapter 3 and Table 2). Increasing difficulty within the game session is difficult to embed into board game mechanics, whereas in digital games it is an engaging element, like game characters and backstory.

In *Proteins in the Backyard*, different daily life contexts are used to make transfer of knowledge of protein chemistry possible for the player-learners (Gilbert, 2006). Molecular gastronomy (MG) has already shown potential to be an interesting and relevant context for teaching and learning chemistry (e.g. Mata, 2013; Miles & Bachman, 2009; Västinsalo et al., 2010) and according to this research adolescents are especially interested in the chemistry of fudges, cream foam and meringues. Because molecular gastronomy is about cooking and baking, the idea of the *Fluffy Meringues* hands-on activity (Vilhunen et al., 2013) was embedded into the game as an essential part of its mechanics and dynamics. Embedding a hands-on activity into a card or board game is unique and has not been reported in previous studies concerning the design of educational chemistry card and board games. It is similar to chemistry simulations, which are used, for example, if actual practical work is difficult to execute in school (Lunetta & Hofstein, 1991). Like educational games, in hands-on activities collaboration is more effective in learning than competition (Okebukola & Ogunniyi, 1984) as it gives students the opportunity to construct knowledge together and form a “classroom community of scientists” (Hofstein & Lunetta, 2003). In this study, students played the game in pairs and the video data showed the importance of peer support and collaboration.

Secondly, the game was tested on 9th grade students in an authentic classroom situation. The usefulness of *Protein in Backyard* game in the students’ process of in-game transfer of chemistry knowledge was apparent in the applied case study (Section 8.3.4.5). These sessions showed that direct transfer of chemistry knowledge from context to another was easier for students than transfer of reversed knowledge. The relations between engaging game elements, in-game emotions and in-game learning were clearly visible in each of the seven excerpts presented in this study concerning in-game transfer of knowledge. This indicates the quality of this game, being in line with the given instructions for quality game elements and their meaning in successful in-game learning processes (Warren & Jones, 2017). Considering the content and playability of *Proteins in the Backyard* board in the context of transformational play (Barab et al., 2010), person, content and context are interconnected in this game. More precisely, a player is positioned as a first-person game character in the storyline and chemistry contents are bound to in-game challenges in different in-game contexts. The only difference between transformational play in digital games and in this board game is that in this game the in-game context does not change depending on the players’ decisions within the context.
In this case study, transfer of knowledge was apparent in gaming. Chee (2015) describes games with meaning-making and contextualization activities as games-to-learn, instead of content and right-answer focused games-to-teach.

The current results support the results of prior research. Educational games have the power to enhance the interplay between students and enable the construction of meaningful knowledge together (e.g. Franco-Mariscal, Oliva-Martínez, Blanco-López, & España-Ramos, 2016; Ke, 2008; Lujan & DiCarlo, 2006), and gaming with questions and feedback is significantly more effective than mere gaming or conventional instructions (Cameron & Dwyer, 2005). According to Warren and Jones (2017), in educational games, there should be a link between in-game activities and learning, otherwise a mere entertainment game has been designed. Additionally, the existence of engaging game elements were clear in gaming session (Section 8.3.4.5), which indicates a quality game. Educational games possess the potential to make learning enjoyable and fun, yet effective (e.g. Akkuzu & Uyulga, 2016; Bayir, 2014).

In this study the focus in learning was particularly on in-game transfer of knowledge. Therefore, links between observed engaging game elements and learning, as well as the quality of transfer of knowledge, were not studied.

10.4 Significance of the research

Theoretical bases for developing research-based quality educational chemistry games were presented in this study in particular, with design decisions concerning both game mechanics, game dynamics and game material described so that how they are designed to support in-game learning can be clearly seen. This transparency is unique, as well as the concept of embedding a hands-on activity into the board game, at least in comparison with previous research in the field. According to this study, when using quality educational games, in-game engagement and learning is possible at least via in-game transfer of knowledge in daily life contexts. This kind of research concerning in-game learning and in-game engagement has not been reported in the previous studies of educational games in chemistry education. Because of the qualitative nature of this design-based research, these results are not directly generalizable, only directional.

The main value of this research lies in these four research-based artefacts, three games and a game design tool, which can directly be used in chemistry education, at least at the lower secondary level. The Periodical Domino and Collect a Triplet card games, with their argumentation and build-your-own-model features, offer a novel research-based perspective for card and board games in the topic of the periodic table.
The *Proteins in the Backyard* board game is unique in its multifaceted game elements: narrative, game characters, daily life connections, engaging elements and argumentation. It also gamifies a molecular gastronomic hands-on activity. It is more like digital educational games than typical educational board games. Additionally, it is aesthetic, meaning all the game material form a coherent, visual unity. It also has been showed to promote in-game transfer of knowledge, but also other non-chemistry daily life connections.

The CHEDU Game Design Tool is the first tool designed specifically for card and board games, and especially for chemistry education purposes. In this study, its capability both as a design and an evaluation tool has been shown. The tool expands the theories of educational games and answers the need to develop relevant tools for evaluating educational games (Li & Tsai, 2013).

### 10.5 Future research possibilities

The CHEDU Game Design Tool consists of classes, of which the majority are about games, card and board games, some about pedagogy and one in particular about the Finnish chemistry curriculum for basic education (Finnish National Agency for Education, 2014). Thus, possibly with minor modifications, this tool is transferable from the context of lower secondary chemistry education to upper secondary chemistry education or from the chemistry context to other school subjects or contexts in different countries. Similar steps or principles as those in the prescription of the successful design and evaluation tool design process that produced the CHEDU Game Design Tool can be followed in a tool design process for other educational development purposes, but all these are research possibilities in the future.

According to Ke (2009,) there is a little research about the effects of educational games as a part of teacher education. In this study the CHEDU Game Design Tool was used in the case study of chemistry pre-service teachers’ game design processes, but more research on its usefulness in teacher education is needed. Ke (2009) has also mentioned that current research concerning game structure is focused on studies between similar kind of elements. Perhaps elements in the CHEDU Game Design Tool could offer something new and different in this research area.

