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Designing Pedagogical Infrastructures in University Courses for Technology-Enhanced Collaborative Inquiry

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Abstract

In the present article, a specified Pedagogical Infrastructure Framework, including technical, social, epistemological and cognitive components, is introduced as a conceptual tool for design-based research to examine the design of complex learning settings. The applicability of the framework was assessed by retrospectively exploring an evolving design effort in four, consecutive, undergraduate courses in cognitive psychology. The development of the course design was driven by the principles of the Progressive Inquiry model, such as grounding the inquiry process on students' authentic knowledge problems, sustained engagement in the elaboration of explanations, the promotion of collaborative activity, or the use of appropriate technological tools to mediate collaborative knowledge creation. The Web-based software system that was utilized in the courses evolved in parallel with the pedagogical development. The results provide insights into the critical aspects of the pedagogical organization of the courses influencing the characteristics of students' collaborative inquiry. The most important benefit of the framework was that it helped structure an overview of various design features in a concise form that facilitates the examination of the interplay between the critical components. In order to serve as a practical design tool for educators, the components of the framework need to be further specified and concretized.

Introduction

The challenges created by changes in society and working life have led learning researchers to propose that educational practices should pay special attention to advancing skills for knowledge creation and collaboration, which should be supported by problem-based activities that simulate the practices of professional or scientific communities (Brown & Campione 1994; Carey & Smith, 1995; Hakkarainen, Paavola, Palonen & Lehtinen, 2004). In this kind of learning, students are seen as active and autonomous contributors who share valuable knowledge with each other, solve challenging open-ended problems, and systematically create new knowledge and explanations for the use of the community (Bereiter, 2002). University teaching is said to have a special task to enculturate students into the practises of academic disciplinary communities, not just to exploit and assimilate generally received knowledge (Geisler, 1994; Gellin, 2003). In reality, university students are often supposed to master such skills without actually being expressly guided in them. The emphasis in teaching lies, instead, on content mastery, and the advanced working practices are believed to be acquired as a matter of course along the way (Muukkonen, Lakkala, & Hakkarainen, 2005; Rodríguez Illera, 2001). There is a need to help university teachers develop their conventional pedagogical practices, simultaneously taking into account curricular constraints and limited resources in university teaching.

Current learning theories and pedagogic models emphasize social and cultural dimensions of learning as well as the skills of collaboration, instead of individual cognitive processes and learning (Bruner, 1997; Salomon, 1993; Sfard, 1998). There already are various pedagogical models available that were created to develop educational practices in that direction, such as problem-based learning, co-operative learning, collaborative learning, reciprocal teaching or various forms of inquiry learning. At the same time, computers and web-based technologies are increasingly applied in teaching and learning, especially as tools for social interaction, inquiry activities and collaborative working with knowledge (Scardamalia & Bereiter, 1994; Winn, 2002). The use of technology provides new, unique possibilities for promoting collaborative inquiry practices.

All these current educational viewpoints and the possibilities of technology generate new, pressing, demands for university teachers to profoundly transform their teaching methods and to incorporate the usage of modern web-based technology into their ordinary educational practice. A major question that arises, in discussing the transformation of pedagogical practices is, From what viewpoint should the pedagogical designs be examined? Educators may benefit from guidance and methods that help them better realize and evaluate the design of complex educational settings, including such elements as task instructions, student groupings, and the use of web-based technologies and information sources. Teachers and educators face such design challenges every day in organizing their courses. Therefore, it is reasonable to expect that educational researchers will offer some research-based conceptual tools to help them in that overarching challenge.

From a methodological viewpoint, the concrete educational needs and the rise of collaborative learning practices as a consequence of the socio-cultural paradigm shift have challenged conventional experimental research strategies, which are based on building controlled settings with quantitatively measurable variables to investigate individual students' learning; these generally aim to verify or falsify pre-defined hypotheses and theories. It has been argued that such experimental research does not take the complexity of educational context into account, and the results are not easily applicable in real educational settings (Sandoval & Bell, 2004). Therefore, an increasing number of educational studies utilize the *design-based research* approach (also called 'design experimentation' or 'design research'; see Brown, 1992; Sandoval & Bell, 2004) which combines empirical educational research

with theory-driven design of learning settings. Design-based research aims at understanding how to orchestrate innovative pedagogical practices in authentic educational contexts and simultaneously develop new theoretical insights about the nature of learning and teaching (Design-Based Research Collective, 2003). In the design-based research approach, the designs are transformed iteratively in successive research and development phases; it is considered valuable as a form of educational research because it provides results that can be directly applied to improve educational practice (Brown, 1992; Edelson, 2002; Winn, 2002). Because the focus of such research is on the design of educational settings, there is a need for conceptual frameworks that help to explicate the central elements and structures of pedagogical designs in generalizable terms.

The purpose of the present article is to introduce a specified *Pedagogical Infrastructure Framework*, including technical, social, epistemological and cognitive components, as a conceptual tool for examining the transformations in pedagogical designs, especially in complex educational settings representing technology-enhanced collaborative inquiry. The applicability of the framework is tested by using it to retrospectively describe a long-term design-based research effort involving four consecutive undergraduate university courses; these were traditional lecture courses enriched by introducing the elements of inquiry supported by a collaborative software system. The development of the course design was driven by the principles based on the *Progressive Inquiry* model (Hakkarainen, 2003), such as grounding the inquiry process on students' authentic knowledge problems, sustained engagement in the elaboration of explanations, the promotion of collaborative activity, and the use of appropriate technological tools to mediate collaborative knowledge creation. The courses were real courses, part of an existing curriculum, and they were conducted by the members of the present research group. Deliberate efforts were put into developing the pedagogical arrangements as well as related collaborative software system from one course to another, based on the experiences and results of the previous courses.

Generally, our goal was to assess whether the Pedagogical Infrastructure Framework provides a useful tool for examining the evolving pedagogical design effort and how the observed inquiry practices were related to the different pedagogical designs in the courses. First, the approaches for examining the pedagogical design of technology-enhanced collaborative settings are discussed and the framework is explained. Second, the four courses as well as the methods and results of examining the evolving course design are described. Finally, the challenges of designing complex learning environments and the usability of the Pedagogical Infrastructure Framework are assessed, based on the results.

How to Examine the Pedagogical Design for Collaborative Inquiry?

Routinely, university teachers have always used various conventions for designing their teaching, and they have applied multiple kinds of pedagogical methods in their courses, more or less deliberately following some systematic model or approach. When starting the study, the present researchers tried to find existing research approaches that could provide useful conceptual tools for examining the pedagogical design of technology-enhanced collaborative practices. The research field that has especially focused on investigating the design of educational settings and learning materials has, so far, predominantly followed the models of *instructional design*, which represent learning research based on cognitive psychology (Gagne & Merrill, 1990; Häkkinen, 2002). In instructional design conventions, the learning content is rather systematically determined and pre-structured, and learners' activity is predefined to follow specific, uniform sequences. In recent studies, the instructional design models are revised to better adapt to the design of complex, authentic tasks which are believed to result in qualitatively better learning outcomes (see Merriënboer,

Kirschner, & Kester, 2003). But these strategies still examine the design mainly from the individual student's viewpoint in situations where the learning of certain contents or procedures is the primary aim. The approach does not seem to provide appropriate tools for examining collaborative inquiry settings, where the processes and outcomes emerging are (and should be) strongly shaped by the joint activity and interaction of the participants themselves and cannot be fully designed in advance (Dillenbourg, 2002).

