How to design educational settings to promote collaborative inquiry: Pedagogical infrastructures for technology-enhanced progressive inquiry

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Abstract

Educational practices should pay special attention to improving the skills necessary for collaboration and knowledge work, in order to address current societal changes. Strategies of scientific, question-driven inquiry are stated to be important cultural practices that should be educated and promoted in schools and universities. The present study focuses on investigating multiple efforts to implement a research-based pedagogical model of Progressive Inquiry and related Web-based tools in primary, secondary and university level education, to develop guidelines for educators in promoting students' collaborative inquiry practices with technology. A special characteristic of the Progressive Inquiry model is that it explicates epistemic activities that are generally important in academic and scientific inquiry; i.e., in collaborative activity that aims at improved solving of ill-structured problems, utilization of knowledge sources, and explication and elaboration of ideas, explanations and theories.

The research consists of four studies that present a continuum from focusing on issues related to teacher guidance during the inquiry process, towards overarching structural aspects in designing and organizing student's inquiry practices. In Study I, the aims were to investigate how a human tutor contributed to the university students' collaborative inquiry process through virtual discourse forums, and how the influence of the tutoring activities is demonstrated in the students' inquiry discourse. Study II examined a fairly challenging effort to implement technology-enhanced progressive inquiry as a distance working project in an ordinary middle school context. Study III examined multiple teachers' methods of organizing progressive inquiry projects in primary and secondary classrooms through a generic framework for analyzing pedagogical solutions. In Study IV, a design-based research effort consisting of four consecutive university courses, applying progressive inquiry pedagogy, was retrospectively re-analyzed in order to further develop and test the generic design framework.

The results indicate that appropriate teacher support for students' collaborative inquiry efforts appears to include interplay between spontaneity and structure. Careful consideration should be given to content mastery, critical working strategies or essential knowledge practices that the inquiry approach is intended to promote. In particular, those elements in students' activities should be structured and directed, which are central to the aim of Progressive Inquiry, but which the students do not recognize or demonstrate spontaneously without explicit modeling or promotion, and which are usually not taken into account in existing pedagogical methods or educational conventions. Such elements are, among others: productive co-construction activities; sustained engagement in improving produced ideas and explanations; critical reflection of the adopted inquiry practices, and sophisticated use of modern technology for knowledge work. Concerning the scaling-up of inquiry pedagogy, it was concluded that one individual teacher can also apply the principles of Progressive Inquiry in his or her own teaching in many innovative ways, even under various institutional constraints. Researchers, administrators and policy makers should strive to develop in-service teacher training methods and change the official curriculum to acknowledge the importance of teaching culturally relevant, technology-enhanced knowledge practices to students.

The developed Pedagogical Infrastructure Framework enabled recognizing and examining some central features and their interplay in the designs of examined inquiry units. The framework may help to recognize and critically evaluate the invisible learning-cultural conventions in various educational settings and can mediate discussions about how to overcome or change them. In order to be a practical tool for educational practitioners, the framework should be further concretized. It should be considered whether it is possible to create a procedural guide for teachers to intentionally evaluate and reflect on their pedagogical practices in light of emerging challenges.

Tiivistelmä

Yhteiskunta muuttuu koko ajan ja kansalaisilta edellytetään kehittyneitä ongelmanratkaisutaitoja ja kykyä uusien innovaatioiden kehittelyyn yhteistyössä muiden kanssa. Siksi erityisesti tieteelliselle toiminnalle luonteenomaisia tapoja käsitellä tietoa kriittisesti ja ongelmalähtöisesti pidetään nykyisin tärkeinä kulttuurisina taitoina, joita pitäisi opettaa laajasti kouluissa ja yliopistoissa. Tämä väitöskirjatutkimus tarkastelee esimerkkitapauksia, joissa tutkivan oppimisen (Progressive Inquiry) pedagogista mallia ja verkkoteknologiaa on käytetty koulu- ja yliopisto-opetuksessa. Tavoitteena on ollut kehittää opettajille tutkimuspohjaisia malleja ja ohjeita siitä, miten oppilaiden yhteisöllisen ongelmanratkaisun ja tiedontuottamisen taitojen kehittymistä voisi tukea.

Väitöstutkimus koostuu neljästä osatutkimuksesta. Ne muodostavat kokonaisuuden, joka laajenee tutkivan oppimisen ohjaamisen tutkimisesta koko opetustilanteen suunnittelun ja organisoinnin käytäntöjen tutkimiseen. Osatutkimus I käsittelee verkkotyöskentelyn ohjaamista ja ohjaustapojen vaikutusta opiskelijoiden tutkivan oppimisen prosessin etenemiseen yliopistokurssilla. Osatutkimuksessa II tutkitaan ohjauskäytäntöjä usean opettajan yhteistyönä toteutetulla tutkivan oppimisen etäopiskelukurssilla peruskoulun yläasteella. Osatutkimuksessa III tarkastellaan ala- ja yläkouluissa sekä lukioissa toteutettujen tutkivan oppimisen projektien pedagogista toteutusta yhtenäisen analyysikehikon avulla. Osatutkimuksessa IV tarkastellaan tutkivan oppimisen soveltamista ja pedagogisten ratkaisujen kehittämistä neljällä peräkkäisellä yliopistokurssilla sekä kehitetään edelleen yhtenäistä analyysikehikkoa pedagogisten suunnitelmien tarkasteluun.

Tulosten perusteella voisi luonnehtia, että yhteisöllisen, tutkivan oppimisen taitojen harjoittelussa avoin oma-aloitteisuus ja opettajan tarjoamat ohjaavat rakenteet ovat vuorovaikutuksessa keskenään. Opettajan tulisi harkita tarkoin, mitkä ovat niitä keskeisiä seikkoja opiskeltavissa asiasisällöissä tai työskentelytaidoissa ja tietokäytännöissä, joiden oppimista nimenomaan tutkivan oppimisen menetelmän on tarkoitus edistää. Opettajan pitäisi selkeästi strukturoida ja mallintaa erityisesti sellaisia käytäntöjä ja taitoja, jotka ovat tutkivan oppimisen kannalta keskeisiä, mutta joita oppilaat eivät hallitse oma-aloitteisesti ja joihin muut opetusmenetelmät tai nykyiset opetuskäytännöt eivät juuri kiinnitä huomiota. Tällaisia ovat esimerkiksi yhteisöllisen tiedonkehittelyn taidot, pitkäjänteinen tuotettujen ideoiden ja selitysten kehittäminen, itse tutkivan oppimisen käytäntöjen kriittinen arviointi ja sekä modernin verkkoteknologian mielekäs hyödyntäminen tietotyössä. Tehdyissä tutkimuksissa saatiin rohkaisevia kokemuksia siitä, miten yksittäinen opettaja pystyy soveltamaan tutkivaa oppimista omassa opetuksessaan innovatiivisesti, vaikka kouluissa ja yliopistoissa onkin paljon erilaisia institutionaalisia rajoitteita, jotka hankaloittavat opetuskäytäntöjen kehittämistä. Tutkijoiden, virkamiesten ja poliitikkojen tulisi pyrkiä vaikuttamaan myös laajemmin opettajien täydennyskoulutukseen ja virallisten opetussuunnitelmien muuttamiseen, jotta niissä nykyistä paremmin huomioitaisiin kehittyneiden teknologian tukeminen tietokäytäntöjen opettaminen. Analyysikehikko (Pedagogical Infrastructure Framework), joka kehitettiin tutkivan oppimisen sovellusesimerkkien tutkimiseen, auttoi tarkastelemaan joitakin oppimisprojektien pedagogisen organisoinnin keskeisiä piirteitä ja niiden yhteisvaikutusta. Mallia voisi ehkä käyttää yleisemminkin tunnistamaan ja arvioimaan kriittisesti vallitsevia oppimisen ja opettamisen käytäntöjä. Jotta kuka tahansa opettaja voisi käyttää mallia käsitteellisenä työkaluna oman opetuksen kehittämisessä, siitä pitäisi tehdä käytännönläheisempi, esimerkiksi laatimalla konkreettinen opas, jonka avulla opettaja voisi tarkastella ja arvioida, miten hänet omat opetuskäytäntönsä tukevat kehittyneiden tietotyön taitojen oppimista.

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List of original publications

This thesis is based on the following publications, referred to in the text by their Roman numerals (I-IV):

I Lakkala, M., Muukkonen, H., & Hakkarainen, K. (2005). Patterns of scaffolding in computer-mediated collaborative inquiry. *Mentoring & Tutoring: Partnerships in Learning, 13*, 281–300.

II Lakkala, M., Ilomäki, L., & Palonen, T. (2007). Implementing virtual, collaborative inquiry practices in a middle school context. *Behaviour & Information Technology, 26*, 37–53.

III Lakkala, M., Lallimo, J., & Hakkarainen, K. (2005). Teachers' pedagogical designs for technology-supported collective inquiry: A national case study. *Computers & Education, 45*, 337–356.

IV Lakkala, M., Muukkonen, H., Paavola, S., & Hakkarainen, K. (2008). Designing pedagogical infrastructures in university courses for technology-enhanced collaborative inquiry. *Research and Practice in Technology Enhanced Learning, 3*, 33–64.

1 Introduction

The goals of formal schooling and higher education are tightly integrated with the development and requirements of surrounding society. Such terms as ‘knowledge society’, ‘network society’ and ‘innovation society’ have been used to characterize the current societal changes (Castells, 2000; Hargreaves, 2003; Harkins, 2002). Characteristics of these changes are, e.g., the rapid growth in the amount of available information; the increasing role of knowledge work, where knowledge has replaced material objects as the object of working; increased emphasis on collaboration and networking between people; the continuous creation of new technical and social innovations; emphasis on openness to change and the responsibility for developing one’s own competencies; and the rapid development of information and communication technologies (ICT) as interaction and knowledge creation tools. These ongoing transformations create new requirements for the competencies that citizens should have in order to act as prominent contributors in the present and future working life and other areas of society. As a consequence, various educators (Bereiter, 2002; Hakkarainen, Palonen, Paavola & Lehtinen, 2004; Kozma, 2005) have proposed that educational practices should pay special attention to improving the skills necessary for collaboration and expert-level knowledge work, rather than mere establishment of content mastery or basic skills in some subject domains. Specifically, the strategies of scientific, question driven inquiry are stated to be important cultural practices that should be taught and promoted in schools and universities (Barab, Dodge, Thomas, Jackson & Tuzun, 2007; Edelson, Gordin & Pea, 1999; Hakkarainen, 2009).

The requirements for transforming educational practices are, especially, bound to the development and utilization of information and communication technology (ICT). In many countries, during the last decades, a great amount of resources has been spent to provide schools and universities with ICT tools and to educate teachers to use technology in pedagogically relevant and innovative way (Kozma, 2003; 2005; Organization for Economic Co-operation and Development, 2004). The availability and spreading of Internet with World Wide Web and other network technologies, especially, has been considered to provide new, valuable possibilities for education, such as effective means for communication and collaboration, access to various information

repositories and real-life examples, and tools for developing knowledge management and higher-order thinking skills (Hofer 2004; Roschelle, Pea, Hoadley, Gordin & Means, 2000).

In addition to benefits, technology creates new challenges for students, and also for teachers, in the form of increased skill demands to harness the technology for improving their ways of learning and working with other people and knowledge. Several investigators have recognized the problem of increasing pedagogically meaningful usage of ICT in schools (Cuban, Kirkpatrick & Peck, 2001; Pedersen et al., 2006). For instance, in a survey made in the Educational technology project of Helsinki City (Ilomäki et al., 2001), the number of those teachers who used Internet in their classroom at least monthly rose substantially in two years (from 1997 to 1999), but most common student activities were searching for information in the Internet or 'surfing' freely through the www-pages. Emerging Web-based technologies, such as Web 2.0 applications, so-called “social software” and semantic services, further address new social and digital competencies that will be needed from everybody, in order to be able to participate in social and epistemic activities that are going on in various areas of society (Ilomäki, 2008; Pedersen et al., 2006). Even though present-day school and university students probably use network technologies a great deal, they do not appear to spontaneously adopt effective information literary or knowledge management skills (Anson & Miller-Cochran, 2009; Bowler, Largeb & Rejskindc, 2001; Kiili, Laurinen & Marttunen, 2008; Mittermeyer, 2005). It appears that the arguments, presented by Lauren Resnick (1987) in her influential article twenty years ago, are still valid: Formal education should promote skills that are needed outside school, but its special role in this endeavor is to concentrate on intellectual work that engages reflection and reasoning to cultivate cultural knowledge and related practices.

When the present study started, computer-supported collaborative learning (CSCL) was an emerging approach in the area of technology-related educational research (Koschmann, 1996; Kienle & Wessner, 2006). CSCL is an interdisciplinary field of research and design, focusing on the use of information and communication technology (ICT) as a mediating tool within collaborative methods of learning (Koschmann, 2002; Lipponen, 2001). Lehtinen (2003) noted that in the first edited book about CSCL by Koschmann (1996), most reported cases were based on collaboration *around* a

computer, but in the next book, edited five years later (Koschmann et al., 2002), almost all experiments were about collaboration *through* a computer, indicating a clear increase in the use of so-called *Web-based learning environments* in educational settings. Such systems typically include various kinds of tools for the organization and enabling of collaborative activities and sharing of knowledge artifacts, such as the structuring of separate working spaces for sub-groups and sub-processes, threaded discussion forums, repositories for saving and sharing documents and links, functionalities for commenting, or awareness functionalities to increase awareness of other participants' actions in the spaces. Corresponding technologies were used in all educational units investigated in the present dissertation, with somewhat varying functionalities depending on the piece of software and context of the study. The adjective '*technology-enhanced*' is used instead of 'technology-supported' in order to emphasize the role of technology as providing added value and new possibilities for learning and collaboration in addition to just supporting it.

The first study (Study I) in the present dissertation was explicitly connected with the CSCL tradition. In the subsequent studies, CSCL was no more referred to because, actually, the focus in the present research has been somewhat different than in the mainstream of CSCL research. The main focus in most CSCL studies has been on individual students' learning of certain domain content or skills, which the technology-supported collaborative activities, such as guided discussion or argumentation, are supposed to promote (Andriessen, 2006; Stahl, Koschmann & Suthers, 2006). Generally, social interaction and discussion activities to support students' content learning are emphasized in CSCL, whereas the interest in the present study has been on the enculturation of students in academic inquiry skills and expert-like practices to work with knowledge, thus on pedagogical means to promote competencies and cultural conventions needed in knowledge society.

The pedagogical approach that was implemented and investigated in the case studies of the present dissertation was the model of Progressive Inquiry, developed by Kai Hakkarainen and his colleagues (Hakkarainen, 2003; Muukkonen, Hakkarainen & Lakkala, 2004) as a heuristic model for supporting and promoting expert-like, scientific inquiry practices in educational settings. The model is described in detail in Section 2.4. Progressive inquiry pedagogy together with Web-based collaboration technologies has

already been implemented and studied in various educational contexts, e.g., in elementary classrooms (Lipponen, 2000; Veermans & Järvelä, 2004), as a pedagogical model for designing digital learning objects (Poldoja, Leinonen, Valjataga, Ellonen & Priha, 2006), and in undergraduate courses teaching crafts design (Lahti & Seitamaa-Hakkarainen, 2005) or cognitive psychology (Muukkonen, Lakkala & Hakkarainen, 2005).

Previous studies both from schools and universities have reported that students' spontaneous and self-directed inquiry does not often reach the stated ideals of the inquiry model. Students' inquiry outcomes are not necessarily conceptually very high-level and the inquiry process does not progress or deepen without guidance or does not create equal participation and strong mutual collaboration (Krajcik, Blumenfeld, Marx & Soloway, 2000; Lehrer, Carpenter, Schauble & Putz, 2000; Lipponen, Rahikainen, Lallimo & Hakkarainen, 2003; Mandl, Gruber & Renkl, 1996; Muukkonen et al., 2005). In one study, Hakkarainen, Lipponen and Järvelä (2002) compared students' technology-enhanced question- and explanation-driven inquiry practices in Canadian and Finnish elementary level classes. According to the analysis of the knowledge produced by the students, a mature progressive-inquiry culture emerged only in one Canadian classroom. The comparison of separate teachers' guidance notes revealed that there was a clear difference between the teachers' guidance practices of the epistemologically more and less advanced classrooms. In the classroom with more high-level epistemological outcomes, the teacher commented on students' explanations in an elaborated way and indirectly tried to guide them towards deepening their inquiry and articulate their theories. In the less advanced classroom, instead, the teacher's comments were mainly general encouragement, and his requests for explanation appeared to guide students quite directly towards specification of their own conceptions or towards a right answer.

Such results highlighted the important role of a teacher or tutor in building an expert-like inquiry culture and appropriately directing students' inquiry efforts towards improved practices. It is rather intriguing that Carl Bereiter and Marlene Scardamalia, the developers of the acknowledged Knowledge Building approach, have done much research on students' epistemic advancement in technology-enhanced collaborative knowledge building processes, but they have not concretely reported teachers' ways of

guiding or promoting the students' knowledge building efforts (see Scardamalia, Bereiter & Lamon, 1994). Some studies had reported that tutoring style, indeed, has an influence on the progression of students' on-line discourse (Ahern, Peck & Laycock, 1992; Rourke, Garrison & Archer, 2001), but usually CSCL studies concentrate on students' behavior and learning outcomes, teachers' role or pedagogical arrangements have been investigated less often.

The present study, especially, focuses on investigating multiple efforts to implement a research-based pedagogical model of Progressive Inquiry and related tools in primary, secondary and university level education, in order to develop frameworks and guidelines for helping educators in promoting students' collaborative inquiry practices with technology. Some researchers have suggested that we should aim at a radical and overarching change in the culture of schooling, such as the ideas of knowledge-creating schools (Hargreaves, 1999) or schools as knowledge-building organizations (Scardamalia & Bereiter, 1999). Without abandoning such idealized visions, in the present study a more modest strategy was chosen by focusing on the "meso-level" (Jones, Dirckinck-Holmfeld & Lindström, 2006) through investigating the new pedagogical innovation in some small-scale educational units. First, the pedagogical arrangements for progressive inquiry were investigated by the researchers themselves in some of their own university courses (Studies I and IV). In addition, another line of study was the issue of disseminating the pedagogical innovation to ordinary schools by testing the model with a group of primary and secondary school teachers in a few educational units (Studies II and III). The pedagogical principles of Progressive Inquiry are abstract and idealized goals for education, and teachers have a challenging task to apply the principles in actual settings; especially when there is a new technology with which they are not familiar. First, in the next section the theoretical concepts and approaches in the background of the present study are reviewed and explained.