The game materials of *Periodical Domino* and *Collect a Triplet* can be modified and expanded. Playing cards can be removed or added, the clues in the cards can be modified to be easier, more challenging, or the area of topics can be expanded to include different bond types or other related topics. These games have not yet been tested with students and they should undergo further design work to better fulfill the criteria for quality educational card game. Their capability to perform as formative assessment tools could be researched in the future.
The game material of *Proteins in the Backyard* can be modified and expanded (The Design-Based Research Collective, 2003). Playing cards can be removed, added or modified, the game board can be modified, and, for example, the chemistry of fats and carbohydrates can be added into the game. However, the cohesion between the backstory and game materials in the current game might then be slightly disturbed. The results of this study indicated existence of in-game learning and transfer of knowledge, but the game’s capability to bridge theory to hands-on activity was not clarified. Therefore, this game’s possibilities in promoting and enhancing the learning of chemistry, transfer of knowledge and capability to bridge theory to hands-on activity require much further research. According to Hofstein and Lunetta (2003) it is probable that learning resulting from simulation differs from learning that results from well-designed inquiry-based hands-on activities. Whether learning is the same when it is the result of an actual hands-on activity or a hands-on activity embedded into the game could be researched. The in-game mission cards could first be classified according to Bloom’s taxonomy (see Artym et al., 2016; Sardone & Devlin-Schere, 2016) and then studied as to whether there is any difference in transfer of knowledge in the in-game missions that challenge students’ higher-order thinking skills (consistent with Bloom’s taxonomy), compared to the missions supporting only lower-order thinking skills.
REFERENCES


<table>
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<th><strong>RESEARCH ARTICLE (n = 31)</strong></th>
<th><strong>DISCIPLINE</strong></th>
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<td>Amadeo, 2010</td>
<td>digital game evaluation tool</td>
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<td>Barah, Scott, Siyamahan, Goldstein, Ingram-Goble, Zuker, &amp; Warren, 2009</td>
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## PERIODICAL DOMINO

### GENERAL INFO
- **Game developer**: Majju Tuomisto (2015)
- **Game material**: 28 cards and 2–4 long periodic tables
- **Grades**: 8th–, for lower secondary education and upper secondary education
- **Learning objective**: The players are developing their skills in periodic table and in argumentation.
- **Game objective**: In *Periodical Domino* card game, the aim for the players is to set in turn periodic table-related cards on table in a way, that cards are forming interrelations between each other. Every card set on the table must be explained and argued by the player in turn with the help of the periodic table and approved by the other players. The winner will be the player, who has least cards left in the end.

### PLAYERS
- **Players**: 2–4 players or 2–4 player couples
- **Playing time**: 20–30 min

### GAME RULES

#### Before
- The cards are shuffled and three cards are dealt each of the players.
- The players place the cards on the table front of them and face up.
- The rest of the cards are placed face down as a deck on the table.
- The first card in play is drawn from the card deck and set on the table.

#### Beginning
- The player on the left side of the card dealer starts the game. The first player sets one card on the table to match with one of the clues in the first card on the table. At the same time, the player owns a duty to explain and reason to the other players, with the help of the long periodic table, why this card is the right choice. The other players accept or reject the reasoning. The clue in the accepted card will be set against the clue on the table.
- After that, the player draws one card from the card deck. This will be done as well, if the player can not set a card on the table.
- Turn changes. The players take turns clockwise.

#### Play
- After the beginning, the player in turn follows next rules:
  - The player tries to continue the card line on the table with a card which matches one of the clues on the heads of the card line on the table. The player owns a duty to explain and reason to the other players, with the help of the long periodic table, why this card is the right choice. The other players accept or reject the reasoning. The clue in the accepted card will be set against the clue on the table.
  - If the player has no suitable cards, then one card will be picked up from the deck and the turn changes. The player picks one card from the deck. This will be done as well, if the player could not set a card on the table. Turn changes.
  - If the card deck has run out, then only the turn changes.

#### Example

<table>
<thead>
<tr>
<th>Second player’s card</th>
<th>First card on the table</th>
<th>First player’s card</th>
</tr>
</thead>
</table>

### Ending and winning

The game ends

1. When one of the players manages to set his/her last card on the table. The winner of the game is the player, who first set his/her last card in the tile line on the table.
2. When the card deck runs out, the game continues, until none of the players can set a card on the table. The winner is the one with the smallest number of cards in hand.
<table>
<thead>
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<th>Group</th>
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<td>Li</td>
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<td>1</td>
<td>odd</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>Mg</td>
<td>2</td>
<td>1</td>
<td>even</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>Ne</td>
<td>2</td>
<td>1</td>
<td>odd</td>
<td>noble gas</td>
<td>gas</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>1</td>
<td>even</td>
<td>noble gas</td>
<td>gas</td>
</tr>
<tr>
<td>He</td>
<td>1</td>
<td>1</td>
<td>even</td>
<td>noble gas</td>
<td>gas</td>
</tr>
<tr>
<td>Al</td>
<td>3</td>
<td>1</td>
<td>odd</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>S</td>
<td>3</td>
<td>1</td>
<td>even</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
<td>1</td>
<td>even</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
<td>odd</td>
<td>non-metal</td>
<td>metal</td>
</tr>
<tr>
<td>Na</td>
<td>1</td>
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<td>even</td>
<td>non-metal</td>
<td>nonmetal</td>
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<tr>
<td>K</td>
<td>1</td>
<td>1</td>
<td>even</td>
<td>non-metal</td>
<td>nonmetal</td>
</tr>
</tbody>
</table>

**Properties of Sodium (Na):**
- Reacts similarly to iodine (I)
- One more electron and this element will be like a noble gas in its electron structure
- Similar properties with selenium (Se)
- Highly reactive nonmetal
### Appendix 3. Collect a Triplet card game material

#### COLLECT A TRIPLET

<table>
<thead>
<tr>
<th>GENERAL INFO</th>
<th>GUIDEINES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Game developer</strong></td>
<td>Maju Tuomisto (2015)</td>
</tr>
<tr>
<td><strong>Game material</strong></td>
<td>48 cards and 2–4 long periodic tables</td>
</tr>
<tr>
<td><strong>Grades</strong></td>
<td>8th–, for lower secondary education and upper secondary education</td>
</tr>
<tr>
<td><strong>Learning objective</strong></td>
<td>The players are developing their skills in using the periodic table and in argumenting.</td>
</tr>
<tr>
<td><strong>Game objective</strong></td>
<td>In Collect a Triplet card game, the aim for the players is to set in turn periodic table-related cards on the table in a way, that the cards are forming interrelations between each other, and this way to collect as many card triplets as possible. Every card set on the table must be explained and argued by the player in turn and with the help of the periodic table. The winner will be the player, who in the end owns most card triplets and least cards in hand.</td>
</tr>
<tr>
<td><strong>Players</strong></td>
<td>2–4 players or 2–4 player couples</td>
</tr>
<tr>
<td><strong>Playing time</strong></td>
<td>30 min–</td>
</tr>
</tbody>
</table>