In the field of computer-supported collaborative learning, some researchers have suggested an intermediate solution, between classic instructional design and an "open" collaborative learning approach, based on the idea of structuring collaborative learning by scripts. Instead of strict pre-structuring of tasks, the computer-based collaborative learning setting is designed through *scripts* that guide students' collaborative activity to make it more productive. Dillenbourg (2002) defined a 'script' as a rather detailed set of guidelines, rules and structured tools describing how the group members should interact, how they should collaborate and how they should solve the problem. For example, Weinberger, Ertl, Fischer and Mandl (2005) designed computer-based epistemic scripts to facilitate students' knowledge-construction activities and social scripts to structure the interaction of learners in a collaborative learning setting. This design approach takes into account the support for the social dimension of learning but, as Dillenbourg (2002) stated, the scripts may end up disturbing natural interaction and problem solving processes and may lead to superficial collaboration. In a recent article, Dillenbourg and Tchounikine (2007) made a distinction between designing *micro-scripts* that scaffold the interaction process in itself at a detailed level, and *macro-scripts* that set up higher-level conditions in which collaborative activity is likely to occur. Similarly, Jones, Dirckinck-Holmfeld and Lindström (2006) stated that the actualization of computer-supported collaborative learning settings is based on *indirect design*, which means the provision of basic supporting activity structures and tools that offer affordances for the eligible learning activity but do not prescribe the exact activities or outcomes.

The Pedagogical Infrastructure Framework

Following the idea employed by Bielaczyc (2001) and Guribye (2005), we suggest using the notion of *infrastructure* as a metaphor to discuss the design of the critical components in collaborative inquiry learning settings. Usually, the concept of infrastructure refers to technical or physical aspects that are built in a society to provide for smooth functioning of people in their everyday life processes (Star, 1999). They are deliberately built into the system according to some societal or cultural reasons but, for actors, they are mostly unnoticed if they properly support desired activities. According to Star, infrastructure is embedded in the system and is transparent, meaning that it need not be adjusted for each task, but it invisibly supports those tasks; it is learned as part of membership and thus mediates cultural conventions that are a target object for newcomers.

In a complex learning setting, the elements that build affordances for students' actions, designed by the teacher or based on the conventions of the educational institution, can similarly be said to consist of components that form a *pedagogical infrastructure* to afford and facilitate certain types of learning activity. Pedagogical infrastructure mediates cultural practices and directs students' activity both explicitly and implicitly (Lipponen, Lallimo & Lakkala, 2006); there is always a pedagogical infrastructure of some sort in an educational setting. In conventional lessons where activity is based on teachers' lecturing, students' note-taking, and common discussions, the type of pedagogical infrastructure is so familiar that it is taken for granted and participants do not question it. Educators need to understand the effect and interplay of various elements in a learning setting and should

deliberately align the pedagogical infrastructure to promote desired activity according to the articulated pedagogical aims; otherwise components in the setting might work against each other or the stated goals. For example, when incorporating collaborative tasks into a university course, simultaneously applied institutional practice that grounds course assessment on individual grades based on student's achievement in examinations might act against the aims of collaborative work.

Bielaczyc (2001) was the first to use the notion of *social infrastructure* associated with designing and analyzing technology-enhanced learning environments. She stated that, characteristic of successful computer-supported collaborative learning experiments, is the building of an appropriate social infrastructure around technical infrastructure, such as classroom culture, working practices, and the ways of employing the Web-based tools for collaboration. Other researchers have stressed the importance of systematic and adequate structuring of social practices in technology-enhanced collaborative learning (Akar, Ozturk, Tuncer, & Wiethoff, 2004; Dillenbourg, 2002; Wegerif, 1998). In a previous study (Lakkala, Lallimo & Hakkarainen, 2005), the social infrastructures of eight computer-supported collaborative learning projects were compared by categorizing the designs according to the *social nature of activities* (individual or collaborative activities and individual or collaborative product) and the *structuring of collaboration* (open collaboration or scaffolded collaboration). For instance, there is a difference in the social infrastructure of a course where students are only generally encouraged to comment on each other in joint virtual discussions, and a course where the commenting responsibilities are explicitly arranged according to certain rules.

We propose to broaden Bielaczyc's social infrastructure framework by considering a more comprehensive set of components to enlighten the design and analysis of educational settings for collaborative inquiry. Paavola, Lipponen and Hakkarainen (2002) stated that educational settings should also be examined from the viewpoint of the relationship to knowledge that the practices reflect. They suggested that besides technical and social infrastructure, an educational setting should be shaped by an *epistemological infrastructure*, involving, e.g., the role and responsibilities of various agents in knowledge creation, approaches to the process of knowledge advancement, and the nature of knowledge sources used. In general, such infrastructure is characterized by the way knowledge is treated in a given pedagogical setting. Similarly, Sfard (2000) discussed meta-discursive rules that determine the epistemological infrastructure of the educational discourse in mathematics teaching. In educational practices aiming at knowledge-creating inquiry, the knowledge that is associated with the process does not merely represent subject domain content that the individual students should try to internalize; rather, knowledge is a primary object of joint development work (Bereiter, 2002; Hakkarainen *et al.*, 2004). In a recent article, Bielaczyc (2006) elaborated the social infrastructure framework to include a *cultural beliefs* dimension and an *interaction with the "outside world"* dimension, both of which seem to include elements relating to epistemological design issues, such as "how learning and knowledge are conceptualized" (p. 303) or "bringing in knowledge from the outside" (p. 304). In Lakkala, Lallimo & Hakkarainen (2005), the epistemological infrastructures of eight classroom projects were categorized according to 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).

In addition to designing an educational setting to provide students with relevant technological tools (technical infrastructure), encourage them to collaborate effectively (social infrastructure), and direct them to treat knowledge as something that can be shared and developed (epistemological infrastructure), we propose that educational settings should also be designed to include explicit *cognitive infrastructure*. Sfard (2000) stated that the

meta-discursive rules are often implicit and are learned by participating in the discourse, but the teacher has the responsibility for ensuring that students will eventually be able to apply the rules in other contexts by consciously understanding the rules and strategies. In addition, if one wants students to learn to independently and deliberately improve their competencies in collaborative inquiry practices, educational settings should include elements that explicitly advance students' "metacognitive knowledge for action" (White & Fredriksen, 2005). The development of such expertise can be supported first by providing students with concrete *conceptual tools* for constructing cognitive and metacognitive knowledge, such as guidelines, models, templates, and scaffolds for planning, monitoring, and reflecting their work. Second, support should include *metacognitive tasks*, such as requirements for explicit justification for students' actions or tasks to reflect on the produced knowledge and processes (Choi, Land, & Turgeon, 2005; White & Fredriksen, 2005). Providing students with concrete scripts (Dillenbourg & Tchounikine, 2007) can be regarded as an example of building cognitive infrastructure for collaborative inquiry. Such explicit support can gradually be withdrawn from the instructional situation when students have internalized the effective ways of working (Vygotsky, 1978).

The design of such cognitive support in an educational setting may also be regarded as an element of the other infrastructure components. For example, explicitly modeling and justifying rules for collaboration is an element of social infrastructure. However, we want to consider the cognitive component as a separate element in the Pedagogical Infrastructure Framework in order to highlight, for educators, the importance of its design. We argue that for educational practitioners, the alignment of the tools and practices that form the cognitive component of an educational setting is a special design task that needs specific attention. For instance, results from the studies of tutoring in technology-enhanced collaborative inquiry (Hewitt, Reeve, Abeygunawardena, & Vaillancourt, 2002; Lakkala, Muukkonen & Hakkarainen, 2005) revealed that tutors did not spontaneously draw the students' attention to higher-order metacognitive strategies that might help the latter gradually manage the inquiry on their own.

To conclude, we propose a *Pedagogical Infrastructure Framework*, including technical, social, epistemological, and cognitive components, to be used as a conceptual tool in design-based research studies. The four components are overlapping and cannot, in reality, be totally separated, but we think that they represent fundamental aspects that can be identified in various designs, and which enable the design, analysis and comparison of a variety of educational settings. The goal in the design-based research effort, examined in the present article, was the implementation of technology-enhanced collaborative inquiry practices into undergraduate university courses. The notion of *inquiry practices* highlights that the pursuit of inquiry learning is not only a conceptual affair but involves creating shared epistemic routines and social practices that channel participants' efforts according to knowledge-creating inquiry (Hakkarainen *et al.*, 2004). The analysis of the transforming course designs was directed to those features that were varied in the consecutive course implementations, based on the results from the previous iterations. Table 1 summarizes the components of the Pedagogical Infrastructure Framework and lists the features that were changed from one course to another in the special designs of four undergraduate courses for technology-enhanced collaborative inquiry. The designs are explained in detail in the methods section.

