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The Artifact Project
Promoting Design Learning in the Elementary Classroom

Kaiju Kangas

Academic dissertation

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Abstract

Designing, from its very premise, aims to create something new. Therefore, it can be seen as a form of object-oriented process of knowledge-creation, which, in turn, is considered a fundamental future competence. In order to productively participate in the future society, students need experience of creative knowledge work practices from an early stage of their education. Since the objects and effects of design are daily apparent all around us, engaging in and comprehending design processes provides a means of developing a deep understanding of the less tangible issues affecting us humans and the world we inhabit. However, design learning and knowledge-creation have not, especially at lower levels of education, attracted much research interest. The general aim of the present study is to examine how knowledge-creation exemplified by collaborative designing could be promoted at the elementary level of education. This objective is two-fold; on one hand, the present study investigates the nature of students' collaborative design learning processes and, on the other hand, the facilitation of these processes. Further, the study explores the role of social, material, and embodied dimensions of designing in the learning processes as well as in their facilitation.

The study represents design-based research, where the pedagogical approach Learning by Collaborative Design (LCD) was, for the first time, applied at the elementary level of education. In order to examine and further advance the approach, a longitudinal project, the *Artifact Project*, was organized in an elementary school in Helsinki, Finland. Video data (approximately 16 h) from the project's lamp designing phase constitute the main data source of the present study. The leadership of this phase was provided by a professional designer, and the data consists of interaction between him and the students, as well as of the student teams' peer collaboration. In addition, selected views from the Artifact Project's Knowledge Forum database were analyzed. The data was approached through iterative cycles of qualitative content analyses.

The findings indicate that elementary students are able to engage in and learn creative knowledge-creation and design processes, and that these processes can be structured and promoted using the pedagogical LCD approach. Three foci of participants' activity were

identified in the study, indicating that in order to engage in genuine design inquiry, students need support in understanding the rationale directing the design practice, in actually engaging in these practices, and in the reflection and sharing of their emerging design knowledge.

From the findings, four pedagogical implications were drawn. First, creative knowledge-creation and design processes evolve within long, preferably undefined periods of time. Second, design is inherently interdisciplinary, and students' emerging design knowledge also calls for knowledge of science and the humanities. Third, design competence develops through several connected levels – social, material, and embodied – of thinking, interacting, and meaning making. Fourth, collective and participatory learning facilitates creative designing and knowledge-creation. The implications drawn are linked with the emerging maker culture, which may provide new prospects for implementing design learning as well as underlining its significance in general education.

Keywords: design learning, knowledge-creation, elementary school, design-based research, social and material mediation, embodiment

Tiivistelmä

Suunnittelu pitää sisällään ajatuksen jonkin uuden kehittämisestä. Se voidaankin käsittää ilmentymäksi kohteellisesta tiedon luomisen prosessista, jota puolestaan pidetään yhtenä tärkeimmistä tulevaisuudessa tarvittavista taidoista. Kyetäkseen toimimaan tulevaisuuden yhteiskunnassa, oppilaat tarvitsevat jo varhaisessa vaiheessa koulutusta kokemuksia luovista käytännöistä, joilla tiedon parissa voidaan työskennellä. Suunnittelun tuotokset ja vaikutukset ovat nähtävissä kaikkialla ympärillämme, jonka vuoksi osallistumalla suunnittelun prosesseihin on mahdollista ymmärtää myös monia abstrakteja ihmisiin ja maailmaan vaikuttavia asioita. Suunnittelun ja tiedon luomisen opiskelua, erityisesti koulutuksen varhaisilla asteilla, on kuitenkin tutkittu melko vähän. Tässä tutkimuksessa tarkastellaan yhteisöllisen tutkivan suunnittelun kautta tapahtuvan tiedon luomisen opiskelua alakoulussa. Tutkimuksen tavoite on kaksitahoinen: yhtäältä tutkimus perehtyy oppilaiden yhteisöllisten suunnitteluprosessien luonteeseen, ja toisaalta tutkimuksessa tarkastellaan näiden prosessien tukemista. Lisäksi tutkimuksen kohteena ovat sekä prosesseihin että niiden tukemiseen liittyvät erilaiset sosiaaliset, materiaaliset ja keholliset ulottuvuudet.