#### GAME RULES

##### REGULAR VERSION

| Before | • The cards are shuffled and three cards are dealt for each of the players.  
• The players are keeping cards in hand and they are not shown to the other players.  
• The rest of the cards are placed face down as a deck on the table. |
| Beginning | • The player to the left of the dealer starts the game.  
• The first player sets one of the cards in their hand on the game table to start a first triplet on the table: only a card with a name or a chemical symbol is allowed. There can be a maximum three forming triplets (= 3 cards set) on the table at the same time.  
• After that, the player pick up one card from the deck. This will be done as well, if the player could not set a card on the table.  
• Turn changes. The turn moves on clockwise. |
| Play | • After the beginning, the player in turn is follows next rules when setting a card on the table:  
  - First card in a triplet can only be the card with either element's name or chemical symbol.  
  - Second card in a triplet must be related to the first card, and this relation the player must explain and argue to the other players with the help of the periodic table. The other players either accept or reject the reasoning. The accepted card will be set beside the first card in the triplet. Otherwise the player fails, takes the card back into the hand, and picks an extra card.  
  - Third card in a triplet must be related to both two previous cards in the same triplet. This relation between a new card and the other two cards the player must explain and argue to the other players with the help of the periodic table. The other players either accept or reject the reasoning. If a player successfully adds the third card into the triplet, the triplet is ready, removed from the table and the player gains a point. The player picks one card from the deck. This will be done as well, if the player is not able set a card on the table.  
• Turn changes. If card deck has run out, then only turn changes. |
| Ending and winning | • The game ends when the card deck runs out and none of the cards in hand fit on the table.  
The player with the highest score is the winner: the number of collected triplets minus cards in hand.  
• The winner of the game is the player with the highest score: the number of collected triplets minus cards in hand. |
| Different ways to play | EASY VERSION 1: Instead of cards in hand, all the players set their card on the front of them, so that the cards are visible to the other players.  
EASY VERSION 2: The second card in the triplet is set on the top of the first card. This way the third card in the triplet must be related only to the uppermost second card. |
Li

**The Outer Energy Level**

**Period 2**

**Sodium**

an extremely reactive metal

**Magnesium**

a similar kind of element with barium (Ba)

**Group 2**
Ca

the outer electron energy level

period 4 or period 5

B

GROUP 13

The 2nd electron energy level is not full.

aluminum

THE OUTER ELECTRON ENERGY LEVEL

A METAL IN GROUP 13
CARBON  

group  

14  

Si  

semi-metal  

3  

three electron energy levels  

nitrogen  

Group  

15  

two electron energy levels in an atom
**P**

an uneven number of electrons in an atom

---

**OXYGEN**

a nonmetal in group 2

---

**S**

reacts similarly to selenium

(Se)

---

THE OUTER ELECTRON ENERGY LEVEL

---

even number of electrons in an atom
**F**  
a highly reactive nonmetal  
an atomic number below  
10

**Jodine**  
the outer electron energy level  
more than  
10

**Helium**  
group 18  
a very passive element
<table>
<thead>
<tr>
<th><strong>Ar</strong></th>
<th><strong>Be</strong></th>
<th><strong>Selenium</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>AN ELECTRON OCTET IN THE OUTER ELECTRON ENERGY LEVEL</td>
<td><strong>forms ionic compounds with fluorine (F)</strong></td>
<td><strong>forms an ion 2-</strong></td>
</tr>
<tr>
<td>as many electron energy levels as in chlorium atom (Cl)</td>
<td><strong>donates one or two electrons while reacting</strong></td>
<td><strong>forms molecular compounds</strong></td>
</tr>
</tbody>
</table>
## PROTEINS IN THE BACKYARD

### GENERAL INFO

<table>
<thead>
<tr>
<th>Game developer</th>
<th>Maiju Tuomisto (2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Game material</td>
<td>Game board, dice, 36 playing cards, 36 chips, 3 tokens, 3 game character cards, clue booklet and guidelines</td>
</tr>
</tbody>
</table>
| Supplementary material (essential for gaming) | • smartphone, tablet or computer with internet access  
• textbook (and notebook)  
• 3 post-it notes and pencils |
| Foreknowledge    | Players should have basic knowledge about proteins and denaturation, preferably players have also done an experiment about denaturation before playing. |
| Learning objective | Players apply and broaden their knowledge about proteins in situations that happen in everyday life, especially when baking meringues. |
| Game objective  | In the Proteins in the Backyard board game, players collect the ingredients needed to prepare "World’s best meringues" by answering different missions that the backyard of this board game offers. Once a player has collected all the ingredients, first he/she rushes to the school and Home Economics classroom to bake meringues with the recipe they’re given, and then reveals the chemistry behind the successful meringues. The winner is the player or team (one character can have two players) that first succeeds at collecting all the ingredients in their recipe and going to Home Economics classroom on the board and to write the things that make the proteins denature in their recipe on a post-it note. Those things are making the winning meringues best in the world. |
| Players         | 2–3 players or 2–3 teams |
| Playing time    | 30–45 min |
| Difficulty levels | Short game: players collect three ingredients for meringues.  
Long game: players collect four ingredients for meringues. |

### BACKGROUND STORY (To be read out loud before starting the game)

You are three classmates: **Indigo, Sofia and Taylor**, who live along the same street. The backyard and neighbourhood consist of three homes, a school, a meadow, Sam’s Sugar Bakery, Corner Shop and a neighbour with his cat.

Your Home Economics and Chemistry teachers have arranged a contest for 9th graders in which the world’s best meringue recipe is sought. Meringues will be baked with the winning recipe for next years Spring party. The winner will also get a reward for the knowledge about chemistry involved in baking meringues.

Everyone of you have found a recipe for the best meringues in the world that you can not reveal for others. Now you have to get all the ingredients you need from the backyard and neighbourhood. Then all you have to do is to go to home economics classroom to bake the meringues and to write down on a post it what things in your recipe make the proteins denature.

Backyard and neighbourhood offer questions and challenges in which you have to remember, apply, seek and estimate different knowledge about proteins. The reward for your effort is money or supplies for baking the meringues. Surprising twists and turns are part of the game. Every game character has their own little secret that might help them as the game progresses.
<table>
<thead>
<tr>
<th>GAME RULES</th>
</tr>
</thead>
</table>
| **Before playing** | - Set the game board on the table. Divide the playing cards into six piles according to their names: SCHOOL (8), CORNER SHOP (5), SAM'S SUGAR BAKERY (5), HOME (8), NEIGHBOUR AND A CAT (5) and MEADOW (5). The piles are set next to the game board backside up.  
- Following chips: 1 bottle of water, 1 lemon, 1 vinegar, 1 can of chickpeas, 2 eggs, 1 berry juice, 1 granulated sugar and 1 icing sugar are placed to the marked square in CORNER SHOP. The rest of the chips are placed next to the game board face up.  
- Every player or team choose a game character for themselves: INDIGO, SOFIA or TAYLOR. The game character card contains a secret recipe for meringues and a personal secret of the character. **You don’t show these cards to others.** |
| **Starting the game** | - Every player or team sets their token to their home on the game board.  
- INDIGO can start. If Indigo is not playing, Sofia and Taylor roll the dice and the one who gets a bigger number starts. |
| **Playing** | - In their turn:  
  - Player rolls the dice and moves as much as the dice tells to either direction on the game board. From the end of the board you transfer to the other end of the board.  
  - Player **draws a card according to the square he is on the board.** Cards include a story, a mission, a reward and information on the aids that are allowed in this mission. **The story and mission are read out loud.** HOME card can be drawn only when you are at your own home.  
  - Players must complete the mission explained in the card. If the answer is correct, the player has achieved the reward mentioned in the card. If the answer is incorrect, the player won’t get the reward. Used cards will be placed next to the game board into their own stack.  
  - Players place collected chips on the table in front of them so that other players can also see them.  