Table 1. The Pedagogical Infrastructure Framework.

Component	*Definition*	*Features examined in the investigated courses*
Technical	Providing technology and technical advice; the appropriateness of tools for the desired activity; and organizing the use of technology.	• Access to technology and technical guidance. • Diversity of tools provided.
Social	Explicit arrangements to advance and organize students' collaboration and social interaction; openness and sharing of the process and outcomes; and the integration of various social spaces, such as face-to-face and technology-mediated activity.	• Structuring of collaboration. • Sharing of the inquiry process. • Individual or collective nature of the inquiry outcomes. • Integration of multiple social spaces.
Epistemo-logical	Ways of operating with knowledge; conceptions of knowledge that the practices reflect; nature of knowledge sources used; and actors' and content materials' role while sharing and creating knowledge.	• The emphasis on question-driven inquiry. • Main source of acquired information. • Concrete knowledge object as an outcome.
Cognitive	Support for students' awareness and independent mastery of the critical aspects in the desirable practices; timely guidance provided for the students; scaffolding embedded in tools; and methods used to promote metacognitive thinking and meta-level reflection of the practices.	• Modeling of inquiry strategies. • Human guidance provided. • Scaffolding embedded in tools. • Promotion of meta-reflection.

The questions addressed in the present study are the following: (1) Does the application of the Pedagogical Infrastructure Framework to re-examine the design-based research effort help to explain how the pedagogical arrangements influence students' engagement in inquiry and their self-reported experiences?; and (2) What are the benefits of the Pedagogical Infrastructure Framework as a conceptual tool for examining transforming pedagogical practices, and what recommendations might be appropriate to develop the framework further?

Method

Educational Context and Participants

The applicability of the Pedagogical Infrastructure Framework was explored by investigating a development process of four, consecutive university courses realizing technology-enhanced collaborative inquiry. Some courses were previously investigated separately as part of the design-based research venture (Lakkala, Muukkonen & Hakkarainen, 2005; Muukkonen, Hakkarainen, & Lakkala, 1999; Muukkonen *et al.*, 2005). In the present study, data from all four courses are combined and re-analyzed in order to examine the relationship between the course designs and emerging student practices and experiences. All four investigated courses were 2-credit undergraduate courses in the domain of cognitive psychology, conducted in the University of Helsinki. Table 2 presents an overview of the course settings. The main content of all courses was almost identical, regardless of different course titles. Also, the overall extent was similar — 24 lessons (45 minutes each) combined with distance work, such as virtual collaboration or a final report — but the target group and phasing of the lessons varied from one course to another, partly for practical reasons and partly because of the deliberate changes in the course design. The requirement for course

credit in all courses was to contribute actively to the seminar sessions and to the discourse in the Web-based environment as well as to accomplish all assigned tasks. The assessment was based only on pass/fail grading. The grading was not very detailed in any of the courses because of the experimental nature of the course settings.

The participants of the courses were aware of the research and development aspect related to the course. It was easy to justify that to the students because the course topic itself was about learning and technology. In addition, the students voluntarily provided feedback on the functionalities of the technology for technical developers.

Table 2. Overview of the investigated undergraduate courses.

Course title	*Time*	*Lessons/ week*	*Target group*	*Students*	*Instruc-tors*	*Tutors*
1. Perspectives of cognitive psychology on media education	11/1998 - 02/1999	3	Students of media education	13	1	0
2. Psychology of Learning and Thinking II	02/1999 - 5/1999	2	Students completing a minor unit in psychology [b]	17[a]	1	3
3. Perspectives of cognitive psychology on media education	11/1999- 02/2000	3	Students of media education	10	1	1
4. Psychology of modern learning environments	3/2002- 5/2002	4	Students completing a minor unit in psychology [b]	13	0	3

[a]Eighty students took part in the course, but they were divided in two conditions, so that 17 students volunteered to use the Web-based environment between lectures for collaborative inquiry. The data from that group were used in the present study.
[b]Undergraduate students from various faculties of the university of Helsinki who took part in the course to complete a ten-credit minor unit in psychology. They studied, e.g., forensics, mathematics, history, languages, or education.

As is typical for design-based research, the investigated course contexts were authentic in that it was not possible to control all elements in the settings; yet we consider that they were similar enough to be comparable with each other and that the differences in the characteristics of the inquiry discourse may be interpreted to have resulted, at least partly, from the changes in the pedagogical design. For example, with somewhat varying combinations, the same teacher and tutors conducted the courses. In addition, although the participants of the courses came from two different study programs, media education is a subject that can be studied only as a minor in the University of Helsinki. Therefore, the target groups of all courses were rather similar with students who have their major in various faculties of the university.

The pedagogical approach, which was an object of design, was based on the model of *Progressive Inquiry* (Hakkarainen, 2003; Muukkonen *et al.*, 2005) which describes the elements of expert-like inquiry practices in the form of a cyclic process. It relies on cognitive research on education and is closely associated with the knowledge-building approach of Scardamalia and Bereiter (1994; Bereiter, 2002) and the Interrogative Model of Inquiry proposed by Hintikka (1999). In a progressive inquiry process, the teacher creates a context for inquiry by presenting a multidisciplinary approach to a theoretical or real-life phenomenon, after which the students start defining their own questions and intuitive working theories about it. Students' questions and explanations are shared and evaluated

together, which directs the utilization of authoritative information sources and iterative elaboration of subordinate study questions and more advanced theories, explanations and writings. The model is not intended to be a rigid prescription for the phases of inquiry; rather it offers conceptual tools for educators and students to describe, understand and take into account the critical elements in collaborative knowledge-creating inquiry.

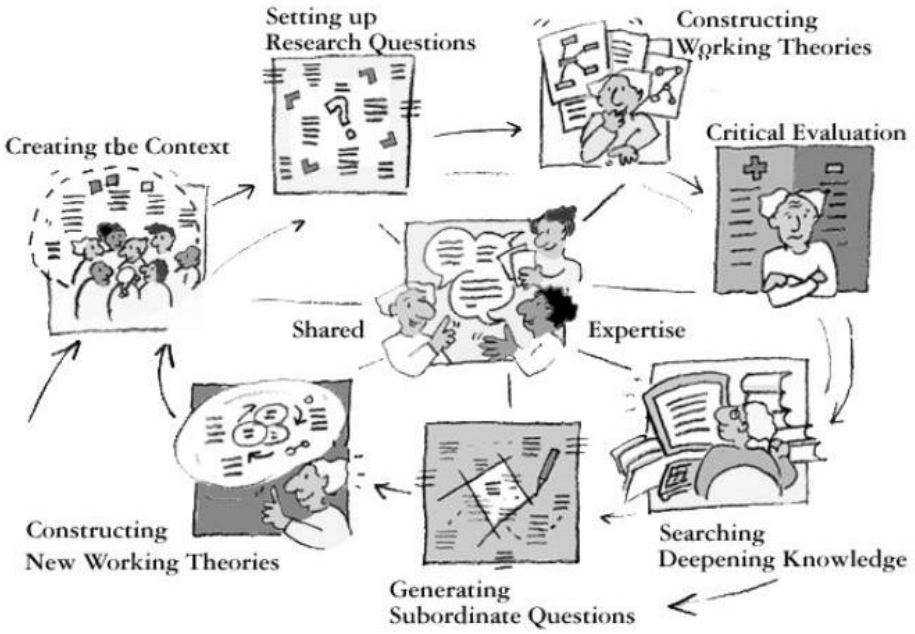

Figure 1. Elements of progressive inquiry.