2 Theoretical framework of the study

2.1 Individual learning as embedded in social and cultural processes

As described in Jonassen and Land (2000), there was a substantial change in the basic premises of learning theories during 1990's, from emphasizing the transmission of knowledge and individual cognitive processes to theories that emphasize the social and cultural nature of learning, thinking and activity. A wide consensus appears to be between various contemporary learning-theoretical approaches regarding the essential characteristics of recommended pedagogical practices. These characteristics include, among others, working in collaboration, simulating domain-related "real-life" practices, solving open-ended and ill-structured problems, coaching and modeling the thinking skills, providing opportunities for reflection, exploiting various knowledge sources, and using web-based tools for collaboration (Barab & Duffy, 2000; Kozma, 2003). Simultaneously, in the field of educational research there is an increasing amount of discussion about the need to find a new paradigm for learning research that takes the complexity of learning and authentic pedagogical practice into account (Sandoval & Bell, 2004). According to Jörg, Davis and Nickmans (2007), it involves, for example, the rejection of the attempt to pre-determine learning outcomes, and the pursuit of novel theoretical and methodological means to deal with the complexity of reality in learning processes. The notion *authentic educational practice* is used in the present study to refer to the choice to investigate educational settings that were not designed for research purposes but were, for the participating teacher and students, part of the normal schooling or institutional curriculum, even though a new pedagogical approach was applied.

The study does not clearly follow any learning-theoretical paradigm, but it can be characterized as falling between socio-cognitive and socio-cultural approaches to learning. *Socio-cognitive approaches* consider learning as primarily individual, cognitive process but recognize that it is strongly enhanced and structured by social factors, such as social interaction as a promoter of individual thinking, or comparison of one's own viewpoints with those of peers as a means to deepen individual

understanding (Herrenkohl, Palincsar, DeWater & Kawasaki, 1999). Theoretical conceptualizations and pedagogical methods in learning research, related to the socio-cognitive approach are, for instance, distributed cognition (Brown & Palincsar, 1989), situated cognition (Choi & Hannafin, 1995), or cognitive apprenticeship and reciprocal teaching (Collins, Brown & Newman, 1989). In *sociocultural approaches*, human activities are more broadly seen as socially and culturally mediated, which entails that also learning is embedded in the social processes of knowledge construction mediated by cultural tools, conventions and practices rather than being an individual venture (Bruner, 1996; Vygotsky, 1978; Wells, 2000). A central viewpoint in the approach is the notion of strong interdependence between individual and social processes, seeing development as a process of internalizing external socially shared cultural activities (John-Steiner & Mann, 1996). Specific educational settings can be seen as "microcultures for 'culturing' children through the design and enactment of activity systems" (Bell, 2004, 248) and the focus of pedagogical design is on intended activities rather than measurable learning results. In the investigation of learning and teaching, the viewpoints towards integrated individual and social or cultural processes differentiate socio-cognitive and sociocultural approaches from behaviorist/empiricist views that focus only on external, observable processes, and cognitive/rationalist views focusing on internal processes (Greeno, Collins & Resnick, 1996; John-Steiner & Mann, 1996).

One theoretical construct that has been central to the present research although not explicitly discussed in the articles, is the concept of the Zone of Proximal Development, introduced by Vygotsky (1978). The concept was conceptualized as the distance between a learner's actual development (in problem solving) and the level of potential performance under adult guidance or in collaboration with more capable peers. Vygotsky considered the learner's level of potential development to be more relevant for education than the actual independent developmental level. This relates to the pedagogical idea of tailored support for learners, especially in those skills that they cannot manage alone, but can acquire with that support, be it human guidance or conceptual or cultural tools provided in the educational situation (Pea, 2004).

At the beginning of the present study, the research was somewhat more based on cognitively oriented aspects; meaning that the implementation of collaborative inquiry pedagogue in the educational units was considered at aiming to support students' in-

depth understanding of certain domain content and, simultaneously, to help them learn mature epistemic inquiry strategies. Later, the emphasis of the research changed towards emphasizing more overarching induction of students into the social practices and cultural conventions of sustained inquiry, important in knowledge work and systematic creation of knowledge innovations (see also Hakkarainen, 2009). The adoption of socio-cognitive and socio-cultural paradigms entailed that the research focus on indirect, intertwined relationships between a) activity structures and cultural tools embedded in inquiry-based settings, and b) the participants' activities and knowledge productions in the settings; both foci instead of individual students' measurable learning gains through experimental research methods, which has been the prevailing approach in learning research. Especially in Studies III and IV, the pedagogical design of educational settings was examined from the viewpoint of setting-up the overall conditions that would help students grow into the advanced cultures of inquiry.

The concept *engagement* is used in the present research to delineate the quality of students' inquiry activity in order to evaluate the success of the pedagogical intervention: a central aim was that students demonstrate sustained engagement in an active and deepening process of improving ideas and explanations as well as in critical reflection of inquiry practices (see sub-studies I and IV). In psychological and educational research, 'engagement' is primarily used as a theoretical construct describing *individual* level commitment and investment of efforts. For instance, in game research (Brown & Cairns, 2004; Lessiter, Freeman, Keogh & Davidoff, 2001), the concept is used to describe player's involvement and immersion in the gaming activity. In educational studies, engagement may either refer to students' involvement in schooling and school community in general (Marks, 2000; Ryan, 2000) or involvement in tasks and activities in single classroom settings (Helme & Clarke, 2001; Wise, Chang, Duffy & Del Valle, 2004). In the sub-studies of the present research, student engagement is examined only in single educational settings following progressive inquiry pedagogy, but in the background of the pedagogical approach is more overarching goal of providing students with attitudes and skills that have an effect on their engagement in academic practices more generally. According to Fredricks, Blumenfeld and Paris (2004), educational studies often differentiate three types of

engagement: behavioral, emotional and cognitive. Engagement in inquiry, examined in the present study, mostly resembles cognitive engagement (e.g., flexibility in problem solving, being strategic and self-regulated, preference for challenge), but as a characteristic of *collaborative* activity, evaluated through the progression of technology-mediated inquiry discourse.

2.2 The pedagogical model of Progressive Inquiry

The pedagogical approach that was implemented and investigated in all case studies of the present dissertation was the model of *Progressive Inquiry*, developed by Kai Hakkarainen and his colleagues (Hakkarainen, 2003; Muukkonen, Lakkala & Hakkarainen, 2008). Hakkarainen (1998) created the first ideas of Progressive Inquiry model in his doctoral dissertation about elementary students' inquiry practices. The model was developed for guiding educators and students to learn new ways of working with knowledge through imitating the practices of scientific research communities and solving problems of understanding.

There are various models for so-called "inquiry learning" introduced in educational literature, but they are primarily developed for educating experimental research logic and practices in well-defined domains in natural sciences. They frame inquiry practices through such elements as defining hypotheses, designing studies, making experiments, collecting data, and interpreting empirical evidence. Some recognized projects following this line in the field of technology-supported inquiry learning in science are, e.g., the Web-based Inquiry Science Environment (WISE; Linn, Clark & Slotta, 2003); Learning through Collaborative Visualization (CoVis; Gomez, Fishman & Pea, 1998) and Project-Based Science (Krajcik, Blumenfeld, Marx, Bass, Fredricks & Soloway, 1998). Differing from these approaches, a special characteristic of the Progressive Inquiry model is that it emphasizes and explicates *epistemic* activities that are generally important in academic and scientific inquiry; i.e., in collaborative activity that aims at improved ways of solving ill-structured problems, the utilization of knowledge sources, and the explication and elaboration of ideas, explanations and theories.

The most influential theoretical perspectives in the background of the Progressive Inquiry model were the Interrogative Model of Scientific Inquiry (Hintikka, 1999) and Knowledge Building (Scardamalia & Bereiter, 1999). In the *Interrogative Model of*

Inquiry, a central aspect is viewing scientific inquiry and knowledge creation, in general, as a sharpening question-answer process (Hintikka, 1999). The model separates two levels and two types of questions (Hakkarainen & Sintonen, 2002): First, there are initial, principal questions determined by the goals of inquiry, and small subordinate questions that need to be answered in order to approach the principal question; second, there is a distinction between ill-defined explanation-seeking why-questions and well-defined so called *wh*-questions (i.e., who-, where-, when-, and which) and yes/no-questions. Principal questions are often explanation-seeking in nature, emerging from inquirers' need to understand new phenomena on the basis of their existing knowledge.

Knowledge Building is a widely acknowledged approach to education and innovation, developed by Marlene Scardamalia and Carl Bereiter in the University of Toronto. Scardamalia and Bereiter define Knowledge Building as "… the production and continual improvement of ideas of value to a community, through means that increase the likelihood that what the community accomplishes will be greater than the sum of individual contributions and part of broader cultural efforts" (Scardamalia & Bereiter, 2003, 1371). The approach emphasizes that in the knowledge society, all people need to work creatively with knowledge, and practicing of such competencies should start from the early age. According to the basic message of Knowledge Building, we should not wait until students master existing pieces of knowledge or necessary sub-skills, such as critical thinking or collaboration; instead, the exercise that offers the best preparation for life in the knowledge society is the participation in the full process of collaborative knowledge creation by elaborating answers and explanations to true questions of understanding. What is radical in this approach is treating knowledge as an object, something that can be created, improved and re-used together. In conventional educational insights, knowledge is personalized and principally regarded as content located in individual people's minds (Ludvigsen & Mørch, 2003). Bereiter (2002) proposed that individual learning that occurs through engagement in knowledge building activities can be characterized as indirect learning that cannot be taken for granted; it occurs as a byproduct of knowledge creation efforts carried out for another purpose. According to him, a special potential educational value in knowledge building is the possibility for students to learn to *be knowledge builders*; i.e., to learn the practices and competences for expert-like knowledge creation. However, this goal also

requires deliberate pedagogical efforts from teachers, and cannot be taken for granted just because students appear to be engaged in the relevant activity (Bereiter, 2002).

Originally, the Progressive Inquiry model mostly represented the socio-cognitive approach to learning and, hence, relied on cognitive research on educational methods, in addition to the above-mentioned theories; such as the cognitive significance of self-explanation in understanding (Perkins, Crismond, Simmons & Under, 1995), social distribution of cognitive efforts (Brown & Palincsar, 1989), or the necessity of working with explanatory scientific knowledge for deepening one's understanding (Chi, Bassok, Lewis, Reiman & Glaser, 1989). As a result from the present researchers' improved understanding of professional knowledge practices and educational reality, through empirical and theoretical research, the model has evolved, during the last ten years, from the initial cognitively oriented one toward versions that highlight pragmatic and socio-cultural aspects of inquiry (Hakkarainen, 2009; Muukkonen & Lakkala, 2009; Paavola & Hakkarainen, 2005). This transformation has also affected the shift in the emphasis of the present sub-studies, as was mentioned in the previous section.

2.2.1 Central elements of the Progressive Inquiry model

The *Progressive Inquiry* model presents knowledge creation as a cyclic process, in which some central elements of collaborative inquiry are explicated (see Figure 1). It proposes that students' genuine questions and previous knowledge of phenomena are a starting point of a deepening process, in which students explain phenomena, share their expertise and build new knowledge collaboratively with the support of technology and knowledge sources. The objective is not to follow the elements mechanically in an educational setting, but the model offers conceptual tools to discuss and make visible the strategies and activities that are crucial in knowledge-creation efforts and collaborative inquiry (Muukkonen et al., 2008). The activity specified by the model should not merely aim at content mastery; a parallel emphasis is on developing the skills of solving problems and constructing new knowledge by imitating the practices of mature knowledge communities (Hakkarainen et al., 2004).

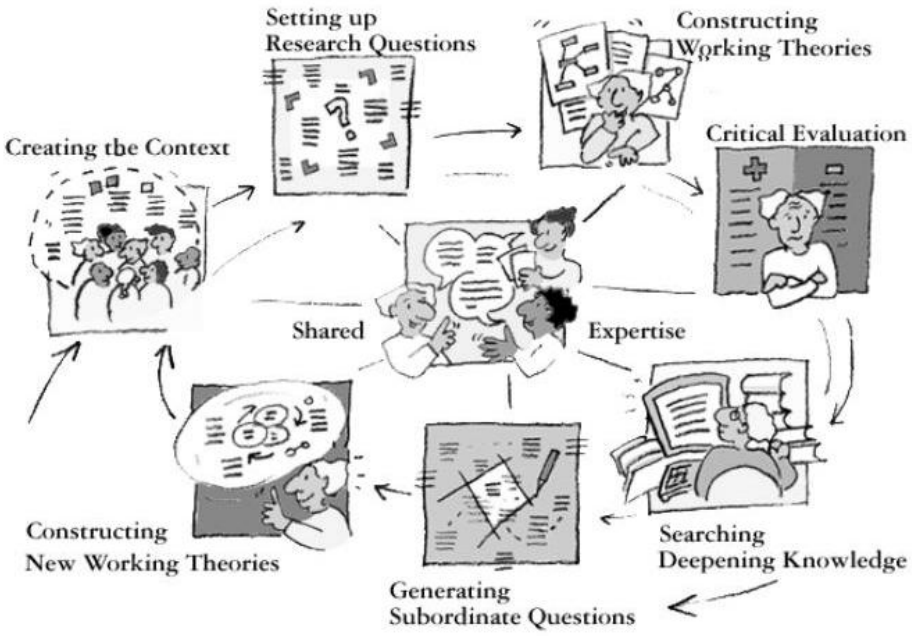

Figure 1. Elements of Progressive Inquiry

Below, the basic elements of the Progressive Inquiry model (based on Hakkarainen, Lonka & Lipponen, 2004; Muukkonen et al., 2008) are briefly explained with some comments related to the challenges of implementing the principles in prevailing educational practices.

Shared expertise: The central principle of the model is that all phases of the inquiry process should be conducted together and all knowledge be shared between participants. The diversity in expertise and interaction with various information sources and experts is considered to promote the improvement of ideas and explanations. Web-based technologies are considered to provide unique affordances for sharing the process through offering easy access to materials and produced knowledge as well as tools for co-constructing ideas produced by the students. It is still quite rare in conventional learning settings in schools and universities that all ideas, writings and productions made by the students are openly shared between all participants; usually students submit their work mainly for the teacher.

Creating the context: At the beginning of the process, the teacher is expected to organize orienting activities, in order to jointly create the context for the inquiry project. This anchors the problems being investigated in the central conceptual principles of the domain or complex real-world problems, not only to some themes that are defined in the

curriculum or school book without an explicated reason. The purpose of context creation is to direct students to start reflecting on questions that are interesting and worthwhile to investigate, and foster their personal commitment to the problem-solving process. It is essential that the topic be sufficiently complex and multifaceted so that it can be approached from various perspectives. This goal of multidisciplinarity appears to be a problem particularly in secondary level education where teaching is organized in separate lessons based on clear-cut borders between subject domains. The context may be created, e.g., by introducing a critical text or article, showing videos, presenting stories or having a study visit.

Setting up research questions: An essential aspect of progressive inquiry is to set up questions or problems that drive and direct the whole process of inquiry and knowledge creation. Especially valuable are questions that students create and formulate themselves, based on issues that they want to know or are interested in concerning the chosen phenomena. Questions provide heuristic guidance for the process by constraining and directing the search for information. Many educators, who have been acquainted with the model, appear to be very suspicious, especially, about this idea of framing the whole educational unit according to students' own questions emerging during the process, because they feel insecure about whether the essential questions come up. The concrete methods for creating, evaluating and choosing appropriate questions for each inquiry process can vary from setting to setting: questions can, e.g., be constructed individually first and later in groups, they can be chosen based on groups' interests or they can be formulated together in combined groups, and then allocated for each sub-group with the support from the teacher.

Constructing working theories: Before using academic literary sources to answer the created questions, students should write their own explanations to the questions with their existing background knowledge, and openly share these explanations with each other. This serves to illuminate students' prior conceptions of the issues being studied and creates a culture where knowledge is treated as something that can be questioned, created and elaborated together. Typically, students do project-type work in schools and universities by choosing a topic and, directly after that, starting to collect information related to the topic, without explicating clear epistemic goals or criteria for recognizing relevant information from irrelevant one. Starting from the stated research questions and

related explanations provides a more focused basis for the subsequent process, which also ought to prevent simple copying of ready-made explanations from information sources.

Critical evaluation: Critical evaluation addresses the need to assess the strengths and weaknesses of different theories and explanations produced, in order to direct and regulate students' joint efforts and the evaluation of the process itself. Through evaluating whether and how well the working theories explain the chosen problems, student groups seek to assess the strengths and weaknesses of different explanations as well as identify contradictory explanations, gaps of knowledge, and the limitations of intuitive explanations. Critical evaluation helps students rise above their original achievements by creating a higher-level synthesis of the results of the inquiry process. Explicit emphasis on such evaluation activity is supposed to provide students with opportunities to practice the critical reflection of joint work and inquiry outcomes from a "metalevel", which does not usually emerge spontaneously and is not a frequent activity in typical educational settings.

Searching deepening knowledge: Students should explore diverse information sources (text books, journal articles, Web-sources, the teacher and other experts) to find answers to their questions. A comparison of intuitively produced working theories with well-established expert knowledge or scientific theories tends to clarify the weaknesses of students' explanations. The information sources should be used in an elaborative and evaluative way, rather than simply copying information. The question-driven approach is meant to provide heuristic guidance for students, in learning to exploit scientific or expert information from academic literary sources for answering various open-ended knowledge problems. It may first be a challenge for students to exploit authentic professional resources in addition to readable text books, but the purpose of progressive inquiry is, precisely, to practice the utilization of various information sources in productive and knowledgeable way.

Generating subordinate questions: The inquiry process progresses through the transformation of the initial, broad, non-specific questions into subordinate, more specific questions based on the evaluation of the knowledge produced. The dynamic nature of inquiry is based on the fact that generation of intuitive explanations and obtaining of new scientific information create new research questions that could not

have been foreseen at the beginning of inquiry. By finding answers to subordinate questions, students gradually approach answering the big initial question. For a teacher, the challenge is to motivate and promote students to continue their question generation process after the first round, because typical school work is based on practices where the product (e.g. a report or an answer in an examination) is completed at a particular time, without engaging in improving the produced solution.