In addition to stated above:  
- Every player can use their secret once in the game in their own turn. The secret is read out loud and then used.  
- A player with 2 € chip can go straight to the CORNER SHOP and buy any product from the shop’s selection.  
- A player that arrives in the same HOME square as another player can change one chip with the other player.  

If the game cards run out:  
- If some of the places in the game board run out of game cards, the player only stays in their place until the next turn. |
| **Winning the game** | - The game ends when one of the players or teams  
  - **Collects all the ingredients** for the "World’s best meringues"  
  - **Makes it to** the Home Economics classroom in the SCHOOL square in their own turn.  
  - **And writes down all the things in their recipe that make the proteins denature on a post-it note.** The teacher (your real teacher) must check the answer and declare the winner. The winner gets glory and maybe also meringues.  

Exceptions:  
- If you run out of time, then the player that has collected the most ingredients for the meringues wins.  
- If none of the players or teams cannot explain the chemistry behind the meringues, then the player who is the first in the Home Economics classroom with all ingredients wins. |
| **Postgame** | The teacher and the players can discuss about learning during gaming, and about chemistry in different meringue recipes in the game character cards. The meringues also can be baked based on those recipes and then evaluated them with blind test. |
YOU CAN CONTINUE FROM SCHOOL TO MEADOW.

SET HERE THE CHIPS THAT ARE FOR SALE IN CORNER SHOP.

IF YOU HAVE 2 €, YOU CAN MOVE HERE TO BUY AN INGREDIENT.

YOU CAN PICK UP HOME CARD ONLY WHEN YOU ARE IN YOUR OWN HOME.

WHEN TWO PLAYERS ARE AT THE SAME HOME, THEY CAN CHANGE ONE CHIP WITH EACH OTHER.

YOU CAN CONTINUE FROM MEADOW TO SCHOOL.

Pictures: Finlin (openclipart, CC0), gustavonnezende (openclipart, CC0), TheDigitalArtist (Pikabay, CC0), Ixenry (openclipart, CC0), PinkJellyfish (openclipart, CC0), ODU (openclipart, CC0)
Indigo
9th grade

World’s best meringues

2 egg whites
½ tbls lemon juice
1 ¼ dl icing sugar

- Foam egg whites into an airy, durable foam with an electric mixer. The foam has to stay in the bowl even if you turn it around.
- Add the icing sugar while stirring vigorously. Keep stirring until the foam is shiny and smooth.
- Add lemon juice (and grated lemon peel). Mix the merengue until the color is even.
- Use spoons to lift small piles of merengue foam to greaseproof paper.
- Keep the meringues in oven for 45 minutes in 125 °C.

<table>
<thead>
<tr>
<th>INGREDIENTS TO COLLECT</th>
<th>SHORT GAME</th>
<th>LONG GAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN EGG</td>
<td></td>
<td>2 EGGS</td>
</tr>
<tr>
<td>ICING SUGAR</td>
<td></td>
<td>ICING SUGAR</td>
</tr>
<tr>
<td>A LEMON</td>
<td></td>
<td>A LEMON</td>
</tr>
</tbody>
</table>

SECRET
You’re turning 16 this week. You can ask Indigo or Sofia to your birthday party and get a chip you want from them as a present (one ingredient or 2 €).

(Can be used only once.)
**Sofia**

9th grade

---

**World’s best meringues**

1/2 dl water from can of chickpeas

(it contains plant-based proteins)

2 dl granulated sugar or icing sugar

½ teaspoon vinegar

½ teaspoon berry juice

- Drain the chickpeas and save the water.
- Whip the water with electric mixer until it becomes a light and hard foam. This will take approximately 10 minutes.
- Add sugar a little at a time while mixing.
- Add vinegar and mix.
- Add berry juice to give color. Mix until the meringue mass is hard and shiny.
- Extrude chunks to greaseproof paper.
- Set them in oven to dry for 90 minutes. Use the heat of 125 °C.

---

**INGREDIENTS TO COLLECT**

<table>
<thead>
<tr>
<th>SHORT GAME</th>
<th>LONG GAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>A CAN OF CHICKPEAS GRANULATED SUGAR OR ICING SUGAR VINEGAR</td>
<td>A CAN OF CHICKPEAS GRANULATED SUGAR OR ICING SUGAR VINEGAR BERRY JUICE</td>
</tr>
</tbody>
</table>

**SECRET**

You are the vice-president of a local nature association and you often take pictures of butterflies and plants in the meadow nearby. That's why you can go to the meadow in your turn, lift a card and get the reward in it without doing the mission.

(Can be used only once.)
## Taylor
9th grade

### World's best meringues

- 2 egg whites
- 1 ¼ dl granulated sugar
- 1 dl hot water

- Whip egg whites into a hard foam.
- Dissolve the sugar into hot water (120 °C).
- Pour the syrup as a thin lace to the egg white-foam using an electric mixer at the same time. Keep mixing until the temperature of the foam decreases to room temperature.
- Extrude big foam dumpings to greaseproof paper.
- Let the meringues dry in room temperature.

<table>
<thead>
<tr>
<th>INGREDIENTS TO COLLECT</th>
<th>SHORT GAME</th>
<th>LONG GAME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AN EGG</td>
<td>2 EGGS</td>
</tr>
<tr>
<td></td>
<td>GRANULATED SUGAR</td>
<td>GRANULATED SUGAR</td>
</tr>
<tr>
<td></td>
<td>A BOTTLE OF WATER</td>
<td>A BOTTLE OF WATER</td>
</tr>
</tbody>
</table>

### SECRET

The sugarbaker Sam is your uncle. In your turn you can go to his bakery and get one ingredient to your meringues.

*(Can be used only once.)*
NEIGHBOUR AND A CAT
Your neighbour's cat walks along the street when you leave home. You pet it and take it to your arms.

MISSION: Name four things that a cat has that are formed of proteins.

REWARD: You get an egg chip.

NEIGHBOUR AND A CAT
All the shine from your neighbour's cat's fur has disappeared and even the colour has faded. The neighbor says that he feeds the cat with dry food.

MISSION: Open the Clue Booklet's page CAT FOOD. Examine the information and explain to your neighbour why the cat should also eat raw meat.

REWARD: You get an egg chip or a can of chickpeas chip.

NEIGHBOUR AND A CAT
Your neighbour wants ielt a ball from wool for his cat but doesn't know how.

MISSION: Wool consists of protein. Share two tips with your neighbour about how to make the protein lose its original form.

REWARD: You get a 2 € chip.
NEIGHBOUR AND A CAT
A neighbour asks for your help, because his cat is missing and it’ll be a really cold night. You don’t want to refuse so you follow the paw prints to the snowy meadow.

MISSION: Go to meadow on the game board and stay there for one turn. Hopefully you have dressed in warm clothes! You find a 2 € coin on the way to the meadow.

REWARD: You get a 2 € chip.

NEIGHBOUR AND A CAT
Your neighbour plants flowers into his garden and tells you that every plant needs iron to form chlorophyll.