The model of progressive inquiry includes the following elements that are placed in a cyclic form to describe the collaborative inquiry process (see Figure 1):

- *Shared expertise*: All phases of the process should be shared among participants, usually by using collaborative technology. Diversity in expertise among participants, and interaction with the information sources and/or expert cultures, is considered as promoting knowledge advancement (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione, 1993). It includes shared cognitive responsibility for the success of the inquiry.
- *Creating the Context*: At the beginning of the process, the context for the project is jointly created in order to anchor the problems being investigated in the central conceptual principles of the domain or complex real-world problems. The learning community is established by joint planning and setting up common goals. It is important to create a culture of learning that supports the collaborative sharing of knowledge.
- *Setting up Research Questions*: An essential aspect of progressive inquiry is that students generate their own questions to direct the inquiry. The learning community should be encouraged to focus on explanation-seeking questions (Why? How? What?) that are a result of students' own cognitive efforts and needs to understand (Bereiter, 2002).
- *Constructing Working Theories*: After question formulation, students are directed to explain phenomena with their own existing background knowledge before using authoritative information sources. This practice aims at making visible students existing conceptions of the issues at hand (Perkins, Crismond, Simmons & Under, 1995). Through sharing the explanations with each other, students make the gaps and contradictions in

their own knowledge more apparent. It serves to create a culture where knowledge is treated as a developing object (Bereiter, 2002).

- *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 joint cognitive efforts and the evaluation of the process itself. Critical evaluation is a way of helping the community to rise above its achievements by creating a higher-level synthesis of the earlier results of the inquiry process (Scardamalia & Bereiter, 1994).
- *Searching and Deepening Knowledge*: Students are supposed to explore diverse sources of information to find answers to their questions. A comparison of intuitively produced working theories with well-established expert knowledge or scientific theories tends to make the weaknesses of the community's explanations explicit. The search for relevant materials provides an opportunity for self-directed inquiry and hands-on practice when struggling to grasp the differences between various concepts and theories.
- *Generating Subordinate Questions*: The process of inquiry advances through transforming the initial big and unspecific questions into subordinate and more specific questions on the basis of the evaluation of the knowledge produced (Hintikka 1999). Formulation of subordinate questions refocuses inquiry.
- *Constructing New Working Theories*: New questions and the scientific and/or expert knowledge that the participants explore give rise to new theories and explanations. The process also includes the publishing of the summaries and conclusions of a community's inquiry. If all productions to the shared database in a Web-based environment have been meaningfully organized, participants have easy access to prior productions and theories, making the development of explanations a visible process.

A typical progressive inquiry project in school or university can last 4-6 weeks, with 3-6 hours per week, but the elements of progressive inquiry can also be applied in shorter or longer learning periods. Usually, students work in groups of 2-4 students, having a common research question, but also the whole classroom has common discourse sessions face-to-face or on-line. The teachers' role in progressive inquiry is to organize the whole educational setting which includes, for instance, scheduling the process, planning the use of technology and information sources, and organizing students' collaboration and group work. It is usually necessary for the teacher to structure and scaffold the process, keep it active and focused during the progression of the course, and to help students gradually take upon themselves the responsibility of higher-order cognitive processes.

Web-based Learning Environment

The technology used in each investigated course was a version of Future Learning Environment (FLE), an asynchronous groupware system designed to support collaborative knowledge building and progressive inquiry in educational settings (Leinonen, Kligyte, Toikkanen, Pietarila, & Dean, 2003; Rubens, Emans, Leinonen, Gomez Skarmeta, & Simons, 2005). FLE is an open source and free piece of software developed by the Media Laboratory, University of Art and Design, Helsinki, in collaboration with the present research group in the Department of Psychology, University of Helsinki. FLE consists of modules, of which the following two were used in the investigated courses: A user's WebTop (virtual desktop) and a Knowledge Building module (Leinonen, et al., 2003). Each user has a personal WebTop where one can store knowledge items, such as documents, files and links, and arrange them in folders. Users in the same course can visit each other's WebTop and see its content. The Knowledge Building (KB) module provides a shared space for the participants, in the form of threaded discourse forums for sharing and elaborating problem definitions, explanations, and theories together (see Figure 2). The KB discourse is scaffolded and 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), corresponding to the Progressive Inquiry model. The idea is based on the similar functionality in the Knowledge Forum software (see Scardamalia & Bereiter, 1994).

Figure 2. An example of the screen view in FLE3's Knowledge Building module in Course 4[1].

Evolving Course Design

In *Course 1*, the students had weekly face-to-face seminar sessions, led by an instructor, and joint discourse in FLE. In the first seminar session, the instructor introduced the goals and themes of the course and explained Progressive Inquiry as a heuristic model to structure the inquiry process. The KB discourse in FLE was organized according to the research problems that were collaboratively constructed by all students in the first seminar session and posted to the database by the instructor. Information sources used by the students were the weekly lectures and scientific articles distributed by the instructor as well as other self-sought materials. The role of the instructor was central in sharing expert knowledge in lectures and in organizing the study group's work according to the starting questions, but he did not participate in the virtual discourse during the process. The course was conducted soon after the establishment of the first working pilot version of FLE (http://fle.uiah.fi), and only the Knowledge Building module was available for collaborative knowledge sharing; WebTops was not used.

The main lessons learnt from Course 1 (see Muukkonen *et al.*, 1999) were that although the inquiry discourse was active in FLE, the inquiry process did not appear to advance and lead to any deeper conclusions spontaneously. There also was great variety in

[1] The research problem stated in the open note is: "What will the roles of teachers and students be like in collaborative web-based environment compared to traditional classroom studying?" The thread continues with one student's hypotheses for the issue of roles, another student's comment to the hypothesis, and successive notes about how to activate students, motivating function of FLE tool, how to activate students with learning disability, activation and motivation in web-based environment, and student's role and motivation.

the students' participation activity. Students reflected, afterwards, that they needed a tutor to help focusing and structuring the discussions. There were many technical difficulties because of the immaturity of the system.

Course 2 was also based on the weekly lectures given by the same instructor as Course 1, but the organization of the FLE work was changed to promote more systematic collaboration and focused and responsible inquiry activity than open discourse would generate, by explicitly organizing the students to work in small groups. Each group was provided with a tutor (a post-graduate student) whose role was to keep the discourse active, deepening, and focused on the generated research questions as well as to encourage the students to build on each other's ideas and evaluate the inquiry in line with the principles of progressive inquiry. The research questions, formulated amongst the whole class in the first lectures like in Course 1, were grouped together in three lists, consisting of 3 to 4 questions. The students worked in three isolated groups in FLE, with four to seven students in each group. Each group's responsibility was to work on a set of the research problems; the groups did not have access to each other's working areas. The students were guided to decide which particular problems they would mainly pursue, in order to increase their individual accountability of the process. Each student was supposed to write a reflective summary of one's own contributions and inquiry process at the end of the course. The function of the final task was to provide an explicit conclusion to the process. In addition to the KB areas, the personal WebTops were also available in FLE, but students were not required to use them.

A central experience from Course 2 was that it was not necessarily a good solution to organize students to work in small, isolated groups and direct each student to choose one special question as his or her personal responsibility. There were not enough members in each group to keep the discourse active and going, and all tutors needed to remind their group members of the importance of active participation and commenting on others' postings. Some students produced reflective summaries of high quality; in general, the content and quality of the summaries varied considerably. Three tutors had rather different style in contributing to students' technology-mediated inquiry (see Lakkala, Muukkonen & Hakkarainen, 2005) and the lack of possibility for face-to-face guidance was experienced as presenting difficulty.