Constructing new working theories: New research questions and the scientific or expert knowledge that the participants explore give rise to new theories and explanations. Web-based technologies, if used throughout the process, are supposed to facilitate the saving and documentation of all ideas, explanations and versions of theories produced by the participants; such documentation makes the development of explanations a visible process and all knowledge easily reusable for summing-up. The process includes publishing summaries of the inquiry results in various intermediate stages and in the end. Although the inquiry process itself is a central learning experience for students, a requirement to produce a concrete final product (such as a written report, poster or presentation) is intended to create a shared mediating object that makes students' joint work more systematic and goal-oriented.

2.2.2 Web-based technology for progressive inquiry

The usage of Web-based technology was closely integrated into the Knowledge Building approach, which materialized in the pioneering work of Scardamalia and Bereiter with their colleagues (Scardamalia et al., 1994; Scardamalia, Bereiter, McLean, Swallow & Woodruff, 1989) to develop the Computer-Supported Intentional Learning environment (CSILE) and later its revised version Knowledge Forum (KF). KF is widely used in many countries, especially integrated to research projects for developing educational practices. CSILE/KF is designed for supporting knowledge building communities to work on shared ideas through virtual knowledge views that enable the textual and graphical representation of ideas and reorganization of knowledge artifacts that are called *notes*. Notes can, for instance, be written, searched for, co-authored, quoted, commented on, replied, linked together and rearranged spatially. "Rise above" notes support the improvement of ideas through synthesizing and generalizing previously produced knowledge (Scardamalia, 2004). One of the main innovations in

CSILE/KF is a feature to specify each note by a built-in label ("Thinking type") that represent the essential aspects of knowledge building inquiry (e.g. Problem, Own explanation, I need to know) to structure and support students' explanatory process. Authors should choose one of the labels for each note that they write, in order to intentionally consider and explicitly define the role of the produced idea for theory refinement and constructive criticism (Scardamalia, 2004).

Implementing progressive inquiry in an educational setting does not categorically assume any use of Web-based technology to mediate inquiry activities; for example, some teachers have applied it using papers and pencils as tools for students in settings where any web-based learning environment has not been available. However, factually the usage of technology is highly interrelated with the goals of progressive inquiry because the model was originally developed for computer-supported collaborative learning settings and for educating expert-like knowledge work, in which the usage of technology is an essential element (Hakkarainen, 2009). Web-based tools allow, among other things, the modification of the created, epistemic artifacts, enhance their sharing and co-construction, provide access to the shared knowledge space from distant places, and save the process for later reflection. These all are central prerequisites for the collaborative elaboration of the inquiry questions, explanations and theories as well as for the evaluation of the outcomes and joint inquiry practices.

Like CSILE/KF was designed to support knowledge building with some built-in features, the Progressive Inquiry model is implemented in a collaborative piece of software called Future Learning Environment (FLE), building on the ideas of CSILE/KF. CSILE and KF are commercial products that were originally made for local area networks whereas FLE functions in Internet through a browser, and it is open source and free software. The FLE development project was initiated by the developers in Media lab in the University of Arts and Design in Helsinki; the research group developing the Progressive Inquiry model at the Department of Psychology in the University of Helsinki, participated in the design of successive releases of the system. The present version of the system is FLE3 (see http://fle3.uiah.fi). The basic elements of FLE3 are a user's WebTop (virtual desktop), a Jamming module and a Knowledge Building module (Leinonen, Kligyte, Toikkanen, Pietarila & Dean, 2003). In a personal WebTop, each user can store documents, files and links as well as arrange them in

folders. Users in the same course can visit each other's WebTop and see its content. Jamming is a tool for sharing and versioning collaboratively constructed digital artifacts (files that can be graphs, audio, video, text, etc.). The Knowledge Building (KB) module provides threaded discourse forums for sharing and elaborating problem definitions, explanations and theories together. The inquiry discourse is structured by asking the user to categorize each posting according to one of several specified "Knowledge types" (Problem, Own explanation, Deepening knowledge, Comment, Metacomment, or Summary), similarly as in Knowledge Forum.

In an EU-supported research and development project ITCOLE (Innovative Technology for Collaborative Learning; http://www.euro-cscl.org/site/itcole/) in the years 2000-2003, FLE3 was further developed. In the same project, similar functionalities were implemented in the Synergeia BSCL system (Basic Support for Collaborative Learning, see http://bscl.fit.fraunhofer.de/). The system was based on well-known groupware system BSCW (Basic Support for Collaborative Work) that was developed in the Fraunhofer Institute for Applied Information Technology FIT in the mid-1990s (see http://public.bscw.de/en/index.html). Synergeia BSCL includes similar features as FLE3 to support progressive inquiry practices, such as file repositories for sharing documents, threaded discussion forums for conducting collaborative inquiry discourse, "Knowledge Types" for labeling messages according to the Progressive Inquiry process, and some awareness tools for informing who is online at the same time or what activities each participant has conducted in the shared forums (for details, see Rubens, Emans, Leinonen, Gomez Skarmeta & Simons, 2005).

In the present research, versions of the FLE system were used in Studies I and IV, and BSCL Synergeia system in Study III. In study II, a special system, Virtual Web-School, developed for schools in the Media Centre of the Helsinki City Department of Education, was used in the investigated inquiry learning unit; the system provided only a simple threaded discussion forum tool for virtual collaboration.

2.3 The metaphor of scaffolding as characterizing procedural support

Because various investigators of students' inquiry efforts (e.g., Krajcik et al., 2000; Lipponen et al., 2003; Muukkonen, Hakkarainen & Lakkala, 1999) or online discussions (Hewitt, 2003; Thomas, 2002) observed that students' spontaneous and self-organizing discourse often remains superficial and does not easily progress in theory building, a teacher's or tutor's role in contributing to students' technology-mediated progressive inquiry process was considered as a central question at the beginning of the present study. The phenomenon was studied particularly in the sub-studies I and II.

There is a great deal of research conducted in the fields of "e-learning" or "online learning" about the ways of tutoring to support students in virtual discussions or technology-mediated learning activities. For instance, Berge (1995) divided tutor's roles into four categories – technical, managerial, social and pedagogical – and presented various tasks that belong to those roles. Salmon (2004) introduced a five-stage model for practicing e-moderation, including access and motivation, online socialization, information exchange, knowledge construction, and development. Based on the model, Salmon listed various tutoring activities to be important, such as introducing new questions and topics if necessary, linking discussions to theory, or making summaries of the discussions. However, such studies and models, in general, appear only to provide rather arbitrary or superficial lists of guidelines for the on-line tutoring activity without much theoretical or empirical justification. Most of the studies show no evidence of being grounded in any sound theory-based pedagogy that the tutoring activities are intended to promote.

Since the existing research literature about online tutoring did not provide appropriate conceptual tools for developing analytic frameworks for the present research, the metaphor of *scaffolding* (Wood, Bruner & Ross, 1976) was addressed as a possibly useful notion to conceptualize and model the human tutor's role and contribution to students' inquiry. Originally, the scaffolding metaphor was used to indicate that adapted guidance that a more competent adult provided to help an individual learner accomplish a problem-solving task that was otherwise beyond his or her skill. The support was given only as long as needed, until independent performance was achieved; *fading* was considered an essential feature of scaffolding (Pea, 2004). An

important theoretical construct in the background of the scaffolding metaphor is the concept of the Zone of Proximal Development (Vygotsky, 1978). The implication of the concept of ZPD is that individuals have a learning potential that can be reached with scaffolding provided by other people such as tutors, teachers, or peers (Lajoie, 2005).

In the framework of knowledge-building pedagogy, Bereiter and Scardamalia emphasized that an essential aspect in promoting students' own knowledge building efforts is that the teacher does not do the critical cognitive tasks on behalf of the student, but strive for turning the strategic cognitive activity over to the students. They presented prototypical teacher models A, B, and C to illustrate this principle (see Bereiter & Scardamalia, 1987; Scardamalia, 2002): Teacher A focuses on organizing students' activities without taking cognitive responsibility for their progress; teacher B, in contrast, directly assumes the cognitive responsibility by asking questions and explaining the issues being investigated, acting more as a co-inquirer rather than just a guide for students; teacher C, in turn, engages in an intensive effort to get the students pose questions and elaborate their explanations, seeking to ensure that the students develop competencies to manage the inquiry strategies by themselves. In Study I of the present dissertation, these generic models were considered a useful overall conceptualization for summarizing the results of three tutors' scaffolding patterns in on-line inquiry discourse.

Most of the earlier studies focusing on scaffolding and tutoring (Lepper, Drake & O´Donnell-Johnson, 1997; Wood & Wood, 1996) were based on individual tutoring situations where a tutor was guiding one individual learner in a face-to-face situation. In addition, the tasks that the learners tried to accomplish were rather formal, structured problems that had a known correct solution. Also those studies and models where tutors' scaffolding of group learning or collaborative inquiry was examined, were mainly based on face-to-face group instruction or classroom settings (Hogan & Pressley, 1997; Levin, 1999; Mercer & Fisher, 1993; Roehler & Cantlon, 1997); therefore, they do not necessarily apply to technology-mediated or "virtual" educational settings. If students' work is organized as collaboration around ill-defined problems through Web-based tools, the demands for scaffolding and tutoring change because of the changed communication and activity patterns created by technology-mediation and the nature of tasks.

In the recent research concerning educational technology, the mechanisms of scaffolding have, to a great extent, been studied related to the possibilities of embedding scaffolding structures in the technology itself (Puntambekar & Hubscher, 2005; Pea, 2004). This means that special features are built in the basic functionalities of the software as additional supporting tools to explicitly promote intended user activities and cognitions. Supporting tools may include such aspects as structured workspaces, pre-designed labels to be used in categorizing knowledge and actions, graphical organizers, and prompts. The idea behind these so-called "scaffolds" built in the technological tools is the same as in scaffolding provided by a tutor; namely, students are expected to engage in more complex cognitive or cultural activities with than without them (Pea, 2004). Some notable endeavors that have focused on developing pieces of software including such support for specific practices are KIE (Knowledge Integration Environment) and its argumentation tool SenseMaker (Davis & Linn, 2000); and work that has focused on metacognitive facilitation in Inquiry Iceland software (White & Fredriksen, 2005). The "Thinking types" in CSILE/KF, or "Knowledge type" labels in the FLE system (mentioned in the previous section), are examples of such functionalities that are nowadays called built-in scaffolds in tools.

In previous research results, concerning the inquiry scaffolds in FLE, it was observed that university students do not necessarily use the scaffolds in an elaborated way and appear to have difficulties in appropriating them (Arnseth & Säljö, 2007; Ludvigsen & Mørch, 2003; Muukkonen et al., 1999). However, it is important to realize that the usage of inquiry scaffolds should not be examined for evaluating whether students use them 'in a correct way' or whether they are 'easy to use' by the students. Rather, they should be seen as conceptual tools that promote, for their part, the intentional practicing of central strategies for question-driven inquiry. As Reiser (2004) suggested, software scaffolds should not necessarily simplify the task for learners but *problematize* issues so that the software forces students to recognize some important ideas or elements in the activity that they might otherwise overlook.

Human scaffolding and software scaffolds can be regarded as complementary methods among various means to support learners in complex educational settings, and their influence cannot easily be investigated separated from the context. Therefore, Puntambecar and Kolodner (1998; 2005) suggested widening the notion of scaffolding

to emphasize how various supporting elements in an entire educational setting affect students' activities and learning outcomes. They put forth the notion of *distributed scaffolding* for considering versatile support for student learning in complex learning settings. They proposed that the support needs to be distributed, in a complementary way, across various tools and agents that build up students' learning environment; such as instructional materials, task structures, social arrangements, technological tools, as well as teacher guidance. There should be *redundancy* between the various modes of support, which helps to achieve fading as some of the scaffolds may be removed in the course of time. Tabak (2004) developed this idea further by proposing that the various elements, constituting distributed scaffolding, should be in *synergy* with one another, addressing the same learning goals and reinforcing one another to produce stronger support. These viewpoints were applied especially in Study I to examine the combined role of tutors' on-line guidance and the affordances of the Web-based collaboration tool, FLE, in contributing to students' inquiry efforts.

2.4 Overall pedagogical design of complex educational settings

Procedural support during students' inquiry efforts, discussed in the previous section, appears to be only part of the story when on is discussing teachers' role and responsibilities in implementing collaborative inquiry methods in educational practice. Gavriel Salomon, an acknowledged pioneer in the research on technology in education, stated already in 1992:

> "… what matters is not just the design of a computer tool or program, not even the design of a single task or curricular unit. Rather, the cultivation of minds, which itself requires mindful engagement in a social process of meaning appropriation, requires that *the whole learning environment, not just the computer program or tool, be designed as a well orchestrated whole*. This includes curriculum, teachers' behaviors, collaborative tasks, mode of peer collaboration and interaction, tasks, learning goals, and the like." (p. 64, emphasis from the original reference)

Hogan and Pressley (1997) proposed that the role of a teacher in inquiry practices is not so much to execute a set of specific guidance strategies, as *to organize the whole*

learning environment to establish an underlying culture that focuses on collaborative problem-solving. Teachers' role is not only to guide but, above all, to pre-plan and organize the inquiry activities as a whole. Planning and orchestrating the entire educational setting to follow the principles of knowledge creation and collaborative inquiry requires taking an overarching perspective on the pedagogical design. An interesting question is, what do we actually design when we are designing educational units that follow technology-enhanced collaborative inquiry pedagogues (Barab, 2003)? The challenge lies in the fact that one cannot predict, or design in advance, the processes and outcomes emerging in settings that are based on participants' collaborative activities and solving of ill-structured, open-ended problems (Dillenbourg, 2002).

An issue across the individual sub-studies of the present research was the evident need to find some conceptualization or framework, through which the basic elements in the designs of various educational units, following progressive inquiry, could be described and examined in a systematic and unifying way that is in line with the socio-cultural approach to learning. Requirements for taking that complexity of learning settings into account in the models of pedagogical design and educational research have recently been stated by various researchers (Scardamalia & Bereiter, 2006; Hong & Sullivan, 2009; Jörg et al., 2007; Puntambekar, Stylianou & Golstein, 2007). However, there is a lack of concrete models or frameworks so far been presented in the literature that would support the linking of such visions with the concrete design or examination of actual educational settings.

The inspection of prevailing models of *instructional design* (Gagne & Merrill, 1990; Young, 1993) revealed that they do not seem to provide appropriate theoretical or conceptual frameworks for modeling and exploring with the integrated elements belonging to the design of complex educational settings. According to Reiser (2001), the core practices in the field of instructional design are: a) the use of media for instructional purposes, and b) the use of systematic instructional design procedures. After the 1990's, one factor influencing the development of instructional design models has been the popularity of constructivism as a loose theory of individual learning, and its emphases on designing learning tasks for solving complex and realistic problems, working together with peers to strengthen individual learning, and taking the ownership

of the learning process (Reiser, 2001). However, various researchers (Häkkinen, 2002; Lowyck & Pöysä, 2001; Strijbos, Martens & Jochems, 2001) have stated that models of instructional design are not very useful for pedagogical approaches emphasizing collaboration and knowledge creation because they mainly concentrate on the learning outcomes of individual students, detailed pre-structuring of content and strict sequencing of activities. The models do not adequately account for social element and they overlook socio-cultural perspectives of orchestrating socially mediated, emerging activities in educational settings. Rather, the pedagogical design of collaborative inquiry is *indirect*, focusing on organizing the preconditions for the collaborative activity but not imposing the activities or learning outcomes exactly (Jones et al., 2006).

One design approach especially related to designing CSCL settings is the idea of directing students' epistemic and collaborative activities through structured *scripts*, primarily embedded in a technological environment. A script is a rather detailed set of guidelines, rules and functionalities that are designed to engage groups in essential interactions by structuring the co-learners' activities and thereby supporting coordination between distributed actors as well as guiding them through the collaborative learning process (Dillenbourg, 2002; Weinberger, Ertl, Fischer & Mandl, 2005). Based on the analysis of existing scripts, Kollar, Fischer and Hesse (2006) concluded that scripts usually represent two kinds of structuring: a) scripts that provide support on a content-related or conceptual level; and b) scripts that provide support related to the interactive processes between the collaborators (these are often called *collaboration scripts* in CSCL studies). This design approach acknowledges the social dimension of learning but it is still mainly focused on supporting and stimulating individual learners' content acquisition via, sometimes arbitrary and superficial, structuring of collaborative activity. Scripts are often designed for a special context and purpose, such as creating trust between the collaborators in the study of Mäkitalo, Weinberger, Häkkinen, Järvelä and Fischer (2005). According to Dillenbourg (2002), using of scripts may result in disturbing natural interaction and problem solving processes and may lead to the introduction of fake collaboration. It can be maintained that scripts are not the all-round solution to the design of the entire educational setting, but they can provide one additional means for explicitly scaffolding learners for moving

forward in some specific epistemic or social aspects of activity that the learners do not manage spontaneously.

One recent solution to the design of complex learning settings is to define certain *design principles* that explicate the central features of some pedagogical approach to guide the design (Kali, 2006). Design principles are normative, explicating the characteristics that a designed setting must have to achieve a particular set of goals in a specific context. For instance, Scardamalia (2002) specified principles for knowledge building pedagogy, and a similar approach has been used in the context of an international KP-Lab project (Knowledge Practices Laboratory), where a set of design principles were developed, aiming at fostering so-called "trialogical" knowledge creation practices that center around co-construction of knowledge objects through technological tools (Paavola & Hakkarainen, 2009). According to Bell, Hoadley and Linn (2004), design principles are mediating generalizations between research findings and unique examples that emerge in practice, and they are meant to inform innovative educational practice rather than for falsifying scientific laws. Some design principles are theory-driven (.e.g., the above-mentioned knowledge building principles, or trialogical design principles), others are based on bottom-up, empirically informed approaches (e.g., the Scaffolded Knowledge Integration Framework in Linn, Davis & Eylon, 2004, or a design principles database in Kali, 2006). Concerning the present study, the Progressive Inquiry model (see a section about the model above) sets the "normative", mainly theory-driven design principles for the investigated educational settings. Design principles provide heuristic guidelines about the characteristics and qualities that the elements in an educational setting should include, in order to reach the stated goals; however, they do not help in deciding *what* those critical elements (e.g. the features of technology, collaboration practices, teacher's role) in an educational setting are that should be designed and how to operationalize the principles.