MISSION: Also humans need to get iron from the food daily. Estimate what or which from these three claims on the right are true. Check the answer from the Clue Booklet’s page IRON.

REWARD: You get an extra turn.

HOME
Dad is cooking dinner and asks you to go Corner Shop to buy frozen peas that are missing from the meal.

MISSION: Go to CORNER SHOP. Find out how much (g/100 g) protein frozen peas contain.

AID: You can use the internet.

REWARD: You get a can of chickpeas chip.
HOME
You are wondering at home if you should buy plant-based milk instead of cow’s milk in order to live more sustainably.

MISSION: Compare oat and soy drinks. Check the product information from the Clue Booklet’s page PLANT-BASED MILK ALTERNATIVES. Give your family two noteworthy tips on how to choose a suitable plant-based milk.

REWARD: You get a chip free of choice.

HOME
You invite a friend of yours (Indigo, Sofia or Taylor) to come over. You make omelettes for snack. Bad luck! Your friend drops one egg to the floor.

MISSION: Choose a character whose pawn transfers to your home. Ask him/her to return an egg chip back to the pile of free chips.

REWARD: --

HOME
You are making oven-baked salmon during the weekend. Unfortunately there’s a power outage so you cannot use the electric oven or the stove.

MISSION: Give an idea how to denature the proteins in salmon without heating it though it can take more time.

REWARD: You get a lemon chip.
**HOME**

You’re lying on the sofa and browsing your phone. You start to read a blog text about animal- and plant-based proteins.

MISSION: Read the blog text from the Clue Booklet’s page ANIMAL- OR PLANT-BASED PROTEINS? Tell what are the risks if you only eat unilateral vegetarian food.

REWARD: You get a can of chickpeas chip or an egg chip.

---

**HOME**

Your mom asks you to do the laundry. You use a liquid laundry detergent that contains enzymes.

MISSION: Find out what effect do the enzymes have on cleaning the laundry.

AID: You can use the internet or textbook.

REWARD: You get a vinegar chip or a lemon chip.

---

**HOME**

It’s Tuesday morning and you’re eating breakfast with your little brother.

MISSION: Which ingredient from the list on the right has the highest protein content in your opinion? Check the answer from the Clue Booklet’s page BREAKFAST.

REWARD: You get a berry juice chip or a bottle of water chip.

- oat porridge
- blueberries
- rye bread slice
- cheese slice
- lettuce leaf
- yogurt
- strawberry jam
- cashew nuts
HOME
It’s Sunday evening and you get a fever. Mom brings you water and hot berry juice to drink. Did you know that fever of over 42 °C is dangerous, because the proteins in the brain are starting to denature?

MISSION: You have to stay at home and rest for one turn.

REWARD: You get a berry juice chip or a bottle of water chip.

SAM’S SUGAR BAKERY
You are doing your practice in SAM’S SUGAR BAKERY. You get first to make a sugar cake, then whip some cream and decorate a cream cake.

MISSION: Sugar cake dough contains a lot of eggs. Which two or three things are required to make a sugar cake base fluffy? Check the right answer from the Clue Booklet’s page SUGAR CAKE DOUGH.

AID: You can use the internet or textbook.

REWARD: You get an icing sugar chip or a granulated sugar chip.

SAM’S SUGAR BAKERY
Panic in the Sugar Bakery! Cupcakes are about to burn in the oven. You cannot stay here.

MISSION: Transfer yourself to HOME or CORNER SHOP.

REWARD: --
SAM’S SUGAR BAKERY
You go to the Sam’s Sugar Bakery to buy cinnamon buns for the whole family after your school day. They have the perfect brown surface and smell delicious.

MISSION: Find out, what is Maillard’s reaction and what it has to do with proteins?
AID: You can use the internet or textbook.
REWARD: You get a granulated sugar chip.

SAM’S SUGAR BAKERY
You stop at the Sam’s Sugar Bakery as usual on your way home from school on Friday. It’s time for a blueberry muffin.

MISSION: List three ingredients of the blueberry muffin that contain proteins.
AID: You can use the internet.
REWARD: You get an icing sugar chip.

SAM’S SUGAR BAKERY
The seller in the Sam’s Sugar Bakery had read on a food blog that egg whites can foam only if the bowl is completely clean and dry.

MISSION: Is the claim above true or false? Check your answer from the Clue Booklet’s page EGG WHITE FOAM.
REWARD: You get an egg chip.
MEADOW
You take a shortcut to school. You can see clearly a beautiful spider web in the morning dew. Did you know that spider nets are made of proteins?

MISSION: Find out how humans can utilize the solid structure of spider webs.

AID: You can use the internet.

REWARD: You get an egg chip or a can of chickpeas chip.

MEADOW
A feather has fallen in the meadow. It contains protein from which jewelry and clothes could be manufactured. You also find a place filled with raspberries.

MISSION: List three other animal-based fibers from which one could manufacture clothes, shoes or jewellery.

REWARD: You get a berry juice chip or a lemon chip.

MEADOW
Grasshoppers chirp in the meadow. That makes you to remember, that grasshoppers are protein-rich food that’s allowed to be consumed in Finland too.

MISSION: Estimate with the accuracy of 5% how much protein crickets contain and how much does chicken meat? Check the answer from the Clue Booklet’s page CRICKETS AND CHICKEN.

REWARD: If you get one correct, you get a 2 € chip. If you get both ones correct, you get an extra turn.
MEADOW
You’re lying in a meadow and surfing social media. Someone in there claims that **proteins can be manufactured from air in the future**.

MISSION: Is the claim above true or false? After selecting your answer, you can check it from the Clue Booklet’s page NEW THINGS ARE BEING EXPLORED IN RESEARCH.

REWARD: You get a 2 € chip.

---

MEADOW
There’s a new city bike park right next to the meadow. There’s a demonstrator who offers you a coupon that allows you to use a city bike once for free.

MISSION: Keep this card until you use it.

REWARD: In your turn, you can bike wherever you want on this game board.

---

SCHOOL
Someone has left the Corner Shop’s cart to the schoolyard. Take it back to the shop.

MISSION: Go to CORNER SHOP.

REWARD: You can trade one of your chips with one in the store.
SCHOOL
During chemistry class you study how to recognize different formations of nutrient molecules.

MISSION: Identify which of the pictures on the right depicts a protein molecule. Justify your answer.

REWARD: You get an icing sugar chip or an egg chip.

SCHOOL
In home economics class, you learn about nutrition and amino acids that are vital for life rise up.

MISSION: Explain what amino acids are.

REWARD: You get a vinegar chip.

SCHOOL
You go to your practice straight from school. You need a nutritious and high-energy snack.

MISSION: Choose the most suitable snack from the Clue Booklet’s page SNACK. Justify your choice.

REWARD: You get a bottle of water chip.
SCHOOL
In home economics class you learn that working for a sustainable future requires reducing meal consumption, among other things.

MISSION: Mention three sources of plant-based proteins.

REWARD: You get a 2 € chip.