In *Course 3*, the same solution as in Course 1 to share the inquiry discourse in FLE openly between all participants was restored based on the unfavorable experiences of isolated small groups in Course 2. Changes in the inquiry assignment were introduced to make the inquiry process more target-oriented so that the students also got an explicit assignment (one requirement for course credit) to make a final research report individually or in pairs about a problem related to their personal interests. More detailed general guidelines were provided for the students through FLE during the course to support expert-like inquiry practices. Course 3 was led by the same instructor; he gave the weekly lectures and participated as a subject-domain expert in the virtual discourse. It was decided that one tutor (a post-graduate student), in addition to the teacher, would be enough to provide guidance for all participants through the FLE forums. Her role was to supervise the inquiry process and contribute to it if she judged that it was important for activating, focusing, or advancing it and to give technical guidance if students asked for it. Also in this course, only the Knowledge Building module of FLE was systematically used for collaborative knowledge sharing although WebTops was available.

Experiences from Course 3 of the requirement to produce a concrete research report as an outcome of the inquiry process was evaluated to be a good solution; students took much responsibility for pursuing their inquiry and finalizing the report. A drawback was that most students appeared mainly to have concentrated on their own inquiry process without contributing to the advancement of others' inquiry. The discourse in FLE became more like individual monologues rather than collaborative knowledge creation. Because the FLE

system was constantly under development parallel to its pedagogical testing, some technical changes were made to it during the course by the technical developers; these changes caused severe technical problems for the students.

Based on the experiences of the previous courses, the pedagogical design of *Course 4* was changed considerably in order to give students more actual experience of practicing collaborative inquiry and to define the inquiry task in a more target-oriented and collaborative manner. There was only one expert lecture in the middle of the course, given by the same instructor as in the previous courses. The process was guided by three tutors (post-graduate students); one of them had also participated in Courses 2 and 3, another in Course 2. The joint effort to re-design the course and supervise students was also a valuable learning experience for the tutors. Because both collaboration between students and tutoring of them were experienced in the previous courses as very challenging if conducted entirely virtually, tutors decided that face-to-face seminar sessions would be used for actual inquiry work. Each weekly seminar session included working with FLE in a computer room (first two lessons) and general discussions and small group work in a seminar room (last two lessons). According to the experiences of the previous courses, true collaboration between the students turned out not to come about spontaneously; therefore, the systematic formation of the small groups based on students' similar research interests was explicitly built into the working process. Three sub-groups (including four to five students) were formed based on a special research problem chosen after an initial brainstorming phase. Adapting the successful practice of the previous course, each small group also had a task to produce a concrete research report at the end of the course. In addition, special efforts were made, in the seminar sessions, to guide student groups to pursue their inquiry further through several successive question and explanation phases according to the idea of progressive inquiry, before they started to write the final report. All groups also had access to other groups' postings in FLE in order to ensure open sharing of knowledge and idea diversity. In the last two sessions, the groups presented their research outcomes, and the whole process was evaluated by the combined groups by discussing the experiences. After the course, the students sent in, by email, a self-evaluation of their participation in the course in which they answered three open questions.

The technology used in Course 4 was a revised version of the Web-based environment, FLE3 (http://fle3.uiah.fi), which was already well tested in other contexts before the course. An important change was made in the functionality of the built-in knowledge-type scaffolds: textual guidance was available for each scaffold when the user is choosing one, and the choice of knowledge type was 'forced' so that a user always has to make a new choice about it in a new note; there was no default value and the system did not allow going forward to writing the note before the choice was made.

In Table 3 the central differences and changes in the designs of the four courses are described through the Pedagogical Infrastructure Framework.

Table 3. Differing features of the pedagogical infrastructure in the four courses (KB = Knowledge Building; FLE = Future Learning Environment; PI = Progressive Inquiry).

	Course 1	*Course 2*	*Course 3*	*Course 4*
Technical				
Access to technology and technical guidance	No special access or guidance.	No special access or guidance.	No special access or guidance.	Provided during all seminar sessions.
Diversity of tools provided	KB forums.	KB forums and WebTops.	KB forums and WebTops.	KB forums with built-in guidance and WebTops with additional features.
Social				
Structuring of collaboration	No structuring.	Self-formed sub-groups.	No structuring.	Sub-groups formed through joint negotiations.
Integration of multiple social spaces	Lectures and FLE work separated.	Lectures and FLE work separated.	Lectures and FLE work separated.	Seminar sessions and FLE work integrated.
Sharing of the inquiry process	Shared discourse.	Discourse shared within isolated sub-groups; each student chose one main question.	Shared discourse; a main question defined personally or in pairs.	Shared questions first, later three sub-groups chose one main question; all discussions shared.
Individual and collective nature of the inquiry outcomes	No concrete outcome.	Individual reflective summary.	Research report done individually or in pairs.	Individual and collective self-reflection; collective research report.
Epistemological				
The emphasis on question-driven inquiry	Discourse loosely shaped by starting questions.	Discourse shaped by selected starting questions.	Target-oriented process driven by selected main question.	Target-oriented process driven by iteratively revised inquiry questions.
Main source of information	Lecturing in a central role.	Lecturing in a central role.	Lecturing in a central role.	Students' own utilization of information sources.
Concrete knowledge object as an outcome	No concrete outcome.	Written reflective summary.	Research report.	Research report.
Cognitive				
Modeling of inquiry strategies	Introducing the model of PI.	Introducing the model of PI.	Introducing the model of PI.	Introducing the model of PI and implicitly phasing the activities accordingly.
Human guidance provided	Limited guidance from the teacher virtually.	Guidance from a tutor in each group virtually.	Limited guidance from the teacher and a tutor virtually.	Guidance from three tutors virtually and in seminar sessions.
Cognitive scaffolding embedded in tools	Inquiry scaffolds in discourse forums.	Inquiry scaffolds in discourse forums.	Inquiry scaffolds in discourse forums.	The choice of inquiry scaffold 'forced'; text guidance provided.
Promotion of metacognition	General advice to evaluate the process.	An assignment to write an individual self-reflective summary.	Open-ended post-questions for individual self-reflection; a discourse forum for evaluating the process.	Open-ended post-questions for individual self-reflection after the course; organized common self-reflective discussion.

Data Collection and Analysis

In the present study, four consecutive courses are compared retrospectively in order to test the Pedagogical Infrastructure Framework and utilize the collected data once more for a more overarching examination of the conducted design-based research effort. The main data used in the study consisted of the contents of the database in the FLE system created by the participants during the courses. In addition, the students' written self-reflection reports in Course 4, which they sent by email to the tutors, were included in the analysis. The researchers' participant observations were central in reconstructing the designs and experiences of the courses (Yin, 2003). The overall methodology is mainly explorative and is based on a *mixed-method* approach (Johnson & Onwuegbuzie, 2004), meaning that the courses were investigated, combining various methods and data sources to yield a multifaceted view of the activity in the courses from various perspectives: participant observations of the organization of the courses, descriptive statistics and explorative analysis of the inquiry discourse in FLE, and the content analysis of students' written self-reflections assessing pedagogical arrangments in the courses.

One student activity, central for the Progressive Inquiry approach, was similar in all four courses, namely the *content-related* inquiry discourse in FLE's Knowledge Building forums. A detailed, descriptive analysis was used to compare the students' engagement in this inquiry activity, to enable researchers to take a process perspective on the discourse, in order to evaluate the achievements of goals set by the Progressive Inquiry model. For this purpose, we chose all those KB forums for analysis that included students' postings related to the research questions, own explanations and theoretical considerations. The forums including general guidelines or negotiations of the working practices in the course were not included in the analysis because they were structured in different ways in each course regarding the course design. Two researchers read the discourse data several times and formed their individual opinions of it as regards the goals of progressive inquiry. Issues that were especially examined were the progression of the joint question–explanation process, the development of ideas in dialogue, the incorporation of scientific theories or information from academic literary sources into students' explanations, and metalevel self-reflection included in the notes. After that, characteristic differences in students' engagement in inquiry per course as observed from the database productions were (a) identified by examining the threading of their discourse and (b) qualitatively described and a narrative jointly written after discussions between the researchers. We also analyzed quantitatively how the students used the inquiry scaffolds (Problem, Own explanation, Deepening knowledge, Comment, Metacomment, and Summary) in those KB forums to label their notes, providing information on the students' ways of applying the cognitive tools embedded in technology to structure their inquiry.