Research by Katherine Bielaczyc (2001; 2006) inspired the researchers of the present study to consider the examination of the pedagogical designs for educational settings from a new perspective. She used the notion of social infrastructure as complementary to technical infrastructure in organizing technology-supported inquiry learning settings. *Infrastructure* appeared to be a very suitable notion to be applied in describing the basic conditions that should be designed for shaping and supporting collaborative inquiry

practices in educational settings, because it highlights the indirect nature and cultural connection of the pedagogical setup. For instance, Lipponen and Lallimo (2004) used the notion of 'learning oriented infrastructure' and Guribye (2005) discussed 'infrastructures for learning'. Star (1999) defined infrastructure as invisible, being in the background, but also as fundamentally relational, becoming real infrastructure only in relation to organized practices. She listed infrastructure as having, for instance, such properties as embeddedness, transparency, learnt as part of membership, linked with the conventions of practice or embodiment of standards. For the present research, the term *pedagogical infrastructure* was chosen to represent the conditions and requirements created in some educational setting, aiming at fostering students' progressive inquiry efforts.

In educational literature, the concept *learning environment* has been used as a generic term to describe the overall setting or situation in which learning occurs, either through official instructional efforts or in unofficial situations (e.g., Land & Hannafin, 2000; Lowyck & Pöysä, 2001). Some publications specifically focus on providing frameworks and guidelines for designing a learning environment (see Jonassen, 1999; Kim & Hannafin, 2004), and there might be similarities between the frameworks guiding the design of learning environments and the idea of pedagogical infrastructure. However, because the concept 'learning environment' is often used as a rather broad descriptor of all possible elements in official and unofficial learning situations, rather than a strict construct that supports concrete design of specific educational settings, it has not been adopted in the present study. In addition, in the context of computer-supported collaborative learning, the concept 'learning environment' is also used only to refer to web-based technological systems or online tools that are meant for collaborative learning activities (Oliver & Herrington, 2003; Rubens et al., 2005), which makes the concept too ambiguous to be useful.

A pedagogical infrastructure, deliberately designed and built up by the teacher, can be defined as involving such a "miniculture", mentioned by Bell (2004), which mediates cultural conventions to promote the cultivation of learners' activities towards intended practices. There is always a pedagogical infrastructure of some sort in an educational setting, but when conventional pedagogical methods are followed (e.g., practices based on teachers' lecturing), the influence of the 'invisible' pedagogical

infrastructure often remains unnoticed and unevaluated. However, when more radical changes in the pedagogical practices are aimed at, the pedagogical infrastructure should be explicitly and purposefully redesigned (Lipponen, Lallimo & Lakkala, 2006).

Because one central focus in the present research was the role of Web-based tools in supporting students' collaborative inquiry efforts, naturally the *technical* arrangements are one essential component in the examined pedagogical infrastructures. These include both the features of the tools and whether they provide appropriate affordances for the collaborative inquiry activity (Resta & Laferrière, 2007), and arrangements to provide access and guidance for students to use the technology in appropriate and productive ways from the perspective of the inquiry goals. Based on the socio-cultural perspective, technological tools used in educational settings should been seen as part of cultural resources that are utilized to transfer societal practices across generations, rather than as a means used only for supporting learning of some specific content or skill (Pea, 2004).

Concerning the *social* arrangements of collaborative inquiry settings, several studies have reported that committed and productive collaboration between students does not emerge spontaneously but require explicit rules, agreements and organizational structures (e.g., Dillenbourg, 2002; Wegerif, 1998). In the context of co-operative learning, Cohen (1994) suggested that if students are expected to seriously engage in collaborative action, the tasks should be defined as "genuine group tasks" so that it is not possible to complete them properly without working together. For instance, findings from the study of Rourke and Kanuka (2007) indicated that students put their main efforts at individual reading and writing assignments because those were assessed on the quality and substance; they did not invest much in computer conferencing activity, which was assessed only on the frequency of participation. In progressive inquiry activities, all members are assumed to participate in and take responsibility of creating, commenting, revising and developing common explanations and versions of the knowledge products. Such collective responsibility is strongly emphasized in the knowledge building approach (Scardamalia, 2002) although in the studies of knowledge building it is not clearly explicated how such collective responsibility could, in practice, be promoted or fostered through pedagogical arrangements.

Bielaczyc (2006) defined the social infrastructure to include the following four dimensions: a Cultural Beliefs dimension, a Practices dimension, a Socio-Techno-

Spatial Relations dimension, and an Interaction with the "Outside World" dimension. Although many ideas in her framework are in synergy with the views of the present study, it remains somewhat unclear where the exact dimensions come from and what are the theoretical assumptions that have resulted in those four dimensions. The approach appears to be somewhat technology-centered; the role of the introduced Social Infrastructure Framework for supporting pedagogical design is defined as "to determine the specific elements of the social infrastructure for a given technology-based tool" (Bielaczyc, 2006, 316). The central viewpoints of the present study, namely seeing pedagogical design as a means to mediate and promote central societal practices or cultural conventions through more overarching activity structures and established practices, are not explicitly emphasized by Bielaczyc.

In educational practices aiming at supporting students' competencies for expert-like knowledge work, the knowledge that is associated in the process does not merely represent subject domain content that the individual students should try to internalize; rather, knowledge is treated as a joint object, something that can be created, improved and re-used together (Bereiter, 2002). Therefore, as Paavola, Lipponen and Hakkarainen (2002) stated, besides technical and social infrastructure, the promotion of knowledge creation practices in education also requires an appropriate *epistemological infrastructure*, referring to individual and collective practices of working with knowledge, treating knowledge as something that can be shared and developed, and deliberate efforts to engage students in knowledge-creating inquiry. Similarly, in the context of mathematics teaching, Sfard (2000) discussed meta-discursive rules that determine the epistemological infrastructure of the educational discourse. She argued that the meta-discursive rules of school math should better resemble those of professional mathematicians at least in the basic aspects. Chinn and Malhotra (2002) evaluated the ways of teaching scientific reasoning in schools and contrasted 'simple inquiry tasks', typical in many textbooks, with 'authentic scientific inquiry tasks'. On their opinion, the former ones do not adequately simulate the complex epistemological nature of true scientific reasoning; they claim that inquiry pedagogue in schools should carefully be designed to afford authentic epistemological aspects of scientific reasoning.

As Bereiter and Scardamalia (1987; Scardamalia 2002) illustrated through the teacher models A, B and C, described in the previous section, the ultimate goal for the

progressive inquiry pedagogue should be to coach the students to take responsibility for the higher-level aspects of inquiry upon themselves, and be able to intentionally improve their explanations and working strategies. This goal relates to *cognitive* and *metacognitive* aspects of the inquiry activity. Students should gradually *internalize* the critical elements of the desirable, culturally essential strategies (Vygotsky, 1978). Specific methods should be implemented in the pedagogical infrastructure to foster the advancement of students' self-regulative competencies and metaskills for monitoring and regulating both individual, collaborative, and knowledge-related aspects of the inquiry activity (Bolhuis & Voeten, 2001; Muukkonen & Lakkala, 2009). Such methods may include, among others, giving students concrete *conceptual tools*, such as guidelines, models, templates, and software scaffolds for planning, monitoring, and reflecting their work; or *metacognitive tasks*, such as directing students to explicitly plan their activities and justify their choices for action, or arrange the phases of reflection on the produced knowledge and processes (Choi, Land & Turgeon, 2005; White & Fredriksen, 2005).

The present studies, especially sub-studies III and IV, were strongly shaped by the above mentioned requirements of changing the overall perspective from which pedagogical design is viewed. Another central motivator of the studies was an acknowledged need for practical, theory-based concepts and frameworks which could be used for discussing and examining the critical design aspects in complex pedagogical settings, aiming at technology-enhanced collaborative inquiry practices.

2.5 Institutional aspects in pedagogical development efforts

There always are various institutional, historically developed structures and conventions that influence and hinder the efforts of implementing new pedagogical innovations in educational field; a great deal of research, in general, has been conducted about this issue (e.g., Engeström, Engeström & Suntio, 2002; Songer, Lee & Kam, 2002). Candela, Rockwell and Coll (2004) stated that classroom research should place more emphasis on contextual factors, taking into account the institutional and social regulations and connections. Developing the quality of education in schools and universities as well as the implementation of technology to serve that objective depend on various interrelated issues, such as institutional practises and constraints of the

educational system, appropriate technical facilities and technical support available for teachers, the whole teacher community's support in transforming the practices, or the principals' commitment to support the development work (Dexter, Anderson & Becker, 1999; Ilomäki, Lakkala & Lehtinen, 2004; Roschelle et al., 2000). For instance, in the study of Spillane (1999) about teacher adoption of a reform in mathematics teaching, those teachers who did not significantly change their conventional ways of teaching mathematics, mainly tried to put the ideas in practice alone and in isolation, in their own classroom, without ongoing or sustained support from others for discussing the reform ideas. It appears very important aspect, in promoting pedagogical change in educational practice, to support collegial networking, collaboration with external actors and functional teacher communities (Cobb, McClain, de Silva Lamberg & Dean, 2003; Ilomäki et al., 2004).

It is important to be explicit about the level of phenomena and the primary unit of analysis that the educational investigation is focusing on. However, Lemke (2001) emphasized the importance of analyzing classroom phenomena in multiple time-scales and zooming in and out between the target level and its upper and lower levels. In the present research, the chosen focus was on the pedagogical practices actualized in certain, limited educational units, primarily from the point of view of teachers' responsibilities in constituting the setting and guiding students. However, some results might also require acknowledging the upper level phenomena, in this case institutional conventions and constraints affecting in the background of individual educational settings, as well as lower level phenomena, here the influence of pedagogical solutions into students' actions and learning outcomes as a result of the pedagogical intervention.

3 Research questions

To fulfill the demands for providing educators with research-based models and guidelines to transform their pedagogical methods with modern technology, it is important to systematically examine various efforts to implement innovative, technology-enhanced inquiry practices in educational settings. The present study examined such efforts in primary, secondary and university level education in Finland. The goal of the research was to examine the pedagogical challenges that educators face in implementing technology-enhanced collaborative inquiry practices, and to develop conceptual frameworks for designing and evaluating educational settings concerning such practices. Several aspects of the pedagogical practices are investigated: Educators' procedural scaffolding and situation-specific guidance during the inquiry process, appropriate usage of Web-based technologies to support inquiry, general organization and structuring of students' activities, and teachers' conceptions of the new methods and processes.

The research consists of four studies that form a continuum from focusing on issues related to teacher guidance during the inquiry process towards overarching structural aspects in designing and organizing student's inquiry practices. In Study I, the aims were to investigate how a human tutor contributed in the university students' collaborative inquiry process through virtual discourse forums, and how the influence of the tutoring activities shows in the students' inquiry discourse. In Study II, the aim was to examine a fairly challenging effort to implement technology-enhanced progressive inquiry as a distance working project in ordinary middle school context. In the study, the practices and challenges in organizing students' Progressive Inquiry process was investigated through analyzing teachers' and students' participation in a distance learning project supported by Web-based technology. Study III examined multiple teachers' ways of organizing progressive inquiry projects in primary and secondary classrooms through a generic framework for analyzing the pedagogical solutions. In Study IV, a design-based research effort consisting of four consecutive university courses, applying progressive inquiry pedagogy, was retrospectively re-analyzed in order to develop and test the generic design framework further.

Each sub-study I-IV had its own research aims and questions, relating to the specific cases and contexts. The research questions also evolved from one study to the other, based on the results and new theoretical, methodological and practical viewpoints received from the previous studies. The combined questions can be summarized in the following way, to frame the overarching research questions for the entire study consisting of the present dissertation:

1. *What are the critical features of authentic educational settings for reaching the aims of progressive inquiry?* This question concerns results that will provide information that is a basis for guidelines for educational practitioners about what solutions appear to work and what features in the set-up of an educational setting can be considered critical for reaching the central aims and principles of progressive inquiry pedagogy. Studies I, II and IV provide viewpoints for this question from various perspectives.

2. *What do the data suggest were the possibilities and difficulties in disseminating the usage of technology-enhanced collaborative inquiry pedagogies widely in authentic educational practice?* This question concerns the generally acknowledged problems with "scaling up" the usage of pedagogical innovations and sophisticated usage of ICT widely in educational institutions. Especially Studies II and III examine this question through investigating primary and secondary level teachers' practices in implementing progressive inquiry pedagogy in their teaching groups.

3. *What are the central components in the pedagogical designs of technology-enhanced collaborative inquiry practices?* This question relates to the development of a generic framework through which the pedagogical design solutions and the set-ups of actualized educational settings can be planned, analyzed and evaluated. This question was examined especially in studies III and IV.

4 Methods

4.1 Pragmatism and mixed method strategy

The main motives for the present research were very practical: To provide educators with research-based knowledge about applying technology-enhanced inquiry pedagogy in authentic educational settings. Therefore, from the philosophical point of view the study can be positioned to follow *pragmatism*; as it applies in social sciences pragmatism is defined as a research approach or paradigm that emphasizes the importance of research questions and the utility and practical value of results; the choice of research methods is subordinate to those aims (Teddlie & Tashakkori, 2003). The approach to sound explanations – truth – is through investigation of actual practices.

Although there is much ambiguity in the definitions of other main philosophical research paradigms in social and behavioral sciences, the two, most often recognized paradigms are *positivism/postpositivism* and *constructivism* (Morgan, 2007). Briefly defined, positivist worldviews postulate that there is a singular reality and the one-and-only truth that is to be discovered and defined by objective and value-free inquiry methods, 'objective' data, and generalized explanations, whereas constructivists, contrariwise, represent notions that there exist several subjective realities, that context-free generalizations are neither desirable nor possible, that all data are from a perspective, and that all research is value-bound (Feilzer, 2009). Pragmatists do not share the views of those two paradigms and are not so much interested in seeking to find either objective or relative truth, but to define *workable and applicable theories and explanations* through paying attention to cultural values and collaborative research actions, and looking at actual practices (Johnson & Onwuegbuzie, 2004; Morgan, 2007).

Although it is not relevant to go into detail in the philosophical examination of research paradigms, the differences between the main paradigms are important here because they closely relate to the views and debates of making choices about using *quantitative* and/or *qualitative* research methods in empirical studies. The positivist paradigm is usually associated with the reliance on quantitative research methods, whereas constructivists are considered to favor qualitative research methods. In recent literature, the pragmatic paradigm is linked to so-called *mixed method* strategy, which

abandons the dichotomy between qualitative and quantitative methods and posits that they can be combined in one study when it is relevant for answering chosen research questions and for reaching practical research goals (Feilzer, 2009; Morgan, 2007). Naturally, also in mixed method approach, methods should be used as rigorously as possible, being aware of the premises of each individual method.

When studying the implementation of technology-enhanced collaborative inquiry in a certain educational setting, the unit of analysis is the collective activity as a whole, not the measurement of separate variables indicating individual differences, as is often the case in learning research (Salomon & Perkins, 1998). In the present study, the mixed method strategy was chosen, precisely, because the object of the research is the practical investigation of authentic educational settings that are complex environments where numerous factors occur in relation to other factors, and it is not possible to get an overview of the phenomena through any single method. A variety of sources in data collection were used in all sub-studies, e.g., ethnographical observations, interviews and log-file analyses, and the basic investigative approach was the combination of qualitative and quantitative methods.

Johnson and Onwuegbuzie defined mixed method research as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study" (2004, 17). Mixed methods are becoming increasingly significant in educational research (Giannakaki, 2005). It has been stated that combining quantitative and qualitative methods in a single study can help illuminate various phenomena of the object under investigation in a complementary fashion, providing a multi-faceted and comprehensive picture of the research object and more holistic understanding of it (Sale, Lohfeld & Brazil, 2002). This is particularly valuable when studying complex social settings or aiming at multidisciplinary viewpoints and interpretations that have practical value (Kohlbacher, 2006; Todd, Nerlich & McKeown, 2004), as was the case in the present studies. According to Johnson and Onwuegbuzie (2004), with the mixed method approach, a broader and more complete range of research questions may be answered because the researcher is not restricted to a single method or approach, and stronger evidence for a conclusion can be reached through the convergence and corroboration of findings.

The main emphasis in the present studies was on qualitative methods because of the complex, novel and ill-defined nature of the research object. *Qualitative methods* are powerful, e.g., for describing complex phenomena or rich phenomena as they are situated and embedded in local contexts, or for generating tentative but explanatory theories about a phenomenon (Johnson & Onwuegbuzie, 2004). According to Candela et al. (2004), educational research conducted in authentic classrooms should take into account contextual factors, and it requires methods for integrating a detailed analysis of interaction within the larger activity structures. Windschitl (1998) pointed out that qualitative research approaches are especially valuable in investigating educational phenomena in novel fields. Typical weaknesses of qualitative methods, mentioned in research literature, are problems with the generalizability of results to other contexts, difficulties of testing hypotheses and theories based on the data, the laboriousness of data collection and analysis, and increased possibility for making biased and subjective analyses and interpretations (Johnson & Onwuegbuzie, 2004). For instance, the coding categories and analysis methods used for analyzing the technology-mediated discourse data in each sub-study of the present dissertation were inevitably somewhat case-specific because of the deviating authentic contexts and the partially data-driven approach of the analysis. On the one hand, it decreased the generalizability and comparability of direct analysis results (De Wever, Schellens, Valcke & Van Keer, 2006); on the other hand, such open and flexible analysis methodology enabled investigators to discover interesting phenomena that might have remained unnoticed if only pre-defined, theory-driven categories were applied.

Quantitative methods in data collection and analysis have, for instance, the following benefits compared to qualitative methods (Johnson & Onwuegbuzie, 2004): Data collection is rather quick and also the analysis is relatively less time consuming; the research results are relatively independent of the researcher; and the methods are useful for studying large data sets. In the present studies, quantitative data collection and analysis was used in order to get another type of perspective on some features and structures of the data than qualitative methods could provide. For instance, basic descriptive statistics of the content in the investigated databases helped getting an overview of the participants' technology-mediated inquiry activity and the quantification of the qualitative coding of textual data provided a possibility to use

statistical analysis methods to reveal some general trends in the discourse activity. Weaknesses of quantitative methods, mentioned by Johnson and Onwuegbuzie (2004), are that the defined measures may not adequately describe the actual phenomenon; pre-defined hypotheses may prevent discovering new, interesting phenomena; and information produced by quantitative measures may be too abstract and general for direct application to specific contexts.