SCHOOL
You’re discussing nutrients and the elements that are vital to life in chemistry class.

MISSION: List four elements from which all protein molecules are formed of.

REWARD: You get a vinegar chip or a berry juice chip.

SCHOOL
The classmate sitting next to you in chemistry class still doesn’t understand what protein denaturing means. You’re his/her only hope. <3

MISSION: Explain what protein denaturing means in your own words with help of the pictures on the right.

REWARD: You get a bottle of water chip or a vinegar chip or a lemon chip.
SCHOOL
During break you’re in the mood to challenge your classmate to a quiz about proteins.

MISSION: Choose one of your classmates (Indigo, Sofia or Taylor) and move him/her to SCHOOL. One of the other players runs a quiz in the Clue Booklet’s page PROTEIN QUIZ.

REWARD: The winner of the quiz gets a chip free of choice.

CORNER SHOP
You are about to buy masking tape when your English teacher stops by to choose sock yarn. She ends up with one with stripes and wonders how to wash the socks she’ll knit so that they wouldn’t shrink or get lumps.

MISSION: Tell your teacher two pieces of advice on how you can avoid denaturation of wool’s proteins.

REWARD: You get an egg chip.

CORNER SHOP
Cans of Kiehu milk have appeared to the shop. It’s specifically developed for milk-based porridges, they say, that you cannot burn porridge made with this.

MISSION: Find out how the special property of Kiehu milk is connected to proteins.

AID: You are allowed to use the internet.

REWARD: You get a 2 € chip.
CORNER SHOP
You found a new product: Pulled Oats the Corner Shop. The seller tells you that this award-winning, meat replacing protein product has been developed in Finland.

MISSION: Find out, which three ingredients of Pulled Oats contain a lot of proteins.

AID: You can use the internet.

REWARD: You can choose one chip from the selection in the store.

CORNER SHOP
You notice an interesting topic in the magazine while waiting in the cash queue.

MISSION: Read a piece of news from the Clue Booklet’s page CLOTHES FROM MILK. Identify what proteins have to do with this and what kind of properties this new fiber has.

REWARD: You get an egg chip.

CORNER SHOP
Oh no! On the way home from the market you fall with your bike and your package of sugar breaks. Luckily, you survive with only a few bruises.

MISSION: Return an icing sugar chip or a granulated sugar chip that you have gained, back to the pile of free chips.

REWARD: ---
<table>
<thead>
<tr>
<th></th>
<th>BERRY JUICE</th>
<th>BERRY JUICE</th>
<th>GRANULATED SUGAR</th>
<th>ICING SUGAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (720 ml)</td>
<td><img src="image1" alt="Berry Juice Bottle" /></td>
<td><img src="image2" alt="Berry Juice Bottle" /></td>
<td><img src="image3" alt="Granulated Sugar Package" /></td>
<td><img src="image4" alt="Icing Sugar Packet" /></td>
</tr>
<tr>
<td>2 (720 ml)</td>
<td><img src="image5" alt="Berry Juice Bottle" /></td>
<td><img src="image6" alt="Vinegar Bottle" /></td>
<td><img src="image7" alt="Granulated Sugar Package" /></td>
<td><img src="image8" alt="Icing Sugar Packet" /></td>
</tr>
<tr>
<td>3</td>
<td><img src="image9" alt="Vinegar Bottle" /></td>
<td><img src="image10" alt="Vinegar Bottle" /></td>
<td><img src="image11" alt="Granulated Sugar Package" /></td>
<td><img src="image12" alt="Icing Sugar Packet" /></td>
</tr>
</tbody>
</table>
PROTEINS IN THE BACKYARD
CLUE BOOKLET
# CONTENT

<table>
<thead>
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<th>Topic</th>
<th>Page</th>
</tr>
</thead>
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<td>ANIMAL- OR PLANT-BASED PROTEINS?</td>
<td>1</td>
</tr>
<tr>
<td>BREAKFAST</td>
<td>2</td>
</tr>
<tr>
<td>CAT FOOD</td>
<td>3</td>
</tr>
<tr>
<td>CLOTHES FROM MILK</td>
<td>4</td>
</tr>
<tr>
<td>CRICKETS AND CHICKEN</td>
<td>5</td>
</tr>
<tr>
<td>EGG WHITE FOAM</td>
<td>6</td>
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<td>IRON</td>
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<tr>
<td>NEW THINGS BEING EXPLORED IN RESEARCH</td>
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<td>PLANT-BASED MILK ALTERNATIVES</td>
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<td>PROTEIN QUIZ</td>
<td>10</td>
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<td>SNACK</td>
<td>11</td>
</tr>
<tr>
<td>SUGAR CAKE DOUGH</td>
<td>12</td>
</tr>
</tbody>
</table>
ANIMAL-OR PLANT-BASED PROTEINS?

MISSION

HOME
You're lying on the sofa and browsing your phone. You start to read a blog text about animal- and plant-based proteins.

MISSION: Read the blog text from the Clue Booklet's page ANIMAL- OR PLANT-BASED PROTEINS? Tell what are the risks if you only eat unilateral vegetarian food.

REWARD: You get a can of chickpeas chips or an egg chips.

MATERIAL

THE STRONG KITCHEN BLOG  31.07.2017

ANIMAL- VS. PLANT-BASED PROTEINS
Rebecca Haight

Protein is made up of the important building blocks, amino acids. There are 20 different types of amino acids, but only 9 of them are considered essential and must be obtained through your diet. The remaining 11 are non-essential because they can be manufactured within your body.

But fear not vegetarians; you can still obtain all your essential amino acids through plant-based proteins. You just have to eat more of them, in greater variety, in order to do so. Of all plant sources of protein, soy is widely accepted as the most complete. In fact, proteins from soy and quinoa are both classified as complete proteins because they contain all the essential amino acids, much like the proteins from animal-based foods. The best way to obtain your daily protein requirement, however, is to consume a balanced diet that includes a mixture of plant and animal products.

While animal foods are considered a higher quality protein, we don't want to eliminate vegetables and carbohydrates because the fiber, antioxidants and nutrients provide some health benefits that protein does not. Many protein-rich, animal-based proteins are also rich in zinc and heme iron, which is more readily absorbed in your body than the iron in plant-based protein. A problem many vegetarians face is a lack of adequate dietary protein or iron. But, when you consume protein from plant-based foods, you're more likely to have an increased fiber intake and variety of vitamins not found in meat.

Want to cut out all animal protein or eliminate all plant proteins? Be prepared to put in some extra work to make intelligent food choices.
BREAKFAST

MISSION

HOME
It's Tuesday morning and you're eating breakfast with your little brother.

MISSION: Which ingredient from the list on the right has the highest protein content in your opinion? Check the answer from the Clue Booklet's page BREAKFAST.

REWARD: You get a berry juice chip or a bottle of water chip.

ANSWER:
A slice of cheese is the protein-richest.