Students' written self-reflections (either in FLE or by e-mail) on their course experiences were used as complementary data to illustrate how the features of the infrastructures in each course were manifested from the students' perspective. First, those sections from the students' writings in each course were chosen, including references to the pedagogical arrangements in the course. Second, each segment was categorized, jointly by two researchers, according to the component of the Pedagogical Infrastructure Framework it concerned: Technical, Social, Epistemological or Cognitive.

Results

Students' Engagement in Inquiry

Progression of the inquiry discourse. In Course 1, students (N = 13) posted 125 (M = 9.6) notes into FLE; the teacher posted 17 notes (12.0% of all notes). The database consisted of seven discourse forums structured according to the starting questions, and one forum including students' written self-reflections in the end of the course. The seven inquiry-focused forums included 24 sub-threads (mean length 5.1 notes) and only 6 isolated notes (4.7% of all notes). The discourse appears to have been especially characterized by idea-rich, dialogic and connected discussion where the participants presented their own experiences, opinions, and explanations as well as actively commented on each others' ideas, but the discussion was not very deepening or focused on theory building. The proportion of references to academic literary sources in all of the students' writings was low, and the discourse often did not appear to lead anywhere. One may conclude that this low proportion mostly likely resulted from the lack of requirement for a concrete conclusion or outcome of the inquiry task, relating to the epistemological infrastructure of the course. There was no tutor scaffolding the inquiry process.

In *Course 2*, students (N = 17) posted 203 (M= 11.9) notes; the three tutors posted 38 notes (M = 9.5; 15.8% of all notes). In each of the three isolated groups, there was one discourse forum including discussions for organizing the work, and 3 or 4 forums structured according to the content-related starting questions. The content-related inquiry forums consisted of 31 sub-threads (mean length 5.0 notes) and 27 isolated notes (13.3% of all notes). The discourse may be described as having a focused problem-solving tendency: participants concentrated on the starting questions assigned to the group, presented subordinate questions to previous ones, and produced explanations and summaries, where they also referred to academic literary sources and scientific theories. The tutors reminded the students to focus the inquiry and bring in theories and research findings from literature. However, in each group, the inquiry was somewhat fragmented, and many postings did not arouse any reactions from other students (also indicated by the rather high proportion of isolated notes). This could have been caused by the design solutions related to the social infrastructure: we divided the course participants into small, isolated groups comprising only a few students who interacted merely with each other during the entire course, and we guided each student to choose one inquiry problem on which he or she would mainly concentrate.

In *Course 3*, students (N = 10) produced 261 (M= 26.1) notes; the teacher and the tutor posted 23 notes (M = 12.5; 8.1% of all notes). The discourse consisted of one KB forum including discussion about working in the course, ten thematic forums based on issues or questions created jointly in the first seminar session, and one forum for the students' written self-reflections of the course experience. The content-related inquiry forums included, in total, 35 sub-threads (mean length 4.9 notes) and 49 isolated notes (22.2% of all notes). The students wrote long, elaborated notes including versatile questions, explanations, practical ideas and experiences, as well as scientific information from academic literary sources. The assignment to produce a concrete research report, forming for its part the epistemological infrastructure, presumably promoted the students' working in a very responsible and engaged way. At the same time, the discourse appears to be more like self-reflection on individual students' or student pairs' chosen inquiry questions rather than collaborative inquiry: Typical of the discourse were many isolated notes without any comments as well as discourse threads where individual students frequently commented on their own notes.

In *Course 4*, students (N = 13) posted 181 (M= 13.9) notes, and the three tutors posted 57 notes (M = 19.0; 23.9% of all notes). The FLE database consisted of four forums for process organization issues, one forum for brainstorming research questions, and three

forums for the three groups' inquiry. The content-related forums included 35 sub-threads (mean length 6.6 notes) and only 8 isolated notes (4.8% of all notes). In addition, the WebTops of the FLE system were used for saving and sharing documents and links. Students posted 26 documents and 16 links in their WebTops. The inquiry discourse can be characterized as connected, focused, and task-oriented; the student groups clearly engaged in answering their joint research question by sharing ideas, utilizing various scientific sources and building on each others' explanations. Apparently both the ways of organizing the work into interest-based sub-groups and the requirement for a joint research report had an effect on that. In addition, the tutors gave timely guidance and suggested useful knowledge sources to all groups both virtually and face-to-face. Some students, especially, appear to have taken much responsibility for advancing and directing their group's inquiry, which resulted in a somewhat different quality and progression of the separate groups' discourse. The students did not very actively comment on other groups' contributions; that activity was not explicitly structured in the pedagogical design.

Use of inquiry scaffolds. Every note posted in FLE's KB forums had to be labeled using an inquiry scaffold based on the Progressive Inquiry model. One way to evaluate the students' inquiry practices in each course was to compare the students' use of the scaffolds to represent the contents of their notes (see Fig. 3). Based on a $\chi 2$-test, there was a significant difference between the courses; $\chi 2$ (15, N = 634) = 131.25, $p < .001$.

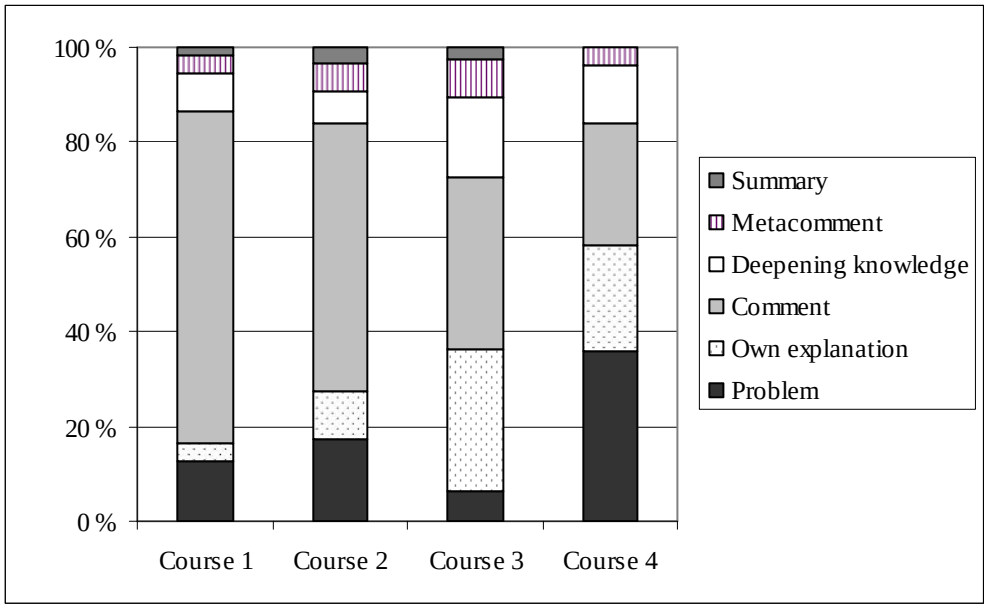

Figure 3. The frequencies of FLE's knowledge type scaffolds used by the students in the four courses.

In Courses 1 and 2, the very neutral inquiry scaffold, Comment, was clearly used more than the other labels, and this raised the question of further developing the functionality of the scaffolds (as a default, FLE suggested the label used in the replied note). When comparing the scaffolds used to the content of the notes, it appeared that students tended to choose the scaffold, Comment, when the note was a reply to some other note although it included the authors' further elaborations of the explanations or new subordinate research questions raised from the previous discourse.