A methodological challenge concerning the mixed method strategy in the present research relates to the compromises that have to be made concerning the strictness of the analysis methods, and the interplay between quantitative methods and various types of qualitative methods. The reliability of analysis is more easily definable by conventional statistical methods when using quantitative measures (e.g., the number of posted knowledge objects in the database) or methods of quantifying qualitative analyses results (e.g., reporting frequencies about the encoded units of textual data; Chi, 1997). More descriptive or interpretative analysis (e.g., describing the progression and characteristics of long-term discourse processes) is less rigorous, when evaluating through established scientific criteria; however, too atomistic an analysis at the micro-level appears inadequate for accounting the multiple dimensions and planes involved in examining educational practices in context across time and space (Candela et al., 2004). For instance, concerning both studies I and IV, the anonymous reviewers of the first article manuscripts gave feedback that quantitative results do not suffice to really understand what happened in the process or to make useful conclusions. Therefore, the characteristics of students' technology-mediated inquiry in separate settings were also compared by descriptively specifying the discriminating structures and patterns in the discourse processes. Reliability was ensured through using two analysts who together constructed the final interpretation.

As Johnson and Onwuegbuzie defined, in mixed method research, a fundamental principle is to "collect multiple data using different strategies, approaches, and methods in such a way that the resulting mixture or combination is likely to result in complementary strengths and nonoverlapping weaknesses" (2004, 18).

4.2 Design-based research

All the studies in the present dissertation have features resembling *design-based research* (also called design experimentation or design research). In particular, the single Study IV follows this approach through the iterative design and investigation of four under-graduate university courses by the researchers. In Study III, ten school teachers designed and implemented educational units based on progressive inquiry, first receiving substantial training on the pedagogical model and the usage of the Web-based collaboration tools. Also all the four sub-studies combined, constituting the entire dissertation, can be characterized as forming a large design-based research continuum, even though the studies did not follow each other in strict step-by-step fashion. However, the results from former studies had an influence on the subsequent solutions about designing collaboration technology or applications of the pedagogical model.

Design-based research is argued to be an emerging paradigm for educational inquiry (Design-Based Research Collective, 2003). Specific to design-based research is that research, theory and practice are intertwined in the studies (Edelson, 2002). It combines empirical educational research with the theory-driven design of learning settings, aiming at understanding how to orchestrate innovative pedagogical practices in authentic educational contexts, and simultaneously developing new theoretical insights about the nature of learning and teaching (Bell, 2004; Design-Based Research Collective, 2003). Design-based research is considered valuable as a form of educational research because it provides results that can be directly applied to improve educational practice, unlike experimental studies conducted in controlled laboratory settings (Brown, 1992; Edelson, 2002; Sandoval & Bell, 2004).

In design-based research, the focus of design can be in various elements of a learning environment – educational artifacts, activity structures, scaffolds, educational micro-cultures, and curricula – and also the research methodologies and theoretical perspectives may vary. Characteristic of design-based research is that it progresses iteratively in successive research and development phases; design solutions are strongly based on prior research and theory but it is also a strategy for developing theories; it investigates complex real-world contexts; practitioners and researchers work together; and it is focused on the development of sustained innovation in education (Bell, 2004;

Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Design-Based Research Collective, 2003).

Edelson (2002) delineates three types of theories that can be developed through design-based research: domain theories, design frameworks and design methodologies. A *domain theory* is a descriptive analysis of some specific educational problem, related to a certain context or outcome of intervention; a *design framework* is a generalized design solution that is prescriptive in nature – it defines the design features that are necessary to achieve certain goals in a certain context; a *design methodology* is a general design procedure, and it is also prescriptive, providing guidelines for the design process. Applying this categorization on the present study, the research related to the first research question (the implementation of progressive inquiry model in educational practice) fall mainly into the design frameworks category, and research concerning the third question (developing a conceptual framework for examining pedagogical designs of technology-enhanced collective inquiry) can be defined belonging to the design methodology category.

In its "strictest" form, a design-based research endeavor includes a definition of certain set of variables, based on some theoretical preconceptions of the researchers, through which actual educational settings are designed. Then the research tries to evaluate how well the conditions were designed, and what should be changed in order to improve the design and related learning gains. Engeström (2008) maintained that such an approach includes serious weaknesses, such as 1) vague unit of analysis; 2) a linear, predefined fashion of the intervention and its desired outcomes which ignores the agency of participants and possibilities for open-ended innovations; and 3) an acceptance of variable-oriented approach, without questioning the problematic notion of causality. Without commenting on the claims in detail, the research methods in Study IV can be defended by maintaining that it did not follow such strict form of design based research as Engeström is criticizing. The implementation of the Progressive Inquiry model in the investigated courses was more exploratory, testing various alternatives to operationalize the heuristic model of progressive inquiry into the reality of university courses; then interpretatively investigating students' inquiry engagement in each setting. Although the criteria or principles of the Progressive Inquiry model

influenced the course designs, they were applied quite openly and tentatively by the researchers who also acted as teachers and tutors in the courses.

One challenge in this type of design-based research endeavor – where the investigated pedagogical innovation is aiming at fostering complex, cultural practices of collaborative inquiry – appears to be, how then to define what counts as success or evidence of desired learning results in the data. It is not possible or meaningful to construct any simple test that would measure the learning gains concerning the inquiry skills or multidisciplinary domain contents, and the development of competencies for complex inquiry practices may last relatively long, taking several years to become fully articulated (Muukkonen & Lakkala, 2009). The analysis of the results apparently has to be able to address the interplay between the principles of the pedagogical model, the observed practices, and the mechanisms of related, indirect and long-term learning processes. In the sub-studies of the present dissertation, *students' collaborative engagement (degree and type) in inquiry*, evaluated through the characteristics and progression of technology-mediated inquiry discourse, was used as an indication of the success of the pedagogical intervention in each setting.

4.3 Multiple case study approach

One central decision made in the present research was to investigate the possibilities and challenges of the progressive inquiry pedagogue in several settings and contexts, not concentrating only on one or two examples. The choice to include multiple educational levels and subject domains was made, in order to be able to identify phenomena that appear similar across specific situations; hence, being able to investigate the scalability of the pedagogical innovation in various contexts. The research approach can be defined to represent *multiple* or *collective case study* (Yin, 2003; Stake, 2000), which is characterized by a study applying case study methodology but extended to several cases.

There is much ambiguity in the research literature, in general, about the concept of case study: its object, research methods or quality of results. Verschuren (2003) suggested using the concept 'case research' and defined it to mean a research strategy where "one single or a few cases are studied by means of an indiscriminate set of

methods and procedures". Yin (2003), who is considered being one of the most prominent experts in case study research, gave the following definitions of a case study:

"1. A case study is an empirical inquiry that

- investigates a contemporary phenomenon within its real-life context, especially when
- the boundaries between phenomenon and context are not clearly evident." (p. 13)

and

"2. The case study inquiry

- copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
- benefits from the prior development of theoretical propositions to guide data collection and analysis." (p. 13)

Typical of case research is that its research problems are open-ended, it investigates complex social phenomena and holistic characteristics of real-life events, it is iterative in nature, and it aims at new theory building of poorly recognized phenomena (Kohlbacher, 2006; Verschuren, 2003). Case research is often criticized of the issue that it provides little basis for scientific generalization (Kohlbacher, 2006). Yin (2003) answered the critic by stating that in case research, the goal is to generalize theories (analytical generalization), not to compute frequencies (statistical generalization). In the present dissertation study, the multiple case study methodology was adopted, precisely, in order to allow for the possibility of stronger interpretations and perhaps more powerful theory development than a single case could produce. Considered separately, sub-studies I and II are single case studies, but the overarching aim in the whole research endeavor was to be able to cumulatively combine the findings from separate sub-studies.

According to Yin (2003), case studies can be exploratory, explanatory, or descriptive. An *exploratory* case study is often some kind of pilot project that examines a new research field in order to develop questions, hypotheses or instruments for later research. *Explanatory* case studies aim at making generalizable, or causal, explanations and interpretations of some phenomena. A *descriptive* case study describes interesting unique cases on the basis of some theoretical framework without an explicit goal for generalizations or comparative analyses. Following this categorization, the case studies in the present dissertation can be described as primarily exploratory, but there were also explanatory elements in them. For instance, in studies I, II and IV one aim was to be able to explain how the teachers' procedural scaffolding and the set-up of the educational setting influenced students' engagement in inquiry.

4.4 Settings and participants

The sub-studies of the present research investigated the implementation of Progressive Inquiry pedagogy both in schools and in university courses. As discussed in the previous section, this solution was chosen because one central idea was to reveal some central, generic elements and phenomena, applicable across contexts and educational levels, in scaffolding and designing educational units for progressive inquiry.

Studies I and IV investigated undergraduate courses in the University of Helsinki that were conducted together with other researchers belonging to the same research group as the present author. In Study I, three tutors guided groups of students in progressive inquiry through Web-based technology in an undergraduate lecture course about cognitive psychology. The students came from many fields of study at the University of Helsinki, including forensics, mathematics, history, languages, and education. They took part in the two-credit course to complete a ten-credit minor unit in psychology. Study IV realizes a design-based research continuum through the investigation of four consecutive courses, mainly run by the same teachers and tutors. The main content of all courses was almost identical, focusing on the issues of technology-enhanced collaborative learning, even though they belonged to two different study programs (Media education and Minor unit in Psychology). Also the target groups of all courses were rather similar with students who have their major in various faculties

of the university. The course investigated as a single case in Study I was one of the courses re-examined in Study IV.

Studies II and III focused on testing the implementation of Progressive Inquiry pedagogy in primary and secondary level education in several schools in the City of Helsinki to investigate how the participating school teachers adopted the pedagogical ideas in their teaching. Study II was a case study in a lower-secondary school where a group of teachers and students participated in a distance learning inquiry course focusing on the topic of human culture. The experiment related to the Educational technology project of the City of Helsinki (see Ilomäki & Lakkala, 2003). Study III consisted of multiple cases where teachers implemented the pedagogical innovations of Progressive Inquiry and Web-based technologies in varying, authentic classroom settings. The 10 primary and secondary school teachers participating in the study were piloting teachers in a research and development project ITCOLE (Innovative Technology for Collaborative Learning, see http://www.euro-cscl.org/site/itcole/) funded by European Commission. The experiments of implementing progressive inquiry pedagogy in schools, investigated in Studies II and III, were conducted with teachers who were already rather competent in pedagogical development work and usage of ICT in teaching. The teachers received rather extensive training about progressive inquiry and computer-supported collaborative learning as part of the project (see details in Haatainen & Korhonen, 2002). One of the cases was a subsequent iteration of the same course, run by same central teachers, as was investigated in Study II.

4.5 Data collection

As is typical of case research, various kinds of methods were used to collect multifaceted data in the sub-studies. Each of the methods naturally has its limitations in revealing the full nature of the participants' experiences or activities in such complex real-life situation; therefore it was considered necessary to collect multiple data from all cases. In the following, all applied data collection methods are briefly described.

4.5.1 Database content and other authentic documents

Because the primary focus of the studies was to investigate educators' pedagogical practices in implementing progressive inquiry especially mediated by Web-based technology, the primary data type in all four studies was the content that was accumulated in the database of the web-based learning environment used in each case. The database content represented authentic documents of the investigated activity because they were not produced for research purposes. The database content included the entire structure of the database (e.g., working spaces, discourse forums and folders) as well as individual files and notes produced by the participants, both teachers and students. The data from discourse forums were retrieved for analysis as text files so that all the posted notes (including title information such as the title, author and the creation date of the note) were arranged in a hierarchical order based on the reply structure; the first notes of each thread were listed in chronological order.

In addition to database content, various other kinds of authentic documents were collected from the investigated cases when available. Such documents were, e.g., task instructions delivered by teachers (Studies II and III) or students' final works and reports of their course accomplishments (Study III).

4.5.2 Observations

One type of data collection in some of the sub-studies was observations. Information received by observations is often useful in providing complementary information for understanding the actual context and the phenomenon being studied (Yin, 2003). In study II, *direct observations* were conducted, meaning field visits to the case study site. We observed two meetings where the teachers discussed the course design, and most of the classroom session in which the students participated during their virtual course. The observer made notes of the teacher meetings. The classroom sessions were videotaped but the video recordings were mainly used as a means to allow the checking of the validity of the observation notes or some details of the situations afterwards.

In studies I and IV, the research team conducted the studied courses and the researchers themselves participated in them as teachers and tutors. This kind of *participant-observation* is a special type of observation where the researcher has an active role in the situation as a participant of the events; it enables better possibilities to

design the educational setting according to the research goals and to perceive the activities and collect data from "inside" (Yin, 2003). This kind of combined researcher-experimenter role is typical in design-based research (Cobb, Confrey et al., 2003).

4.5.3 Interviews

In Study III, also interviewing was used as a data collection method. All ten participating teachers were interviewed after their inquiry projects had ended. The type of interview can be called *a semi-structured interview* (Smith, 1995) or *a focused interview* (Merton, Fiske & Kendall, 1990). The questions were pre-planned and carefully worded so that the same main questions were asked from each teacher. The interviewer could also ask the respondents to specify something according to the previous answers, and the questions were open-ended in nature, guiding the teachers to evaluate and reflect on their experiences, not just to tell facts and details of their classroom projects. The teachers were interviewed individually; each interview lasted approximately one hour. All of the interviews were tape-recorded and transcribed verbatim for further analysis.

4.5.4 Written self-reflections

One data collection method was to ask the participants to self-reflect their experiences and activity by writing, in order to be able to compare the view received from authentic documents and observations with the participants' own considerations. In Study II, the teachers' own explanations of their pedagogical practices were collected by asking them to write biweekly teaching logs structured by pre-defined open questions, and a final report of the actualized learning unit. In Study IV, in all four courses the students were asked to self-reflect their course participation and learning experiences by writing a free-form self-evaluation report or by answering pre-defined open questions after the course. Also in Studies I and III, the participants written self-reflections were collected but they only had a minor complementary role among other data.

4.6 Data analysis

As stated above, both quantitative and qualitative measures were used in all sub-studies. Mainly non-parametric statistical tests or methods were used in the quantitative analyses. The methods of quantifying qualitative data were applied especially for analyzing technology-mediated inquiry processes from the participants' database postings. In addition, some results were obtained as qualitative descriptions of what was perceived in the data without any statistical treatment.

4.6.1 Qualitative content analysis

In the present study, the mixed method approach does not only mean combining quantitative and qualitative methods but also applying different types of qualitative analyses in the same study, representing different analytical methods and units of analysis. Some methods are more descriptive, others more analytical or interpretative (Wolcott, 1994).

In all four sub-studies, ethnographic-type techniques were utilized for re-constructing the overall setup and actualization of the investigated learning units or the process-related characteristics of some activities, combining versatile information of the collected data. Ethnographic analysis aims for a rich, detailed description of observed events in context, to be used to explain the social processes as a whole and figuring out what really happens in the investigated settings (Jones, 1998; Harvey & Myers, 1994). In the present studies, this was conducted by examining the data in various iterations and constructing a timeline story of the process. In Studies I and IV, the nature of university students' technology-mediated inquiry in separate groups and courses was compared by descriptively specifying the differing structures and patterns of the technology-mediated discourse processes. In studies II and III, various data sources, such as observations, database content and other authentic documents, interviews, or reflective writings, were used to build an overall picture of the educational units. First, the principal researchers made the preliminary analyses and interpretations, after which the choices were examined together with the co-authors of the article; disagreements were discussed and final decisions were made collaboratively.

More analytic approach, applying methods of quantifying qualitative analyses of textual data, introduced by Chi (1997), was applied for parts of the data. In the method,

textual data are first segmented following some defined rules, and then the segments are encoded or labeled according to similar properties with certain themes or concepts, based on preliminary theoretical ideas as well as issues emerging from the data. Seidel and Kelle (1995) described such process as creating a "decisive link between the original 'raw data' that is the textual material such as interview transcripts or field notes on the one hand and the researchers' theoretical concepts on the other". (p. 52). Anfara (2002) stated that because this kind of qualitative analysis is not replicable in the 'classical science' sense, he recommends to describe the analysis process and decisions as openly and possible on the grounds of refutability and freedom from bias. In the research articles reporting the present studies, the analytical procedures as well as excerpts from the original data are presented in the article as much as space allowed, to depict the qualitative analysis and interpretations made. All procedures of segmentation and coding of textual data were conducted using the ATLAS.ti-program (Muhr & Friese, 2004).

In studies I and II, Cohen's Kappa was applied to measure the inter-rater agreement of the created categorization in the qualitative content analysis. The principal investigator did the preliminary analysis, after which another researcher independently categorized 10 to 20 % of the data. Cohen's Kappa was chosen as a statistical measure to evaluate the correlation between the coders because it is generally considered a more robust measure than simple percent agreement calculation since it takes into account the agreement occurring by chance (Rourke, Anderson, Garrison & Archer, 2001). In Study II, the unit of analysis for the qualitative coding was an entire note. In Study I, messages were very long, including several ideas; therefore, note texts were segmented into smaller propositions, each of which was considered representing an idea that was encoded separately. The inter-rater reliability of the segmentation was measured through the single measure intraclass correlation (McGraw & Wong, 1996).

4.6.2 Descriptive statistics and non-parametric tests

Because the data used in the studies were mainly qualitative and the quantifiable measures were based on a small number of subjects, only descriptive statistics or non-parametric tests were applied for quantitative analyses. Descriptive statistics were used in all four studies to describe the overall structure and volume of knowledge produced

by the participants in the database of the used Web-based environment, such as the mean number of produced notes and documents, or the frequency or pattern of using inquiry labels in notes. Descriptive statistics include measures of central tendency (averages, mean) and measures of variability about the average (range and standard deviation), which are meant for giving the reader a 'picture' of the data collected and used in the studies.

In all studies, Chi^2 test was used for assessing whether the differences, observed in the quantitative or the categorized and quantified data sets, can be interpreted as being statistically significant. If the differences in the overall distribution of frequencies turned out to be statistically significant, cell-specific exact tests were carried out in order to examine whether the observed frequencies in each cell deviated from what could be expected by chance alone, using the Exacon program (Bergman & El-Khouri, 1987).

4.6.3 Social network analysis

Methods based on *social network analysis* (Scott, 1991) were used in Study II to examine the patterns of social interactions between the participants in the virtual discourse. Social network analysis methods were chosen because they provided special means to examine and illustrate complex sets of relationships between actors. Similar methods have recently been used in other studies in the field of CSCL (e.g., Choa, Gayb, Davidson & Ingraffead, 2007; Hakkarainen & Palonen, 2003; Lipponen & al., 2003; Martinez, Dimitradis, Rubiac, Comez & Fuente, 2003). All social network analyses were performed using the Ucinet program (Borgatti, Everett & Freeman, 1996).