<table>
<thead>
<tr>
<th>BREAKFAST INGREDIENT</th>
<th>PROTEIN CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>oat porridge</td>
<td>1.7 %</td>
</tr>
<tr>
<td>blueberries</td>
<td>0.8 %</td>
</tr>
<tr>
<td>slice of rye bread</td>
<td>7 %</td>
</tr>
<tr>
<td>slice of cheese</td>
<td>23.5 %</td>
</tr>
<tr>
<td>lettuce leaf</td>
<td>1 %</td>
</tr>
<tr>
<td>yogurt</td>
<td>3.6 %</td>
</tr>
<tr>
<td>strawberry jam</td>
<td>0.5 %</td>
</tr>
<tr>
<td>cashew nuts</td>
<td>20 %</td>
</tr>
</tbody>
</table>

(Source: Fineli.fi)
CAT FOOD

MISSION

NEIGHBOUR AND A CAT
All the shine from your neighbour’s cat’s fur has disappeared and even the colour has faded. The neighbor says that he feeds the cat with dry food.

MISSION: Open the Clue Booklet’s page CAT FOOD. Examine the information and explain to your neighbour why the cat should also eat raw meat.

REWARD: You get an egg chip or a can of chickpeas chip.

MATERIAL

A cat needs essential amino acids, which its body cannot produce by itself. Amino acids essential for a cat are argine, histidine, isoleucine, leucine, lysine, methionine, cysteine, phenylalanine, thyrosine, threonine, tryptophan, valine and taurine. Because the proteins are multiways affecting in the body, and in fact, the whole body is constructed of them. A cat cannot live without proteins.

(Source: http://www.elainlaakari.fi/klinikat/kissaklinikka/hoito-ohjeet/havvinen-tarve/)

Taurine cannot face the heating, and therefore when a cat is eating cooked meat, a sufficient supply of taurine must be taken care of in some other way.

(Source: http://www.best-in.fi/fi/ruskinta/kissa-ruskinta)

Phenylalanine and thyrosine are amino acids. In the bodies of cat and dog there is need for phenylalanine in the thyrosine producing process. And then this thyrosine is needed for giving black and red colours for iris in the eye and fur. It is also essential for the brains to work correctly. Best sources for phenylalanine are meat, fish and rice.

(Source: https://www.waltham.com/resources/waltham-booklets/)
CLOTHES FROM MILK

MISSION

CORNER SHOP
You notice an interesting topic in the magazine while waiting in the cash queue.

MISSION: Read a piece of news from the Clue Booklet’s page CLOTHES FROM MILK. Identify what proteins have to do with this and what kind of properties this new fiber has.

REWARD: You get an egg chip.

MATERIAL

REUTERS 06.10.2011

German fashion designer makes clothes from milk

Natalia Drozdiak

A young fashion designer and microbiologist Anke Domaske from the German is revolutionizing high fashion by designing clothes with a staple she can find in her fridge: milk.

Domaske has developed a fabric called QMilch made from high concentrations of the milk protein casein. This in the first man-made fiber produced entirely without chemicals. Milk fabric has been around since the 1930s but was always produced in unecological ways that used a lot of chemicals. Unlike earlier prototypes, QMilch is made almost entirely from casein.

“It feels like silk and it doesn’t smell — you can wash it just like anything else,” Domaske told.

Made from all natural materials, the QMilch fabric is ecological but also has many health benefits, said Domaske, who also said the amino acids in the protein are antibacterial, anti-aging and can help regulate both blood circulation and body temperature.

The casein is extracted from dried milk powder and then heated up in a type of meat-mincing machine with other natural ingredients. The fiber comes out in strands and is then spun into yarn on a spinning machine. [ ]
CRICKETS AND CHICKEN

MISSION

MEADOW
Grasshoppers chirp in the meadow. That makes you to remember, that grasshoppers are protein-rich food that’s allowed to be consumed in Finland too.

MISSION: Estimate with the accuracy of 5 % how much protein crickets contain and how much does chicken meat? Check the answer from the Clue Booklet’s page CRICKETS AND CHICKEN.

REWARD: If you get one correct, you get a 2 € chip. If you get both ones correct, you get an extra turn.

ANSWER

<table>
<thead>
<tr>
<th>COMMODITY</th>
<th>PROTEIN CONTENT</th>
<th>ESTIMATES THAT ARE ACCEPTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRICKETS</td>
<td>66,6 %</td>
<td>60–70 %</td>
</tr>
<tr>
<td>CHICKEN</td>
<td>20,3 %</td>
<td>15–25 %</td>
</tr>
</tbody>
</table>

(Source: http://hyonteistalous.blogspot.fi/2014/07/hyonteisruoan-ravitsemuksesta.html)
EGG WHITE FOAM

MISSION

SAM’S SUGAR BAKERY
The seller in the Sam’s Sugar Bakery had read on a food blog that **egg whites can foam only if the bowl is completely clean and dry.**

MISSION: Is the claim above **true or false?**
Check your answer from the Clue Booklet's page EGG WHITE FOAM.

REWARD: You get an egg chip.

ANSWER
The claim is false. The bowl in which you whisk has to be clean (i.e. free of fat), but it doesn’t have to be dry.

Egg whites contain 9.8% proteins and, among other things, they contain water. Water doesn’t interfere the formation of the foam. In fact, by adding water you can get a richer foam. However, the added water doesn’t necessarily stay in the formed protein network, which makes the foam fall flat over time. On the contrary, flat interferes the formation of the foam from egg whites.
IRON

MISSION

NEIGHBOUR AND A CAT
Your neighbour plants flowers into his garden and tells you that every plant needs iron to form chlorophyll.

MISSION: Also humans need to get iron from the food daily. Estimate what or which from these three claims on the right are true. Check the answer from the Clue Booklet’s page IRON.

REWARD: You get an extra turn.

1) Meat contains a lot of iron.
2) Iron from meat is absorbed remarkably better in human body than iron from vegetables.
3) Milk and plant-based milks alternatives contain a lot of iron.

ANSWER
Claims 1) and 2) are true.

1) Meat contains a lot of iron.
2) Iron from meat is absorbed remarkably better in the human body than iron from vegetables.
3) Milk and plant-based milks contain a lot of iron.
NEW THINGS ARE BEING EXPLORED IN RESEARCH

MISSION

MEADOW
You’re lying in a meadow and surfing social media. Someone in there claims that proteins can be manufactured from air in the future.

MISSION: Is the claim above true or false? After selecting your answer, you can check it from the Clue Booklet’s page NEW THINGS ARE BEING EXPLORED IN RESEARCH.

REWARD: You get a 2 € chip.

ANSWER
The claim is true.

CHEMISTRY 6/2017 (KEMIA 6/2017)

Finish researchers are developing a new way to relieve world hunger. The goal is to manufacture protein with the help of electricity from carbon dioxide that is in air.

In the project launched by Lappeenranta University of Technology LUT and VTT Technical Research Centre of Finland Ltd, the first batch of single cell protein that is suitable for both human and animal consumption has been developed.

According to the researchers, this method frees food production from the constraints in the surroundings. Protein can be manufactured anywhere as long as there is energy, such as from renewable solar energy from the sun.