In Course 3, the students had also used the knowledge type, Own explanation, frequently; this might reflect the nature of the task given to the students to produce a final

research report. Those drafts were shared through KB forums and usually labeled as Own explanations. The use of the scaffolds was most versatile in Course 4. This may be a consequence of improvements in the functionality of the scaffolds in FLE before Course 4: the 'forced' decision about an inquiry scaffold in creating a note without any default, preventing students from going on without choosing one, and written guidelines provided by the system when choosing the scaffold. The use of inquiry scaffolds differed from the other courses especially in the frequent use of the scaffold 'Problem', which might be the result of a more systematic concentration on the question formulation phase of the inquiry process, directed by the tutors in the seminar sessions. The lack of use of the Summary scaffold may relate to the way of sharing the drafts of the groups' research reports mainly through WebTops as text documents and not through KB forums.

Students' Self-Reported Experiences reflecting the Pedagogical Infrastructures

The affordances that the pedagogical arrangements provided for students in each course were also investigated by analyzing, through the Pedagogical Infrastructure Framework, the students' written, self-reported experiences of the courses. Figure 4 presents the distribution of excerpts included in the analysis into the pedagogical infrastructure categories. The overall number of analyzed excerpts is rather small because the students' writings did not include so much inspection of the pedagogical arrangements; mostly the writings described the group process or the students' personal participation and learning. However, issues mentioned by different students in the same course were very congruent with each other, addressing the same features; this suggests that the self-reflections may be interpreted as revealing some central consequences of the course designs on student's experience. Based on a $\chi 2$-test, there was a significant difference between the courses in the distribution of self-reflections concerning the pedagogical arrangements; $\chi 2\ (9, N = 76) = 25.6697$, $p < .01$.

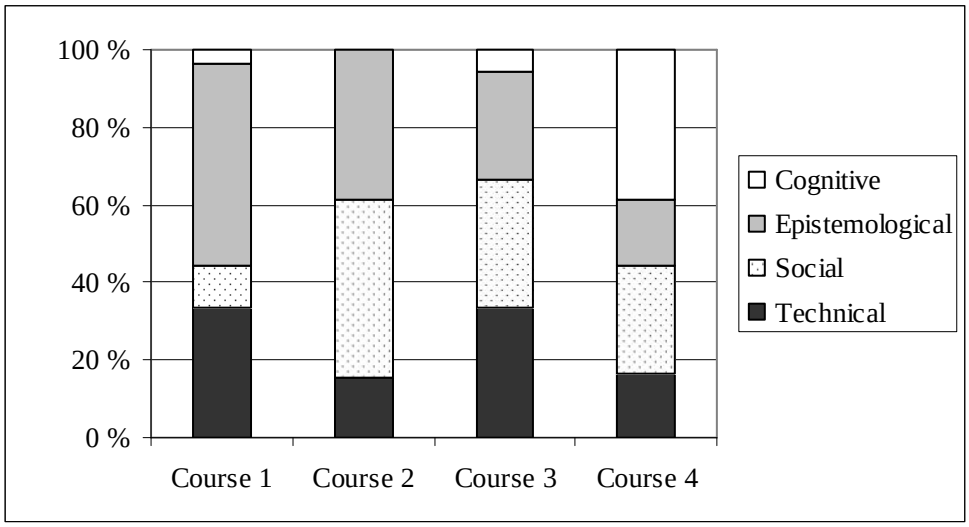

Figure 4. The distribution of students' reflections of the course into the pedagogical infrastructure categories.

Below, the students' experiences of the course arrangements are illustrated through the example quotations from their students' written self-reflections, categorized according to the components of the Pedagogical Infrastructure Framework. Quotations were selected that appropriately represented insights emphasized by multiple students in the same course. The courses were in Finnish; therefore all the text quotations have been translated into English.

Technical component. Excerpts describing the technical arrangements in Courses 1 and 3 addressed the problems that emerged because the FLE system did not function properly, or there was not enough support provided for using it. The following comments written by the students illustrate these problems:

> *When the timetable was so tight, the activity in FLE remained inadequate because of many practical difficulties; first, FLE stopped working; second, the registration for the course was difficult (the procedure did not work as it was expected to work); some of the students could not participate in the FLE work until in the end. (Course 1)*

> *It would have been good if it had been checked in the meetings that everybody really can use the environment. (Course 3)*

> *I did not understand early enough that this time the technology really caused an insurmountable barrier for knowledge building. (Course 3)*

In Course 2 and particularly in Course 4, the FLE system functioned better, and there were only a few, mainly positive comments about the technology in the students' evaluations. The following is a quotation from Course 2: "The idea of FLE is good and this implementation is already in a usable level. I believe that this kind of tool has a future." In Course 4, the possibility and support for using the technology was provided also during the seminar sessions and is praised, as in the following comment: "I think that there was enough guidance and the exercises and tasks made in the computer lab were useful."

Social component. Related to the aspects of social arrangements, the students in Course 1 praised only the face-to-face discussions, not the technology-mediated discourse. For example: "I think that the best part of the course, in addition to the lectures, were the topic-related discussions that were held during the lessons." In Course 2, the students were divided into smaller groups to work on a set of inquiry questions but without an explicit requirement for jointly formulated questions or common outcome. Consequently, students did not experience the activity as very collaborative. This is manifested in the following comments:

> *If there are many themes, like in this case there were, it is probable that one of them dominates the discussion and takes attention from the other themes. The activity is and it should presumably be — collaborative. If the other members of the group are discussing a certain issue, you do not like to toil 'alone' somewhere else. (Course 2)*

> *Everyone is trying to formulate the problem with his or her own world; therefore the theory does not grow deeper. We do not approach the new conceptualization of the problem if everyone is thinking about a different problem! (Course 2)*

In Course 3 students were critical of the lack of mutual commenting and collaboration in the FLE discourse. For example: "I think that alone you cannot get very far in knowledge building; our own building got stuck with the problem that other knowledge builders just did not show up to participate." In that course, students pursued inquiry problems individually or in pairs, and they were not explicitly directed to contribute to others' discourse, which apparently decreased the amount of virtual interaction with other participants in the course.

The social organization was changed considerably for Course 4 from that in the previous courses; it consisted of the explicit instruction to examine and solve a common group problem throughout the course with the support of three tutors. This design raised comments from the students mainly related to the atypical experiences that the arrangements created; for example:

> *The atmosphere in the course was unusually comfortable; dialogic and not as concentrated on performance requirements as I am used to. (Course 4)*

> *When there are many tutors, the discussions are different. The dialogue between students and tutors is easier and more relaxed; not as hierarchic as it (even unconsciously) would easily be*

if there is only one tutor. It is interesting also to be able to follow the discussion and the varying interests and research focuses between the tutors (that is, experts). On my opinion, it supports well the formation of a collaborative atmosphere. (Course 4)

I believe that our course work was more than any one of us could have accomplished alone. (Course 4)

Epistemological component. Aspects concerning epistemological issues of the course design were much criticized in Course 1, particularly the open discussion-type activity in FLE without purposeful inquiry goals. This is well illustrated in the following student comment from Course 1: "The discussion that drifted to somewhat aimless chatting at some point did not motivate at least me very much to commenting (and the execution of a course does not feel as a sufficient motive in itself anymore)." Also in Course 2, the discourse was rather loosely structured by a few starting questions in the isolated sub-groups, which created similar reflections of unsystematic inquiry process:

In the beginning — in the working theory phase — I presented questions, related to mental images, to which I wanted to start seeking answers. However, my unfamiliarity in working with network technology made me forget them there — mainly the topic proceeded meandering freely, following the rule that the previous message created the next one. Now afterwards it is interesting to evaluate how many questions got even some kind of an answer. (Course 2)

In Courses 3 and 4, the activity was more explicitly framed through individual or collective inquiry questions and a requirement for a research report. These appear to have made the task more meaningful for the students, but also raised some comments related to the challenges of dealing with the open knowledge space:

I consider that one important issue is to specify your own problem during the working process. Tutors and other students can also help in this specifying. Many students appeared to have problems with specifying the problem so that they could reach a final outcome of some sort; me too. (Course 3)

Perhaps the tutors could more clearly have suggested appropriate sources; now the suggested ones were intended too much for 'professionals', thus requiring, at least on my opinion, too much background knowledge. Secondly, the sources did not fit/answer to those questions to which we were seeking answers. (Course 4)

Cognitive component. According to the analysis, no one in Course 2 and only one student in Courses 1 and 3 mentioned aspects characterizing the cognitive support of the course design in their evaluations. The two comments concerned the comprehension of the inquiry process; for example in Course 1: "But I think that the whole progressive inquiry process did not open up very quickly, and following of the various themes did not create sturdiness or processing committed to your own progressive inquiry components."