The data for social network analysis consisted of mutual links between the participants' postings in the threaded discourse: who had commented on whose notes in the virtual discourse. A two-way matrix was built based on these mutual commenting structures. The *multi-dimensional scaling* (MDS) technique was applied to provide a spatial view of the communication patterns. The measure of *density* was chosen to examine the general level of interactions in the whole participant group both with and without the teachers' contributions, in order to analyze the teachers' influence on the communication. Density is a simple way to measure a network: the more actors who

have relationships with one another, the denser the network (Scott, 1991). In Study II, the measure of density indicated the proportion of the intensity of mutual commenting among the participants in the virtual discussions. Density was computed from a dichotomised matrix of replies (the participants had or had not sent replies to each other's messages, the frequency of replying did not matter) and it could vary from 0 to 1.

The participants' social position in the virtual communication was analyzed using *Freeman's degree*, which is a centrality measure. Centrality describes the importance or isolation of a member in the communication network. The degrees were counted from the sum of replies that the participants sent to others' messages (outdegree, indicates activity), and replies that the participants received from others (indegree, indicates 'popularity'). *Freeman's betweenness* value was used to show how often a given participant is found in the shortest path between two other students who did not directly comment on each other's messages in the discourse. Thus, it suggests the participant's position in regulating information flow within the communication network (Borgatti et al., 1996). For investigating whether the centrality of the participants varied according to the content of the discourse, and hence revealing whether the participating teachers and students took certain, deviating roles in the virtual communication, data from the qualitative content analysis of the discourse messages were integrated with the quantitative measures of mutual commenting.

Social network analysis is the most useful when investigating social structures and relationships in one community or group. The methods were not used in other sub-studies, because the measures are not easily comparable across groups of communities; e.g., most measures (density, centrality, degree) are related to the size of the group and therefore cannot be directly used to compare groups of different sizes.

4.7. Summary of the settings and methods

In Table 1 is a summary of the central features in the settings and methods of the four studies.

Table 1. Summary of the research settings and methods in studies I-IV.

Study	*Educa-tional level*	*Partici-pants*	*Object of research*	*Research setting*	*Data collected*	*Analysis methods*
Study I	University education	1 teacher 3 tutors 17 students	Scaffolding practices (research question 1)	Single case study (one undergraduate course)	Database content, participant-observations	Descriptive statistics, qualitative content analysis, quantifying qualitative data & non-parametric tests
Study II	School education	7 teachers 14 students	Scaffolding practices Overall pedagogical design (research questions 1 and 2)	Single case study (one lower secondary level project)	Database content, authentic documents, direct observations and videotaping, written answers to open post-questions	Descriptive statistics, qualitative content analysis, quantifying qualitative data & non-parametric tests, social network analysis
Study III	School education	10 teachers 235 students in 12 teaching groups	Overall pedagogical design (research questions 2 and 3)	Multiple case study (8 primary and secondary level projects; one was similar as Study II case and run by the same teachers)	Database content, interviews, written answers to open questions biweekly, written reports	Descriptive statistics, qualitative content analysis
Study IV	University education	1 teacher 4 tutors 53 students in four courses	Overall pedagogical design (research questions 1 and 3)	Multiple case study / Design-based research (4 undergradu-ate courses; one was the same as in Study I)	Database content, participant-observations, written answers to open post-questions	Descriptive statistics, qualitative content analysis

5 Overview of the original studies

The main results of four studies are summarized below. Details of the studies are available in the original publications.

5.1 On-line scaffolding of progressive inquiry in a university course (Study I)

Study I investigated three tutors' activity and efforts to guide university students' progressive inquiry discourse asynchronously through a Web-based learning environment (Future Learning Environment Tools, FLE). The threaded discourse material, produced by three study groups to the database of FLE, constituted the data analyzed in this study. Quantitative and qualitative analyses of the features of the participants' activity in the inquiry discourse were conducted to the database. In addition, three tutors' notes were separately analyzed more closely by the methods of qualitative content analysis to assess their ways of participating in the discourse and scaffolding student groups. The final categories applied to categorize tutors' notes were: Ask explanation-seeking question, Produce expert's explanation, Review and evaluate the discourse, and Recommend study practices.

The results concerning the tutors' scaffolding practices indicated that the tutors contributed to the virtual discourse as organizers and facilitators of students' inquiry process but they also produced many content-related problems and explanations themselves, acting as experts or co-inquirers. Most of the explicit process guidance in the tutors' postings concentrated on rather practical issues, such as using information sources or organizing the threads in the discourse forums. The guidance did not, according to the evidence from the analysis of the tutors' postings, draw the students' attention to higher-order metacognitive inquiry strategies, the promotion of which is one principal idea in the Progressive Inquiry model and should be a central focus in the tutors' scaffolding efforts. Two more experienced tutors demonstrated, in their guidance messages, more efforts to promote the students' assumption of responsibility for the inquiry, compared with the third less-experienced tutor, but not to a great extent. It was concluded that it appears to be a challenging learning accomplishment for educators to

move from approving the productive scaffolding means promoting self-directed inquiry to the point of actually practicing them.

The exploratory analysis of the progression of the students' inquiry discourse suggested that the type and frequency of the tutors' guidance had an effect on the style of the inquiry discourse in each group. The emphasis in the discourse of the three groups was somewhat more on theory reviewing, directing the inquiry, or generating of divergent ideas, respectively, depending on what kind of scaffolding and expert model the tutor of the group provided. The tutor's encouragement to present new ideas and questions activated the students' dialogic interaction, but it did not necessarily guarantee that the goal of deepening inquiry process was met. The results indicate that the type of guidance that seems to promote deepening discourse, may be characterized as explicitly built on the students' preceding discourse and, accordingly, as providing a content-specific and well-timed expert recommendation to refocus the inquiry. Those discourse threads, in which the tutors did not participate at all, were not very sustained and deepening. In general, the analysis of the discourse threads indicates that clear, specific advice was more influential than vague and more general advice, whether it related to content-specific issues, concrete actions and study practices, or inquiry strategies.

One conclusion from the results of Study I was that the process-level scaffolding can affect students' inquiry efforts only to a certain limit. This finding emphasizes the importance of appropriate organization of the overall collaborative activity in promoting students' commitment to the inquiry process. In the investigated course, the consequent activity after the initial question-generation phase was apparently too loosely organized, relying on the students' self-regulation in coordinating and advancing the inquiry and spontaneous appropriation of built-in inquiry scaffolds in the technological environment. The elements of the course design appeared not to be very well in *synergy* with each other (Tabak, 2004). This result directed the subsequent studies towards the investigation of the overall organization of the inquiry process and students' activities, through appropriate pedagogical design of the entire educational unit and structuring of basic preconditions for the intended practices.

5.2 A case of implementing virtual inquiry in a lower secondary school course (Study II)

Study II was a case study about applying progressive inquiry and distance learning using web-based technologies in a lower secondary school in Helsinki. The investigated school course was not a typical example of implementing web-based technology and collaborative practices in school because of the selective student group and the unusually high teacher-student ratio (14/7). In any case, it was a real school course initiated and designed by the teachers themselves, which provided a possibility to examine teachers' efforts in developing their educational practises through actualizing progressive inquiry pedagogy with a regarding challenging distance working period for lower secondary school students. The course can be seen as an experiment of practices that are suggestive of emerging phenomena that are envisioned in the current discussions among educational researchers. Several methods were used to collect research data: interviews, observations, and the students' and teachers' written productions in the database of a Web-based learning environment (Virtual Web School developed in the City of Helsinki). The discourse threads in the database were analyzed using qualitative content analysis and social network analysis. The following data-driven coding scheme was developed to categorize the content of the discourse notes: Subject of inquiry, Process organization, Community building, Assessment criteria and Other issues.

The investigated school course appears to have been successful for students in various ways: They took much responsibility for their work and completed many normal school courses from several subject domains through the course accomplishment. The final works of the student groups were large, multidisciplinary and unique cultural products. Also the traditional student-teacher roles changed in the virtual communication: the teachers gave up their role as knowledge deliverers, and actually some of the students were the most central actors in the virtual interaction.

Based on the analysis of various data sets, it can be maintained that the original goals of progressive inquiry were not very well fulfilled in the students' work although the inquiry process started with the question generation and explication of students' own ideas and explanations through the Web-based environment. Later in the course, the students and teachers generally did not use the web-based environment for deepening

their epistemic inquiry or sharing of knowledge objects; their communication changed towards the organization of practical, task-accomplishment issues within the student groups, and the concrete formation of the end product started to dominate the discussions. It was concluded that the organization of the course activities did not sufficiently support the epistemic inquiry practices: sub-groups had very divergent topics without a clear common inquiry goal, the Web-based system did not have sophisticated tools for higher-level knowledge building or co-construction of shared knowledge products, and the groups' inquiry process was not explicitly structured in the distance learning periods. The teachers taught progressive inquiry principles to the students by lecturing about the model in the beginning of the course, mainly emphasizing students' own active working and self-regulation instead of explicating effective inquiry strategies or epistemic goals for the final work.

The actualization of virtual collaboration throughout the process was another interesting element of the course because it was an unordinary solution to apply distance working at a lower secondary school level. Distance working as such appeared not to be too challenging for the students but the student groups did not use the virtual forums for collaboration as actively as we anticipated. Instead, the sub-groups arranged their own face-to-face meetings without sharing their inquiry process through the forums to a large extent, besides some process organization messages. All students did the final work and received credits from several courses, but some students were very passive in the virtual communication, and the teachers had problems with finding ways to guide them during the distance-working periods.

One intriguing result was emerging tensions between the inquiry pedagogy and the institutional practices of the school, particularly concerning the requirements of official curriculum and related assessment of course accomplishments. Even though the school where the investigated course was actualized had a long history of pedagogical development work, implementing inquiry practices and distance working was still a special experiment that created uncertainty among the students. The teachers were obliged to grade the students according to domain-specific courses in the official curriculum, which was in contradiction to the goals and criteria of the progressive inquiry approach. In the virtual discourse, this issue drew the students' attention heavily

to the grades instead of the inquiry process and results especially towards the end of the course.

The results of the study indicated that the social arrangements (distance working and virtual communication) as such were not too demanding for the participants. The most difficult challenge for the students – and also for the teachers – appears to have been to understand the epistemic nature of the inquiry process and to find effective ways to actualize it in practice. In addition, the Web-based system used in the case did not have sophisticated tools for sharing or co-authoring of knowledge products, and this weakness in the *technical infrastructure* appears to have discouraged sharing the entire, epistemic process-progression among the participants. The results highlighted the requirement for the teachers to explicitly influence students' individual attitudes towards the epistemic and collective practices of inquiry through systematic pedagogical support for epistemic actions. The study addressed the applicability of the concept of *social infrastructure* (Bielaczyc, 2006) to explicate the importance of deliberately designed social arrangements in a pedagogical unit that is relying on collaborative inquiry practices. In addition, the results brought forth a suggestion that the viewpoint of social infrastructure should be complemented with the concept of *epistemological infrastructure* (Paavola, Lipponen and Hakkarainen, 2002).

5.3 School teachers' pedagogical designs for progressive inquiry (Study III)

The purpose of Study III was to investigate teachers' conceptions and practices in implementing the pedagogical innovations of progressive inquiry with modern Web-based technologies in varying classroom settings. The data consisted of the teachers' written reports and interviews, and the contents of the database in the Web-based learning environment (Synergeia BSCL), created by the teachers and the students in the course of the inquiry units. The collected data were used to investigate the teachers' conceptions and pedagogical design practices in organizing students' collaborative inquiry in primary and secondary classrooms, and to start developing the generic framework for modeling and examining the epistemic, social and technical elements in the pedagogical designs. In the article reporting the study, the term *design* was defined to refer to "the plan, the manner of organization, and the actual implementation of such

in the unit of study". The technical, social and epistemological infrastructures were used as categories for analyzing the teachers' designs of the inquiry units. Social infrastructure was defined to include the social nature of activities (individual or collaborative activities and individual or collaborative product) and the structuring of collaboration (open collaboration or scaffolded collaboration). Epistemological infrastructure was specified to consist of the epistemic nature of activities (task-accomplishment, the sharing of ideas or purposeful inquiry) and the structuring of activity (rigidly structured activity, open inquiry, or scaffolded inquiry). The role given to collaborative technology was evaluated by counting several quantitative measures of the shared knowledge in the database, illustrating the usage of the tools for mediating collaborative inquiry; such as the number and type of the artifacts (discourse notes, documents, links) produced, and the teachers' and the students' relative activity in the technology-mediated knowledge sharing.

The analysis of social aspects of the inquiry designs revealed that the threaded discourse areas in the web-based system were experienced by the teachers as a valuable new possibility to promote collective working practices in schools, and many teachers reported how eagerly the students participated in the technology-mediated interaction by reading and commenting on each other's ideas. The most difficult objective appears to have been to induce the students to enter into "serious" efforts for advancing collective understanding and elaborating common knowledge objects, instead of just discussing or sharing ideas. This shortcoming may relate to the fact that, according to the analysis of the teachers' assignments to the inquiry projects, social arrangements in many of the designs still supported rather individualistic ways of working, where students eventually had to produce final achievements individually. Only in one high school project, were the student groups given an explicit assignment to produce a collective research report.

The epistemic nature of activities is different in progressive inquiry than in conventional teaching where the teacher is the deliverer of knowledge and definer of highly-defined tasks; this shift requires considerable change from the teachers in their pedagogical approach. The results from the analysis of eight classroom projects indicated that most of the teachers truly aimed at promoting purposeful inquiry in their pedagogical designs, but they did not necessarily come up with good methods and practices for structuring and scaffolding students' inquiry efforts appropriately. This

result is similar to the results obtained in Study II that the epistemic quality of students' inquiry process remained modest without explicit promotion of inquiry strategies and focus on deepening explanations. Most teachers acknowledged this difficulty themselves in their self-reflective reports and interviews. The primary school teachers rather cleverly built up supporting structures in the students' inquiry process, whereas the secondary school teachers relied a great deal on the students' self-regulation. Some teachers tended to give up the goals for accomplishing progressive inquiry, and turned back to conventional school tasks and assignments defined more strictly by the teacher.

Concerning the use of technology, there were substantial differences in the ways of using the affordances of the Web-based system in separate cases. According to the analyses, these differences were a consequence of varying goals and pedagogical emphases in each educational unit more than, for instance, of the age or technical competence of the participants. It appears that the teachers delicately appropriated the affordances of technology to be in line with the overall design and goals of the educational unit, e.g. introducing only some of the available tools for the students or deciding to use only a sub-set of the built-in inquiry-scaffolds with them. It should be noted that all participating teachers were rather experienced in using technology in teaching; therefore they had no more the typical problems that technically novice teachers tend to have with new ICT tools. In some cases, the technology was used in versatile ways for collective knowledge advancement, combining the use of multiple working spaces, threaded discourse areas, document sharing and commenting as well as links to Web sources.

According to the results, especially the designs of two primary school projects were sophisticated in many ways, evaluated through the principles of progressive inquiry. Also the secondary school designs were innovative and ambitious, but they comprised more features resembling traditional school tasks and activities, which was concluded to relate to more structural constraints in the secondary level school system compared with the primary level projects (e.g. fixed, short lessons for separate subject domains, requirements for grading, and tight schedules for curriculum achievements). Similar difficulties and challenges, relating to combining progressive inquiry principles with the institutional structures of school, emerged an issue in Study II.

The results of Study III indicated that collaboration and inquiry strategies were not sufficiently guided and modeled for students, which was a clear weakness in the actualized designs, raising a challenge to improve the pedagogical support in order to better help students to understand and manage effective inquiry strategies, also reported by the participating teachers themselves.

5.4 Iterative development of progressive inquiry designs in university courses (Study IV)

In Study IV, the complete Pedagogical Infrastructure Framework was specified and applied in the retrospective analysis of a design-based research effort, consisting of four consecutive university courses applying the Progressive Inquiry model and a web-based tool (Future Learning Environment, FLE). The framework was developed and tested to classify the features in the pedagogical designs of the courses, and the differences in the students' engagement in inquiry and self-reflections were examined through several methods.

Building on the previous studies, applying the notions of deliberately designed technical, social and epistemological infrastructures for supporting students' collaborative inquiry efforts, the Pedagogical Infrastructure Framework was, first, defined to include components that would provide students with relevant technological tools (*technical infrastructure*), build explicit arrangements for conducting effective collaboration (*social infrastructure*), and direct students to treat knowledge as an object that can be shared and developed (*epistemological infrastructure*). In addition, the results of Study I (concerning the lack of tutors' visible efforts to promote students' higher-order metacognitive inquiry strategies) as well as results from Studies II and III (about the reported necessity to help students become conscious of strategies that are essential in purposeful inquiry) led to considering the importance of deliberately designed *cognitive infrastructure* in the educational settings. We concluded that if one wants to improve students' success in conducting collaborative inquiry, educational settings should include elements that explicitly advance students' metalevel awareness and understanding of inquiry strategies, which may support their self-regulative competency in the intended practices. The complete Pedagogical Infrastructure

Framework applied in the study was, therefore, defined to consist of technical, social, epistemological and cognitive components.

The analysis of the course designs was directed to those features that were varied in the consecutive course implementations, based on the results from the previous iterations, and were considered central aspects influencing the characteristics of students' progressive inquiry engagement. The analyzed features of the course designs, categorized according to the components of the Pedagogical Infrastructure Framework, were the following:

- *Technical component*: Access to technology and technical guidance, and Diversity of tools provided;
- *Social component*: Structuring of collaboration, Sharing of the inquiry process, Individual or collective nature of the inquiry outcomes, and Integration of multiple social spaces;
- *Epistemological component*: The emphasis on question-driven inquiry, Main source of acquired information, and Concrete knowledge object as an outcome
- *Cognitive component*: Modeling of inquiry strategies, Human guidance provided, Scaffolding embedded in tools, and Promotion of meta-reflection.