"The production doesn’t require any agricultural growth conditions such as specific temperature, humidity or soil quality" Jero Ahola a professor in LUT describes.

Pesticides are not needed either for this is a closed process and only fertilizer-like nutrients are needed.

"Practically all raw materials are obtained from air" leading researcher from VTT Juha-Pekka Pitkänen emphasizes.
PLANT-BASED MILK ALTERNATIVES

MISSION

HOME
You are wondering at home if you should buy plant-based milk instead of cow’s milk in order to live more sustainably.

MISSION: Compare oat and soy drinks. Check the product information from the Clue Booklet’s page PLANT-BASED MILK ALTERNATIVES. Give your family two noteworthy tips on how to choose a suitable plant-based milk.

REWARD: You get a chip free of choice.

MATERIAL

ALPRO ORIGINAL SOYDRINK

PRICE: 1,86 € / liter

KASLINK OAT DRINK

PRICE: 1,49 € / liter

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Nutrition facts 100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy: 185 kJ/44 Kcal</td>
</tr>
<tr>
<td>Oatbase (water, organic whole grain oats 12 %), salt</td>
<td>Fat: 1.0 g</td>
</tr>
<tr>
<td>Preservation: In the fridge +2 - +6 °C</td>
<td>-saturated fat: 0.2 g</td>
</tr>
<tr>
<td>Origin country Finland</td>
<td>Carbohydrates: 7.5 g</td>
</tr>
<tr>
<td></td>
<td>-sugars: 5.7 g</td>
</tr>
<tr>
<td></td>
<td>Dietary fiber: 0.5 g</td>
</tr>
<tr>
<td></td>
<td>Protein: 1.2 g</td>
</tr>
<tr>
<td></td>
<td>Salt: 0.10 g</td>
</tr>
<tr>
<td></td>
<td>Lactose: 0 g</td>
</tr>
<tr>
<td>* Based on nutrient reference values</td>
<td></td>
</tr>
</tbody>
</table>

| NUTRITIONAL INFORMATION (100 ml) |
| energy | 151 kJ / 36 kcal |
| fat | 1.8 g |
| saturates | 0.3 g |
| mono-un saturates | 0.4 g |
| polyunsaturates | 1.1 g |
| carbohydrate | 2.5 g |
| sugars | 2.5 g |
| fibre | 0.5 g |
| protein | 3.0 g |
| salt | 0.06 g |
| vitamins | | |
| vitamin D | 0.75 µg (15%* |
| vitamin B2 | 0.21 mg (15%* |
| vitamin B12 | 0.38 µg (15%* |
| minerals | | |
| calcium | 120 mg (15%* |
| lactose | 0 g |
| * 15% of the nutrient reference values (NRV) |
**PROTEIN QUIZ**

**MISSION**

_SCHOOL_

_In the break you’re in the mood to challenge your class mate a quiz about proteins._

**MISSION:** Choose one of your class mates (Indigo, Sofia or Taylor) and move him/her to SCHOOL. One of the other players runs a quiz in the Clue Booklet’s page PROTEIN QUIZ.

**REWARD:** The winner of the quiz gets a chip free of choice.

---

**PROTEIN QUIZ**

One of the other players is running this protein quiz to the character who has pick up the card above, and to a character (Indigo, Sofia or Taylor) he/she has challenged to participate the quiz.

The one who first is giving out loud a correct answer to the question will get a point. The winner with most points will achieve the reward mentioned in the card above.

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>ANSWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Which smaller molecules are protein molecules consisted of?</td>
<td>amino acids OR amino acid molecules</td>
</tr>
<tr>
<td>2) Some of these amino acid the human body is capable to produce by itself from the elements. But, essential amino acids it cannot produce, and they are needed to get directly from food instead. How many of amino acids can be conted as essentials for human being?</td>
<td>20 (OR the answer which is the nearest the correct answer)</td>
</tr>
<tr>
<td>3) Which of these does not have proteins at all: fish, mushrooms, sugar, bread?</td>
<td>sugar</td>
</tr>
<tr>
<td>4) How is called the chemical reaction, where proteins’ natural structure will first open and then this molecules will form crossing bonds with each other?</td>
<td>denaturation</td>
</tr>
</tbody>
</table>
SNACK

MISSION

SCHOOL
You go to your practice straight from school. You need a nutritious and high-energy snack.

MISSION: Choose the most suitable snack from the Clue Booklet's page SNACK. Justify your choice.

REWARD: You get a bottle of water chip.

MATERIAL

<table>
<thead>
<tr>
<th>Nutrition facts</th>
<th>Chocolate bar</th>
<th>Yogurt muesli bar</th>
<th>Banana</th>
<th>Sugar-free strawberry juice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fat</strong></td>
<td>48 %</td>
<td>31 %</td>
<td>4 %</td>
<td>less than 0.1 %</td>
</tr>
<tr>
<td>Saturated fat</td>
<td>32 %</td>
<td>12 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trans fat</td>
<td>10 %</td>
<td>12 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monounsaturated fat</td>
<td>3 %</td>
<td>5 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>carbohydrate</strong> (dietary)</td>
<td>48 %</td>
<td>60 %</td>
<td>85 %</td>
<td>0.3 %</td>
</tr>
<tr>
<td>Sugar</td>
<td>37 %</td>
<td>33 %</td>
<td>63 %</td>
<td>0.3 %</td>
</tr>
<tr>
<td>Starch</td>
<td>11 %</td>
<td>27 %</td>
<td>22 %</td>
<td>0 %</td>
</tr>
<tr>
<td><strong>Fiber</strong></td>
<td>1 %</td>
<td>2 %</td>
<td>4 %</td>
<td>0 %</td>
</tr>
<tr>
<td>Protein</td>
<td>3 %</td>
<td>7 %</td>
<td>5 %</td>
<td>less than 0.1 %</td>
</tr>
</tbody>
</table>
SUGAR CAKE DOUGH

MISSION

SAM’S SUGAR BAKERY
You are doing your practice in SAM’S SUGAR BAKERY. You get first to make a sugar cake, then whip some cream and decorate a cream cake.

MISSION: Sugar cake dough contains a lot of eggs. Which two or three things are required to make a sugar cake base fluffy? Check the right answer from the Clue Booklet’s page SUGAR CAKE DOUGH.

AID: You can use the internet or textbook.

REWARD: You get an icing sugar chip or a granulated sugar chip.

ANSWER

- Physical work i.e. whisking eggs (denaturation),
- Trapped air (bubbles inside the protein network)
- Evaporation of carbon dioxide gas (in the oven)

Making a fluffy sugar cake base is based on three things. Denaturing happens when the eggs are physically whisked. During this process, air bubbles get stuck into the protein network that is formed, when proteins are denatured by whisking. Also, when heated in the oven, baking podwer (NaHCO₃) as an added leavening agent in the cake dough, will decompose and evaporate carbon dioxide gas (CO₂). All these three factors together are making the cake fluffy.