By contrast, in Course 4, there were many critical comments from the students concerning the difficulty of understanding the inquiry strategies and the need to receive more guidance especially at the beginning of the process. It is intriguing, because there was more guidance available in Course 4 than in the previous courses. Presumably the challenges of expert-like inquiry became more apparent for the students in this course because they were really expected to carry out, in groups, an open-ended inquiry process from preliminary questions to the final research report, relying on their own engagement and capabilities. The following comments are illustrative examples of the students' self-reported experiences:

"Sometimes I clearly felt that I had lost the ball; therefore it would have been great if we had been presented a model about how the process should progress, preferably broken off for each meeting." (Course 4).

"It took a long time before it became clear what the idea of the course was but I do not know whether it was due to lack of guidance or own incomprehension." (Course 4).

Discussion and conclusions

The pedagogical design of technology-enhanced collaborative activities requires one to engage in complex systems thinking that examines learning as a self-organizing emergent process where the effects of individual features of the design on students' collaborative activity cannot be fully separated (Scardamalia & Bereiter, 2006). The *Pedagogical Infrastructure Framework*, introduced in the present study, is one effort to provide a design-and-analysis tool to handle the complexity and to conceptualize the critical elements in the design of complex educational settings.

The framework is meant to provide a conceptual tool for structuring the creation and analysis of specific pedagogical designs through some "universal" basic components of an educational setting that are often not examined or questioned explicitly or systematically. For instance, whatever the pedagogical approach, the social component of the setting is always organized in some way: for example, when the approach is based on encouraging students' individual work. When seeking to be innovative or to transform existing practices, as is the case in design-based research (Sandoval & Bell, 2004), novel viewpoints may result in discovering new, valuable solutions.

The Pedagogical Infrastructure Framework is not normative; it does not prescribe how the technical, social, epistemological, or cognitive components of an educational setting should be designed. The choice of individual features that would build up an appropriate and effective pedagogical infrastructure in each case depends on the goals and the intended nature of activity that the specific educational setting is supposed to promote; the framework just helps in examining the various features in a structured fashion that is applicable to various types of cases, and it enables the comparison of deviating solutions.

In the investigated courses, the pedagogical design was based on the *Progressive Inquiry model* (Hakkarainen, 2003), and the course design was developed from one iteration to the next to better reflect the principles of the model, such as grounding the inquiry process on students' authentic knowledge problems, sustained engagement in the elaboration of explanations, the promotion of collaborative activity, and the use of appropriate technological tools to mediate collaborative knowledge creation. Both the functionalities of technology and the researchers' views of the pedagogical model evolved over time, and the developing design was an intertwined summary of various features, influenced by student feedback and other experiences from the preceding courses.

The Framework 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 in Course 2 to work in small groups, where the inquiry was focused on a few specific questions and supported by tutors' strategic guidance (an assumed epistemological improvement compared with Course 1) the discourse ended up being less active and dialogical. We concluded that the simultaneous arrangement to make the small groups work in isolation with each other did not provide enough *idea diversity* (Scardamalia, 2002) to feed the collaborative inquiry process although it was more focused and academic.

Similarly, although adding an explicit assignment to make a research report as a concrete outcome of the inquiry promoted very engaged and productive student activity in Course 3, it also resulted in infrequent mutual commenting in virtual discourse and feelings of lack of collaborative activity. The new task feature seemingly emphasized individual commitment while, simultaneously, collaboration was not explicitly promoted in the

pedagogical infrastructure. Cohen (1994) used the term *true group task* to emphasize that if students are expected to genuinely engage in collaborative action, the task should be defined so that it requires working together in order to be able to complete. We may speculate, using the concepts introduced by Scardamalia (2002), that the arrangements in Course 3 supported the development of students' *epistemic agency* – the effort to advance personal ideas and understanding in relation to others' ideas – but did not, apparently, promote the development of *collective cognitive responsibility* which would facilitate contributions to the shared, top-level goals, the production of ideas of value to others, and the sharing of responsibility for the overall advancement of knowledge in the community.

The results from Course 4 further address the importance of taking into account the interrelationships of various features in the pedagogical design. In the course, profound changes were made in the design, compared with other courses. The entire course activity was based on student groups' inquiry instead of lecturing and virtual inquiry discourse. A new version of the collaborative software system was in use, with more stable technical functionality and more advanced support for structuring the inquiry discourse through built-in scaffolds. 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 might be a result of an increase in the cognitive challenge of the task: forced choice of an appropriate inquiry scaffold in the system, more emphasis on student-driven inquiry and solving of a joint research problem, knowledge acquisition based on the students' own exploitation of authentic sources, and the requirement to produce a joint research report based on the group's inquiry. This challenge apparently increased the experienced need for systematic human guidance to support students' understanding and managing of the collaborative inquiry process.

One central issue for pedagogical design that has not particularly been addressed in the present study is the role of *assessment* in the pedagogical infrastructure. In the investigated courses, there were no institutional demands to grade students (other than pass/fail), and assessment was not the object of change in the transforming design. However, it is a well-known fact that in educational settings, learners direct their efforts to those issues for which they are assessed and awarded. Roschelle, Pea, Hoadley, Gordin and Means (2000) stated "one of the biggest barriers to introducing effective technology applications in classrooms is the mismatch between the content of assessments and the kinds of higher-order learning supported most effectively by technology" (p. 91). Assessment should be built into the pedagogical infrastructure so that it is in synergy with the goals and other components of the design. For instance, if a central aim is to engage students in certain kinds of collaborative work or production of theoretically high-level explanations, the assessment of those criteria should be explicitly built into the social and epistemological components of the pedagogical infrastructure.

We have suggested that besides using the Pedagogical Infrastructure Framework for analyzing the ways that educational settings are designed, the framework could also be used as a conceptual or heuristic tool for educational practitioners to *design* new settings. So far we have not had systematic experience of that undertaking. It would be fruitful to introduce the framework to some university teachers and investigate how they use it for designing their courses or to find out whether the framework helps them check that all important aspects are planned properly. To serve as a practical tool, the framework probably needs to be specified to include more explicit guidelines or categories, and some examples of the possible issues to be considered when designing the pedagogical infrastructure of a course. It would also be

valuable to elaborate the Pedagogical Infrastructure Framework to better help one consider the interrelationships between the various components of the design.

Although any particular pedagogical infrastructure is designed in advance by the instructors, there should be room for adjusting the structure according to students' progression and emerging activity during the process. Such responsiveness and competency in re-organizing the collaborative activity 'on the fly' characterizes a skilled instructor, and requires experience as well as conscious understanding of the principles of the chosen pedagogical approach.

In the present study, the Pedagogical Infrastructure Framework was used as an analytic tool to categorize and compare the various elements in the transforming course designs. We have found that the framework helped account for the characteristics of the design in each course in providing unifying terms and supplying a framework within which one could compare the design features with the outcomes of the students' inquiry activity and self-reported experiences. Perhaps the most important 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. The results underline the importance of *synergy* (Tabak, 2004) between the various components in a pedagogical infrastructure.

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