In the study, the Pedagogical Infrastructure Framework helped account for the characteristics of the design in each course through unifying terms and compare the design features with the outcomes of the students' inquiry activity and self-reported experiences. It facilitated the systematic analysis of a series of complex situations, and enabled us to see when components mutually supported one another, and when they played against each other. For instance, when organizing the students to work in isolated small groups in Course 2, where the inquiry was focused on a few specific questions and supported by tutors' strategic guidance, the discourse ended up being less active and dialogical than in the settings in other courses, where all course members participated in the same forums and question-formulation was more open and sustained. Similarly, although adding in Course 3 an explicit assignment to make an individual research report as a concrete outcome of the inquiry process, promoted very engaged and productive student activity in individual level, it also resulted in infrequent mutual commenting in the virtual discourse and feelings of the lack of collaborative effort.

Perhaps the most noteworthy benefit was that the framework provided a means to present an overview of various design features in a concise form, thereby facilitating the examination of the interplay between the components in a setting. For instance, we anticipated the last course design to be the most supportive and productive for the progressive inquiry efforts because of several changes in the course design. The entire course activity was based on student groups' inquiry, instead of lecturing complemented by virtual inquiry discourse, and new version of the collaborative software system was in use, with more stable technical functionality and more direct structural support for the inquiry discourse through the improved built-in scaffolding functionality. The guidance for students was planned by the tutors to be much more appropriate and effective than in the previous courses because it was also provided in face-to-face seminar sessions throughout the course based on the groups' specific needs. However, many students in the course reported experiencing the inquiry task as very demanding; they also hoped for more guidance than they received, especially at the beginning of the process. This was speculated to be a result of an increase in the cognitive challenge of the overall task because of the greater demands for self-directness, without sufficiently strengthened modeling of the inquiry strategies.

In the study, the Pedagogical Infrastructure Framework was used by researchers as an analytic tool for categorizing and comparing the various elements in the transforming course designs. In the conclusions of the study, an idea was raised for developing the framework further to serve as a conceptual or heuristic tool for educational practitioners to design new settings or self-reflectively evaluate their own pedagogical practices.

6 General discussion

The present research endeavor started from the desire to examine what kind of on-line intervention from tutors would be functional to elicit more in-depth inquiry than students are able to reach without procedural guidance. This was the main research focus in Study I. Based on the findings it was concluded that human tutoring during the inquiry process can affect the process only to a limited extent, if the students' overall inquiry activity is organized inadequately. Therefore, in the subsequent studies, the object of research changed more towards the critical features in the overall design and set-up of an educational unit based on the technology-enhanced collaborative inquiry approach. Through summing up results concerning both procedural scaffolding and overall design, as called for in the first research question, one may arrive at some recommendations about how to *successfully support students in their progressive inquiry efforts* in various educational settings, using web-based technologies.

In addition to the research concerning successful pedagogical arrangements for progressive inquiry, another line of study was the question of *disseminating the pedagogical innovation to ordinary schools*. When, in Studies I and IV, the researchers themselves tested the pedagogical ideas in their own courses in university (following the design-based research approach), in Studies II and III the focus was on examining, through a multiple case-study approach, how school teachers at primary and secondary levels adopted and implemented the inquiry practices in their teaching groups, and what aspects of progressive inquiry turned out to be challenging to actualize. These studies provided evidence to help answer the second research question.

Finally, an issue across individual sub-studies was the evident need to find some conceptualization or framework through which the basic elements in various pedagogical designs of collaborative inquiry could be described and examined in a systematic and unifying way, fitting with the socio-cultural approach of learning and the specific nature of the investigated collaborative inquiry practices. One goal in the present study, especially in sub-studies III and IV, was to develop and test a *framework for conceptualizing and structuring some fundamental, generic elements in the pedagogical designs* of technology-enhanced collaborative inquiry practices. It may be

said that the developed framework is a central outcome of the present dissertation study, answering the third research question.

In the sections below, results related to each of these three research strands are reviewed and discussed.

6.1 Effective ways to support students' progressive inquiry efforts

Although it is not possible to make any definitive conclusions about the causal connections between the pedagogical design or process-level guidance and the characteristics of students' engagement in inquiry, the results of the sub-studies provide viewpoints that can be used to construct some guidelines for educators to organize educational settings aiming at technology-enhanced collaborative inquiry. Below, some major issues, central from the perspective of the progressive inquiry approach, are discussed.

6.1.1 Overall organization of the inquiry activity

Choices made in the overall set-up of an educational unit and in the framing of students' assignments apparently have an impact on the inquiry practices and outcomes. Based particularly on the results of studies II and IV, it appeared to be important in a context where the aim is to support *epistemologically high-level and deepening inquiry activity* in which students direct their efforts in elaborating questions, explanations and knowledge products, that the tasks and their achievement criteria are accordingly defined. A requirement for a concrete, tangible product (e.g., a report, a model or a presentation) as a goal and outcome of the inquiry process appeared to increase and focus students' inquiry efforts. Both in Courses 3 and 4 of Study IV, where there was an explicit assignment to produce a research report, the students were very engaged and productive in writing their contributions. Our inference is that it is important to set explicit high-level *epistemological* criteria for the quality of the outcome (e.g., systematic summing up of inquiry results with theory-based arguments), otherwise the external form of the end product easily starts to dominate as the object of the work, not the improvement of ideas or solving of knowledge problems (Scardamalia, 2002), as appears to have happened in the process investigated in Study II. In another study

(Muukkonen, Lakkala & Paavola, in press), we observed that an explicit requirement to produce a concrete knowledge outcome that will have real use, in that case a report for a real client outside university, highlighted the epistemological pressure and criteria for the quality of outcomes.

Concerning the aspects of collaboration in progressive inquiry, the results of all sub-studies clearly indicated that most students did not spontaneously take responsibility of the advancement of other students' or the whole community's inquiry. This is quite understandable because conventional learning culture in schools and universities is strongly shaped by individual accountability and grading. In all cases, students conscientiously committed to their own inquiry task, or pursued their own team's advancement if that was the stated goal and explicit requirement, but they hardly ever contributed to the work of others or other teams, if it was not explicitly demanded or built into the task criteria. Similarly, Cohen (1994) maintained that students' co-operation should be promoted through "genuine group tasks" that cannot even be completed without working together. Thus in progressive inquiry, the common goals of the process across individual students and groups should be explicitly defined, and the practical ways of contributing to the common outcomes should be modeled and explicated; for instance, by directing students to together produce a common summary of all inquiry results in the end.

Another challenge, related to the goal of creating a working culture where the inquiry endeavor is common within the whole study group, is the apparent difficulty to have students openly share the entire process-progression (including original ideas, drafts and intermediate knowledge products) for commenting and co-construction through a Web-based learning environment. This difficulty emerged as an issue especially in Study II, investigating a distance learning unit in a secondary level study group. One explanation might be that the students did not do it because they did not see any clear added value that such sharing may have provided them for completing their team's inquiry assignment. A similar phenomenon was observed in the study of Rourke and Kanuka (2007) where students concentrated on individual assignments instead of group discourse because that was more beneficial for them concerning grading. A possible solution to promote the sharing of the process-progression is to agree on some explicit, compulsory midway milestones for publishing and evaluating the intermediate inquiry

outcomes among peers (e.g., report drafts or written reviews of the current stage of the process). Such phasing also serves to explicate strategically important elements of the process, to increase students' awareness of the strategies. In addition, it provides teachers with a possibility to assess the advancement and direction of the work, in order to give tailored scaffolding if necessary.

The role and affordances of the *web-based collaboration tools* in the cases was not a very central object of investigation, but some results can be summed up concerning the technology. In Study II, only very basic discussion forum tool was available, and also in Courses 1, 2 and 3 of Study IV, mainly the threaded knowledge building forums of the FLE system were used for mediating students' collaborative inquiry activities. In Study III and in Course 4 of Study IV, the web-based environment provided more versatile tools for the inquiry activity. Generally, the threaded discourse forums served reasonably well for actualizing and mediating students' progressive inquiry activity, and the participants of the studies were mainly content with the possibilities of the tools (except technical difficulties caused by the immaturity of some versions of the FLE system). Forums were easy to use and available also from distance through the Internet and basic browser software. The inflexibility of discussion forums to allow free, spatial re-arrangement and linking of the produced notes has been criticized by the developers of Knowledge Forum (Scardamalia, 2004); in the scope of the present studies we did not compare different types of environments and, therefore, have no data to make conclusions about the issue.

One functionality in the web-based learning environment that appears important for effective progressive inquiry practices is the possibility to easily combine the sharing of files (e.g. text documents or presentations) with the usage of discussion forums. Forums are best suited for organizing and advancing the inquiry discourse with relatively short textual postings whereas file sharing allows the publication of more elaborated drafts, summaries and final products of the inquiry activity. In the present study, file sharing was used extensively by the students in all cases where the file sharing functionality was available and the inquiry assignment included requirements for producing summative texts or final reports as outcomes (see the results of Study III and Study IV).

A special functionality in the FLE system, tightly integrated with the Progressive Inquiry model, was the categorization of notes by built-in inquiry or knowledge type

scaffolds that students were supposed to use to consider and explicitly define the role of the posted idea in the inquiry process (see Studies I and IV). Similar functionality was available also in the Synergeia BSCL system (used in Study III) but since some teachers decided not to introduce the scaffolds systematically to the students in their cases, the usage of the scaffolds was not investigated in that study. The results of Study IV replicate results of previous studies that university students do not easily adopt the scaffolds (Arnseth & Säljö, 2007; Ludvigsen & Mørch, 2003). Intriguing in the results of Study IV is that the usage of the inquiry scaffolds was more versatile in those courses (3 and 4), in which the inquiry practices were, in general, more systematically structured and organized. The usage of the scaffolds in each course appears to coincide with the way that the inquiry activity was organized and supported; for instance, the task to produce one's own research report about the personal inquiry question in Course 3 is in line with frequent usage of the Own explanation category; or the explicit emphasis on the question generation phase in Course 4 is in line with the frequent usage of the Problem category.

Because the focus of the studies was on the pedagogical arrangements, students' way of using the inquiry scaffolds was not investigated in detail. Nonetheless, we are of the opinion, that in the investigated courses, the teachers and tutors should more deliberately have promoted explicit discussion and reflection on their usage; according to the available data, the appropriation of the scaffolds actualized rather implicitly and spontaneously among other activities.

6.1.2 Added value of human tutoring during the inquiry process

Consistent with the findings of previous studies (Thomas, 2002; Hewitt, 2003), the results of Study I and Study IV (especially concerning Course 1) indicate that those online discourse procedures, in which a teacher or tutor does not participate at all, remain superficial and do not easily progress in theory building. A central question to consider is, what is the special contribution or added value that a human tutor may provide in the process for supporting students' engagement in progressive inquiry?

In Study I, the influence of three tutors' contribution to the students' inquiry in their respective groups' on-line discourse was investigated. The results suggested that appropriately timed and tailored tutoring may have an influence on the progression of

the discourse, and the nature of tutors' own participation for modeling the inquiry strategies (e.g., theory reviewing, focusing the inquiry, or generation of divergent ideas) may somewhat shape the inquiry style and threading of the discourse in the groups. The results indicate, consistent with the findings of Gerber, Scott, Clements and Sarama (2005), that students do not necessarily benefit from the guidance style where the teacher demonstrates too advanced expert behavior. In progressive inquiry, it apparently is not enough that the tutor models the high-level, expert-like inquiry practices by demonstrating them in his or her own on-line performance; there should be other ways to scaffold students themselves to recognize and perform intended high-level inquiry practices and cognitively demanding strategies. Teachers and tutors should not do the critical cognitive tasks on behalf of the student but to strive to turn strategic cognitive activity over to the students (Scardamalia, 2002).

One finding of the studies is that a typical feature of progressive inquiry practices appears to be that the engagement in open-ended inquiry is experienced as challenging, particularly, at the beginning of the process where students try to progress from the original framing of the inquiry questions towards figuring out how to start formulating solutions, exploiting knowledge sources or focusing the inquiry. This phenomenon was observed both in Study II and Study IV. Especially concerning Course 4 in Study IV, where the full inquiry activity was most clearly the responsibility of the students themselves, the students complained, contrary to researchers' assumptions, that the level of guidance was insufficient especially at the beginning of the inquiry process. Similar results were found in our recent study (Muukkonen, Lakkala, Kaistinen & Nyman, 2010), investigating an organizational psychology course where students produced solutions for the knowledge problems of real clients, working according to a virtual teamwork model. The students experienced inadequacy of guidance and modeling of the assignment, resulting in difficulties in starting the inquiry process: they reported about the sense of frustration and confusion, and lack of trust in carrying out a project that they could not understand fully in the beginning. Also in that case, the teachers were surprised about the feedback because they thought that they had provided clear models and guidelines for the process. These results may relate to the parallel increase in the cognitive challenge of the inquiry task together with the increased authenticity that

exposes students to the epistemic complexity of real scientific inquiry strategies (Chinn & Malhotra, 2002).

Such results should not necessarily be interpreted as indicating that students would need more structured or easier inquiry tasks, because then they would not have the opportunity to learn skills needed in the solving of complex, ill-structured problems through 'productive failure' (Kapur, 2008). Therefore, the solution to overcoming the challenges of open-ended inquiry for students is not to decrease the standards of the inquiry task, but to give special attention to encouraging students to struggle at the beginning of the process; e.g., by helping them realize that the phases of confusion and chaos are elementary characteristics of open-ended inquiry; assuring that it is acceptable and, indeed, probable that inquiry efforts do not always succeed; and providing metalevel explanations of the characteristics and strategies of inquiry. For instance, such metalevel scaffolding was not evident in the tutoring activities investigated in Studies I and II.

6.2 Challenges in implementing progressive inquiry widely in educational practice

6.2.1 Teachers' adoption of progressive inquiry pedagogy

The transformation of educational practices with Web-technologies requires change both in teachers' conceptions about learning and knowledge, and in their skills in implementing new practices (Ilomäki, 2008). Finnish teachers are generally characterized as well-educated and aware of learning theories and stated requirements for transforming education with technology and new pedagogical ideas. The investigation of teachers' actual teaching methods reveals how the pedagogical ideas actualize in real classroom practices. In Study II, the teachers very ambitiously experimented with virtual inquiry practices and also planned and conducted the units jointly, sharing responsibility between several teachers from various subject domains; in our experience, such teacher collaboration is rare in school contexts. The educational units designed by the teachers in Study III were innovative and interesting in many ways. Even though the outcomes of the actualized inquiry learning units were, in the studies, assessed quite critically against the progressive inquiry principles, it can be maintained that all teachers' efforts were unique and deserve praising.

Both studies II and III showed that even those teachers who are experienced in pedagogical development work and the usage of ICT face various challenges when implementing the progressive inquiry pedagogue with modern Web-based technology in their teaching. As Scardamalia (2002) noticed, it is a different issue to endorse the background ideas of a pedagogical innovation and actually to consistently practice it. For instance, the teachers participating in Study III appear to have designed the educational units by mixing various epistemic and collaborative types of assignments. Only the projects carried out in elementary level classrooms turned out to be almost 'pure' inquiry designs where the entire process was driven by students, pursuing their inquiry questions in collaborating groups. Even in them, the teachers appear, partially, to have relied on individual assignments where students had to produce an individual report or evaluation summary as an outcome of a collaborative inquiry effort. Many secondary level designs consisted of the progressive inquiry assignment complemented by structured, individual tasks, as if they were needed as 'backups' if it turns out that the inquiry activity does not produce satisfactory learning outcomes. It appears that the appropriation of a new pedagogical model develops gradually and flexibly, and teachers tend to mix conventional methods with the new practices (Huffman, 2006). Educational developers and researchers should recognize this issue in their dissemination efforts of new pedagogical innovations. The success of dissemination should not be evaluated only through comparing the implemented instantiations with the full standards of the idealized pedagogical model; also the minor changes made to the existing practices should be examined and improvements acknowledged.

In Study III, the teachers themselves presented thoughtful opinions about the enacted inquiry units and the success of students' inquiry. The analysis of the units and teachers' self-reflections on them revealed two diverging solutions that the teachers adopted if they detected weaknesses in their students' inquiry engagement and outcomes. Some teachers put efforts in carefully analyzing the reasons for the difficulties and suggested improvements in their own pedagogical practices; e.g., to better structure and guide students' inquiry process and collaboration, in order to reach the progressive inquiry goals. Perhaps those teachers can be said to have accepted and internalized the main principles of the pedagogical innovation and to have trusted in their own competence to improve the implementation of the inquiry model. Other teachers, instead, tended to

give up aiming at the idealized goals of progressive inquiry (e.g. a process driven by students' open-ended inquiry questions, emphasizing collaborative instead of individual achievements), even though recognizing them, and suggested returning to conventional pre-structured tasks and activities, in order to ensure that the goals of the curriculum could be met. The former attitude may eventually lead to successful, intended transformation of pedagogical practices whereas the second one may end up abandoning the innovation altogether. If such a division of teachers into two deviating developmental trajectories in the face of the challenges is typical in the scaling up of pedagogical innovations, it should be taken into account in in-service teacher training. Probably teachers who appear to belong to these two deviating groups would benefit from a different type of support and training concerning their implementation efforts, in order to succeed in adequately establishing pedagogical innovations in their everyday classroom practice.

Both in Study II and Study III, the participating teachers actively discussed their efforts to apply progressive inquiry pedagogy with external professionals (researchers and teacher trainers) as well as with their colleagues, either within their own school or among project participants from various schools. This teacher collaboration was not directly investigated in the present studies, but we may assume that this collegial collaboration and reflection on the core ideas and challenges of progressive inquiry had a positive effect, as reported in other studies (Spillane, 1999; Ilomäki et al., 2004) of teachers' successes in implementing the pedagogical innovation.

6.2.2 Institutional-level constraints

Even though the institutional level phenomena were not the main focus of the present research, some of the results can best be interpreted through acknowledging the effect of the institutional level constraints on pedagogical development work, especially in Studies II and III where progressive inquiry was experimentally undertaken with teachers in authentic school contexts.

Study II revealed some challenges of the progressive inquiry approach from the students' point of view. Grading, especially, turned out to be one obstacle: First, some students retreated entirely from the project that was conducted in the last spring of compulsory school, because they wanted to make sure that they get the highest grades

for their final school report. Second, vague assessment criteria raised heated discussions and disagreements between some students and teachers at the end of the project. It was concluded that students should have a possibility to practice new type of working without restraint and fear of failure that traditional grading usually causes. As the study of Kapur (2008) demonstrated, struggling and failing in a challenging task can, later on, turn out to be a productive learning experience; this questions the adequacy of strict assessment and grading of students' first inquiry efforts.

It is to be noted that in Study III, none of the teachers mentioned grading as a central problem in the conducted progressive inquiry units. One of the reasons might be that the units were actualized in the framework of a broader research and development project that was explicitly based on experimentation and testing with new pedagogical ideas and pilot technology, even though the educational units were part of normal school work following standard curriculum. Other challenges came up in these cases, related to the institutional constraints of schooling. One frequent problem mentioned by the participating teachers was the difficulty of scheduling the sustained, prolonged inquiry activity because of the limited number of lessons or computer resources available, or curricular criteria for effectiveness and domain coverage. The results indicated that the design and set-up of projects carried out in the elementary level classes were more innovative and ambitious, if assessed through the progressive inquiry principles; the advantage held presumably because, at the elementary level, there are fewer institutional barriers to experimentation than at the secondary level, concerning lesson structure, curricular criteria and success expectations. It is intriguing that in the distance learning project of Study II, many of these barriers were explicitly overtaken in the set-up of the unit, but it required collaboration, common agreements and systematic planning between several teachers from various subject domains. The new, unconventional practice in that case, one can conclude, became possible because it was institutionalized as part of the school's commonly accepted curriculum.

Based on the results, one recommendation that could be given to schools, is to start implementing progressive inquiry practices as early as possible, already at the elementary level, and increasing the challenge of the practices for students step-by-step and cumulatively during the years. Such solution would provide students with a possibility to grow up into inquiry culture gradually, throughout their school career.

Naturally, it would require common agreements inside the school about integrating the curriculum at all grade levels, but such integration is already actualized concerning domain contents of regular school subjects. Why would it not be possible also concerning teaching the skills and competencies for knowledge creating inquiry?

The results of all sub-studies, both from schools (Studies II and III) and from university education (Studies I and IV), indicate that there are quite many alternatives and possibilities, even within the same institutional regulations and contexts, to realize educational units following technology-enhanced progressive inquiry pedagogy. Perhaps institutional constraints are sometimes used as excuses for not changing anything. One relevant question for scaling up pedagogical innovations is, how does one especially support those teachers who do not spontaneously have courage or motivation to overcome the institutional constraints and find ingenious ways to transform their pedagogical practices.

6.3 The Pedagogical Infrastructure Framework

A central outcome of the present research endeavor is the developed Pedagogical Infrastructure Framework. It is not a research result in a traditional sense, but in design-based research it is typical to produce theoretical models as outcomes of research to support the subsequent design or investigation of educational settings (Edelson, 2002). Based on previous research (Bielaczyc, 2006; Guribye, 2005; Paavola et al., 2002) and results of the successive sub-studies of the present dissertation, it may be concluded that educational settings that especially aim at fostering technology-enhanced collaborative knowledge creation should consist of deliberately designed *technical*, *social*, *epistemic*, and *cognitive* support structures. The notion of *infrastructure* was adopted as a metaphor for emphasizing how the design of collaborative settings is indirect, setting up background conditions that mediate intended social and cultural practices, but do not prescribe or over-structure the learning activities.

In Study I, the emphasis was on the tutors' on-line scaffolding practices during the university students' inquiry process, but it was acknowledged that the *overall organization* of the educational setting, aiming at promoting progressive inquiry, is critical in influencing students' engagement in inquiry. Results of Study II indicated that the *social* arrangements (distance working, separate groups with diverse topics, several

teachers guiding students, etc.) in the investigated progressive inquiry unit influenced the inquiry activity; for instance, the concentration of virtual discourse on community building and process organization issues, the students' infrequent commenting on other groups' work, or teachers' problems in guiding the students during the distance working periods. In addition, the clear difficulties of students to reach the epistemological goals in the progressive inquiry process suggested that inquiry practices should be explicitly fostered and directed by appropriate arrangements directing students' *epistemic* actions in addition to social actions. In the case investigated in Study II, supportive epistemic arrangements could have included such elements as more systematic structuring and supervising of the whole inquiry process, making the externalization and sharing of the intermediate inquiry results compulsory, or defining concrete epistemic criteria for the outcomes of the process.

In Study III, the categories of technical, social and epistemological infrastructures were explicitly defined and used as an analytical framework in the examination of teachers' pedagogical designs of primary and secondary level progressive inquiry units. The results of the study confirmed the conclusions of Study II that teachers do well to pay more attention to designing the educational units so that the tasks and other arrangements, especially, stimulate students' engagement in epistemologically high-level, deepening inquiry and true collaboration around shared knowledge objects and products. Furthermore, the results indicated, as was concluded also in Study I, that students' own metalevel awareness of or intentional efforts for effective collaboration and appropriate inquiry strategies may be more deliberately and explicitly promoted through modeling and self-reflection activities. These conclusions led, in Study IV, to define the *cognitive* or metacognitive support for students' inquiry engagement as a separate pedagogical design component that requires special attention from the teacher, in addition to technical, social and epistemological components.

One may argue that various other aspects should be taken into account in pedagogical design, for instance motivational elements. However, the approach followed has been that the components are chosen in the framework in order to highlight aspects that are essential, particularly for promoting collaborative inquiry and knowledge creation practices; such aspects are not necessarily considered systematically in conventional pedagogical practices.

The Pedagogical Infrastructure Framework, as such, is not prescriptive; it describes four basic elements that pedagogical designs of educational settings should address but it does not define how that should be done or what are the criteria for favorable designs. Specific design solutions that would build up an adequate pedagogical infrastructure in each case depend on the chosen learning-theoretical approach or pedagogical model; the infrastructure framework merely helps in examining and evaluating the design features in a structured fashion, drawing the designers' or researchers' attention to some critical but often unnoticed elements in the setting. In the present research, the normative design and evaluation principles in the sub-studies were derived from the Progressive Inquiry model (Hakkarainen, 2003; Hakkarainen et al., 2004), such as grounding the inquiry process on students' authentic knowledge problems, sustained engagement in the elaboration of explanations, the promotion of collaborative activity, supporting the development of students' metalevel awareness and competencies on inquiry strategies, and the use of appropriate technological tools to mediate collaborative inquiry.

Based on the experiences of the present research, an applicable methodology for evaluating the designs of complex learning settings appears to be the combination of the generic, descriptive framework and the prescriptive design principles: The generic Pedagogical Infrastructure Framework explicates what elements to concentrate on or take into analysis, and the Progressive Inquiry principles define what characteristics those elements should have or include, in order to reach the goals of the chosen pedagogical approach. The components of the Pedagogical Infrastructure Framework together with some recommendations about setting them up for fostering progressive inquiry is summed up in Table 2, building on the results of the present sub-studies.

Table 2. The Pedagogical Infrastructure Framework and some recommended features for fostering progressive inquiry.

Component	*Definition*	*Features for fostering progressive inquiry practices*
Technical	The providing of technology and technical advice to the participants; organizing and orchestrating the use of technology; the functionality of the tools provided; and their appropriateness for the desired activity	*Flexible co-authoring tools*: Provide students with tools that enable flexible sharing of knowledge and co-authoring of knowledge products. *Integration of technology-mediated and face-to-face activities*: Organize the inquiry process as one overarching entity where technological tools with shared knowledge spaces are ubiquitously available for mediating epistemic and social activities.
Social	The combination of designed individual or collaborative student activities and required outcomes; and actual arrangements to organize students' collaboration and social interaction	*Shared process*: Keep the knowledge-sharing in virtual spaces open and available for all participants, even though the focused inquiry tasks are conducted in smaller sub-groups. *Structured collaboration*: Provide students with explicit rules about mutual working and commenting responsibilities as well as deadlines for that. Do not let anyone concentrate only on his or her own inquiry process. *Shared responsibility*: Define the task criteria so that the task accomplishment requires shared responsibility, co-authoring of outcomes and joint orchestration of everyone's contributions.
Epistemo-logical	The ways of operating with knowledge and the nature of knowledge processing that the assignments promote; nature of knowledge resources used; and the role of participants and information resources while working with knowledge.	*Iterativeness*: Structure the inquiry process into several reflection and revision rounds where the sustained improvement of shared knowledge objects is explicitly expected. *Making epistemological advancement visible*: Make externalization and publishing of intermediate knowledge products compulsory. *Concrete outcome*: Require that students' inquiry include the development of concrete, tangible products as an outcome of inquiry. *Epistemological criteria*: Set high-level epistemological criteria for the quality of the outcome and ensure (through constant scaffolding and students' self-reflection activities) that the criteria are met.
Cognitive	Designed tasks and artifacts or tools performing a modeling and reflective function for promoting students' self-regulative competencies to work in an intended way.	*Modeling of the inquiry strategies*: Provide students with cognitive models and metalevel guidelines of the inquiry strategies. Make the inquiry phases and critical strategies explicit but do not unnecessarily over-structure the activities or decrease the degree of difficulty of the inquiry task. *Scaffolding in the challenges of inquiry*: Accept students' feelings of confusion and incompetence concerning the challenges of the inquiry and explain that they are an essential part of the inquiry process. *Intentional usage of cognitive scaffolds*: Promote explicit discussion and reflection on the meaning and usage of cognitive scaffolds built in the technology as well as related metacognitive strategies.

In Studies III and IV, a version of the Pedagogical Infrastructure Framework provided a tool that enabled describing and comparing some basic elements in separate educational units based on technology-enhanced collaborative inquiry practices. Naturally, the elements delineated by the framework are an abstraction; in reality the educational settings are complex systems where individual features are integrated and overlapping (Scardamalia & Bereiter, 2006). However, in educational research and design, models and frameworks are needed to somehow manage that complexity and focus the design on some elementary characteristics that the pedagogical settings include. The framework enabled the explication of some shortcomings and suggestions for improvements in the presented cases concerning the implementation of progressive inquiry practices.

6.4 Limitations of the studies

The results of the present studies are not generalizable in the same way as studies that follow experimental design or use large samples with quantitative measures (Kohlbacher, 2006), but through combining findings from various individual studies it is possible to make generalizable conclusions about the investigated phenomena; concerning, e.g., challenges that students face with epistemic inquiry strategies and collaborating with peers, or the influence of teacher guidance and structuring into students' inquiry activity. At least, it is fairly safe to assume that the recommendations, defined on the basis of the results, are 'good enough' to warrant being followed and tested in authentic educational settings.

As was mentioned in the methods section, the coding categories used for analyzing the contents and characteristics of technology-mediated inquiry discourse in each sub-study were case-specific because of the deviating authentic contexts and the partially data-driven approach of the analysis. For instance, in Study II the categories 'Community building' and 'Assessment criteria' were specific categories that emerged from analyzing the content of the virtual discourse of students' inquiry activity, not used in any other of our studies investigating technology-mediated progressive inquiry activity. Nevertheless, the results were very useful in explaining some social challenges and institutional level constraints in implementing distance working and progressive

inquiry pedagogy in secondary school context, which would have remained unrevealed if a pre-defined, only theory-driven coding scheme would have been used.

Sometimes it was difficult to interpret the meaning of the results. For instance, in Study IV it was reported that the students did not use the built-in inquiry scaffolds in a very versatile way, at least not in most of the courses. However, it is difficult to judge whether these results indicate that the inquiry scaffolds, as such, are not useful or supportive, or whether they indicate that their usage should be guided better; or did their usage, after all, contribute to increasing students' metalevel understanding of progressive inquiry strategies during the course duration, even if it cannot be proved on the present data? Further, are the feelings of confusion and incompetence especially at the beginning of the inquiry process (see Course 4 in Study IV) a proof of failure in teachers' pedagogical structuring and scaffolding efforts, or an essential aspect of inquiry practice that students necessarily need to experience and learn to overcome? In the discussion about the results, the interpretations were explicated as much as possible and combined with existing research literature reporting similar results.

It is somewhat problematic to generalize the results of studies II and III, received with experienced teachers, to technologically less-competent teachers or schools that do not have similar resources (Ilomäki, 2008). The reason for investigating experienced teachers was not to get positive results for progressive inquiry or in order to be able to tell 'success stories' of spreading the pedagogical innovation. The choice was made in order to avoid getting results only about typical beginners' difficulties that are faced by teachers who are experimenting with ICT and innovative pedagogies for the first time. In any case, we still had quite wide variation of school teachers: A total of 17 teachers, representing varying expertise, school levels and subject domains, participated in the two school studies. Also in the university level studies I and IV, four courses were investigated with five different persons as instructors or tutors participating in carrying them out. Often researchers report investigations where they have followed the practices of only one or two teachers (e.g., Gerber et al., 2005; Puntambekar et al., 2007; Williams, Linn, Ammon & Gearhart, 2004).

6.5 Suggestions for further studies

Despite the design-based research reported in Study IV, all cases investigated in the sub-studies were solitary cases where only one single instantiation of the designed educational unit was actualized and studied. As various research results indicate, it is a prolonged and iterative learning endeavor for teachers to transform their current practices towards a new pedagogical innovation (Huffman, 2006; Scardamalia, 2002). It would be important to be able to follow the implementation efforts of the same teachers in iterative cycles, in order to better understand the characteristics of the developmental trajectories in teachers' professional development when trying to adopt and apply the pedagogical innovation of progressive inquiry. Similarly, in order to find better methods to disseminate technology-enhanced collaborative inquiry practices more widely in educational institutions, the gradual spreading of the new pedagogical practices inside a school community or from one school to another, from pioneering teachers to new teacher groups, should be systematically investigated through longitudinal and iterative research settings. If the ultimate goal is a permanent change in the pedagogical conventions of individual teachers or educational institutions, not only success in temporary development projects, research should provide information and models for supporting major change.

The Web-based technologies used in the cases investigated in the present sub-studies were still quite simple and can already be regarded as old-fashioned, compared with present, more advanced technologies, such as Web 2.0 applications or so-called social software services. Novel, integrated knowledge creation environments provide more versatile and flexible but perhaps also more challenging tools for organizing, carrying out and reflecting on collaborative inquiry processes (Lakkala et al., 2009). It is crucial to continue to investigate the requirements of collaborative inquiry pedagogues for teachers' pedagogical design and scaffolding practices with the emerging technological possibilities. New technologies will also challenge the research methodologies for analyzing technology-mediated collaborative processes, because the data that are assembled from the activities when using sophisticated tools (one that enable, e.g., discussing, chatting, co-authoring, linking, tagging, and reorganizing of the shared recourses through the virtual spaces) are much more complex than the data building up in threaded discussion forums, examined in the present sub-studies.

The Pedagogical Infrastructure Framework was mainly applied for analyzing rather similar pedagogical practices following the Progressive Inquiry model. In future studies, it would be beneficial to test the applicability of the framework for educational settings representing more varied pedagogical approaches. Some pilot efforts towards that direction have already been conducted (Lakkala, Ilomäki & Kosonen, 2009; Lakkala, Kosonen, Bauters & Rämö, 2008; Muukkonen et al., in press). It is more difficult to rise above individual cases towards comparing the settings with each other, or to more systematically explicate some overarching features in a similar way for all cases, if the examined educational settings deviate from each other more than in the present studies. For further research, it remains a challenge to try to define some basic questions or dimensions for each component of the framework, to be used for describing various kinds of pedagogical settings in unifying, universal concepts and criteria. For instance, would it be possible to describe some prototypical types or levels of collaboration that would build up a continuum for evaluating the social infrastructure in various settings through similar notions? Would we, for example be able to address the question whether the designed tasks mainly represent individual work, division of labor, commenting on each others' work, or true co-construction and co-authoring of same, shared knowledge products?

One interesting line of research would be to investigate how educational practitioners (school and university teachers or adult trainers) could benefit from the Pedagogical Infrastructure Framework, when designing new educational units, reflecting on their pedagogical practices, or developing their course designs. So far the framework has been introduced, by the present author, to some teachers in a few in-service teacher training courses, but there has not been any research involved. A fruitful endeavor could include a research and design project, conducted together with some knowledgeable educational practitioners, where the research could focus on investigating how the teachers experience and apply the framework and whether it helps them to take care that essential aspects in their educational units are planned properly. Based on the results, the framework could be developed and concretized further together with the participants. Another important effort would be to receive experiences where other researchers, outside the present research group where the framework was developed, try to apply the framework as a conceptual or analytic tool for their studies.

7 Concluding remarks

Appropriate teacher support for students' collaborative inquiry efforts appears to include interplay between *spontaneity and structure*, and the crucial question is, which issues should be structured and which should not – what to structure, what to support, what to leave for the students to struggle with to reach "productive failure". In conventional teaching methods, the subject-domain content under study or the exercises that students should complete are well-structured and pre-planned. Even though this is not the case in collaborative inquiry practices, it does not mean that everything should be unguided or that students should have a freedom to do whatever they like. Careful consideration should be given to content learning, critical working strategies or essential knowledge practices that the inquiry approach is intended to promote. One important principle in the Progressive Inquiry model is that it aims at simulating *expert-like and authentic cultural practices of collaborative inquiry and knowledge creation*. Those elements in students' activities should be structured and directed, especially, which are central for that aim, but which the students do not recognize or demonstrate spontaneously without explicit modeling or promotion, and which are usually not taken into account in existing pedagogical methods or educational conventions.

An individual teacher – or researcher – cannot always exert much influence on political or institutional issues, but can still start changing his or her own practices in small steps, which, at least, have an effect on those students' life and learning that are currently in his or her classroom; the present study focused on that level and scope. One individual teacher can make a difference in his/her own educational practices; the data of our cases provided evidence that much can be done also in a small scale, even though there always are institutional constraints. Researchers, administrators and policy makers, especially, should be aware and try to also influence the higher levels (curriculum or institutional level) and make efforts to figure out what kind of support schools and teachers would benefit from, in order to be able to transform their pedagogical practices. One issue is to change the official curriculums *to acknowledge the importance of teaching socially and culturally relevant, technology-enhanced knowledge practices* for students. Another issue is to *develop in-service teacher training*

methods to better serve various types of teachers to transform their pedagogical practices towards realizing such pedagogy, taking into account their own contexts, needs and competence levels.

Pedagogical infrastructure can be defined to mean *conditions (activity structures and artifacts) designed and implemented in an educational setting to support and promote desired type of learning activities*. The developed Pedagogical Infrastructure Framework can be used for recognizing and examining some central features and their interplay in the design of educational units, particularly concerning technology-enhanced knowledge practices. The framework may help to critically evaluate the invisible learning-cultural conventions in various educational settings as well as mediate discussions about how to start changing them. In order to be a practical tool for educational practitioners, the framework needs to be further concretized, perhaps in the form of some kind of procedural guide for teachers to intentionally evaluate, reflect on and develop their pedagogical practices.

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