Tutkimus edustaa kehittämistutkimusta (design-based research), jossa yhteisöllisen tutkivan suunnittelun pedagogista mallia Learning by Collaborative Design (LCD) sovellettiin ensimmäisen kerran alakoulun opetuksessa. Mallin soveltuvuuden arvioimiseksi ja sen edelleen kehittämiseksi järjestettiin pitkäkestoinen *Esine-projekti* alakoulussa Helsingissä. Tutkimuksen pääaineistona on projektin valaisinsuunnitteluvaiheessa kuvattu videomateriaali (noin 16 h). Tämän vaiheen ohjaajana toimi ammattisuunnittelija, ja videolle tallennettiin sekä suunnittelijan ja oppilaiden vuorovaikutus että oppilaiden keskinäinen vuorovaikutus pienryhmätilanteissa. Lisäaineistona tutkimuksessa toimivat projektin Knowledge Forum tietokannasta valikoidut näkymät. Aineistoa on tarkasteltu laadullisen sisällönanalyysin keinoin useiden, asteittain syvenevien analyysikierrosten ajan.

Tulokset osoittavat, että alakouluikäiset oppilaat ovat kykeneviä osallistumaan yhteisöllisen tutkivan suunnittelun kautta tapahtuvaan tiedon luomiseen, ja että tätä prosessia voidaan jäsentää ja tukea LCD

mallin avulla. Tutkimuksessa tunnistettiin kolme erilaista toiminnan kohdetta, jotka osoittavat, että kyetäkseen osallistumaan aitoon suunnittelutiedon luomiseen oppilaat tarvitsevat tukea suunnittelun käytäntöjen taustalla vaikuttavien perusteiden ymmärtämiseen, ammattimaisiin suunnittelukäytäntöihin osallistumiseen, sekä oman kehittyvän suunnittelutiedon reflektointiin ja jakamiseen.

Tutkimuksen tuloksista tehtiin neljä pedagogista johtopäätöstä. Ensinnäkin, suunnittelu- ja tiedon luomisen prosessit vaativat pitkällistä luovaa työskentelyä, jonka vaatimaa aikaa ei voida tarkasti ennalta määritellä. Toiseksi, suunnittelu on luontaisesti monitieteistä, ja suunnittelutieto vaatii kehittyäkseen myös tietoa luonnon- ja ihmistieteistä. Kolmanneksi, kyvykkyys suunnittelussa kehittyy useilla eri ajattelun, vuorovaikutuksen ja merkitysten rakentamisen tasoilla – sosiaalisilla, materiaalisilla ja kehollisilla. Neljänneksi, kollektiivinen ja koulun rajoja laajentava oppiminen tukee suunnittelua ja tiedon luomista. Tutkimuksen johtopäätökset linkittyvät kehittymässä olevaan maker-kulttuuriin, joka voi tarjota uusia mahdollisuuksia suunnitteluoppimisen toteuttamiselle ja sen merkityksen korostamiselle perusopetuksessa.

Asiasanat: suunnittelun oppiminen, tiedon luominen, alakoulu, kehittämistutkimus, sosiaalinen ja materiaalinen välittyneisyys, kehollisuus

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This study is about creating knowledge and constructing understanding through collaborative designing. The fundamental assumption is that real understanding evolves through experiences that are personal as well as shared. Likewise, this study itself is the result of collaboration with a number of people whose support, encouragement, and guidance have been essential to both the progress of the study and to my personal development as a researcher. This dissertation was accomplished because of our collective experiences.

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Helsinki, October 2014
Kaiju Kangas

List of original publications

This dissertation is based on the following publications, which are referred to in the text by their corresponding roman numerals (I–IV):

I Kangas, K., Seitamaa-Hakkarainen, P. & Hakkarainen, K. (2007). The Artifact Project. History, science and design inquiry in technology enhanced learning at elementary level. *Research and Practice in Technology Enhanced Learning, 2*(3), 213–237.

II Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Figuring the world of designing: Expert participation in elementary classroom. *International Journal of Technology and Design Education, 23*(2), 425–442.

III Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design expert's participation in elementary students' collaborative design process. *International Journal of Technology and Design Education, 23*(2), 161–178.

IV Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design thinking in elementary students' collaborative lamp designing process. *Design and Technology Education: an International Journal, 18*(1), 30–43.

1 Introduction

”Anything that isn’t a simple, untouched piece of nature has been designed by someone. The quality of that design effort therefore profoundly affects our quality of life.” (Cross, 2011, p. 4)

1.1 Educating in and for the designed world

We live in three worlds: the natural world, the social world, and the designed world. The natural world includes things that would exist without human invention or intervention, such as plants and animals, earth, water, air, and fire. The social world consists of cultures, customs, political and legal systems, religions, economies, and various other systems that we have invented to govern our interactions and relationships with each other. The designed world contains all the modifications that we have made to the natural world to satisfy our needs and wants. The designed world is the product of a design process that provides ways of transforming resources – materials, tools and machines, people, information, energy, capital, and time – into products and systems (STL [Standards for Technological Literacy], 2007).

In the contemporary world, where design is all-pervasive, its social, cultural, and environmental effects are daily apparent, either directly around us or through various media (Hodson, 2009). Designed artifacts and solutions affect our lives and values, both from a personal and societal perspective. Designers, policy-makers, investors, and consumers hold different positions in the design process, but they all make choices that influence our future society. To meet global challenges and promote sustainability, professional designers are dependent on critical and conscious consumers and a design-literate general public. Therefore, design education is important for all. Understanding designing and its effects on the individual as well as societal levels is a vital requirement for developing the general public competence in informed decision-making (Nielsen, 2013; STL, 2007; Tovey, 2013).

Design is a feature of educational policy and practice worldwide. According to Davis, Hawley, McMullan, and Spilka (1997; see also de Vries, 2009), in some cases, it is an explicit component of the national curriculum, but more often design is implicit in the emphasis placed on problem solving and the use of references from the designed world. International trends in science, technology, and environmental education, among others, reveal growing recognition of the need to change education in ways that integrate design as a natural component of learning. While designing, students learn to identify needs, frame problems, work collaboratively, explore and appreciate the contexts within which a solution must work, weigh alternatives, and communicate their ideas verbally, graphically, and in three dimensions. Design is also about making and doing as a way of knowing, putting ideas to work and allowing students themselves to test the value of their learning. In general education, design is unique, because designed objects are all around the real and virtual worlds that students inhabit (Alexander, 1997; STL, 2007).

However, there is considerable variation between countries in how design is included in the curriculum and used in the classroom. Design can be a subject of investigation, a means of investigation, or both. It can be a separate school subject, a cross-curricular subject, or integrated with other school subjects, such as science, technology, art, home economics or social studies. It is either compulsory or optional. The name, content, context, and methodology of design education are dependent on a given country's historical, philosophical, cultural, political, and other frames of reference. For example, in Finland design is an essential aspect of craft education (FNBE, 2004), in the UK it belongs to the school subject Design & Technology (Benson, 2009), and in parts of the United States design is used as a vehicle for learning science (e.g. Kolodner, 2002, Kolodner et al., 2003). Further, the motive for design education depends on the stakeholder that promotes it (e.g. de Vries, 2009). Educators tend to put most emphasis on the cultural and social importance of learning, while governments and industries often have primary interest in assuring a sufficient future workforce. Parents and school boards tend to focus on the general educative merits, such as promoting creativity, and students may experience design as a welcome change amidst more abstract subjects.

Accordingly, more research is needed on the nature of design learning as well as its pedagogical applications. Insufficient research data may contribute to a lack of reflection on and attendance to design activities by both those in the classroom and those discussing the justification of design education (cf. Illum & Johansson, 2012; Johansson, 2008). As a newcomer to education, design education lacks the identity and long tradition of a well-established subject, and still needs a framework and a basic concept as a subject in education (Dahlin, Voll, & Svorkmo, 2013).

1.2 Design learning as knowledge-creation

Designing, from its very premise, involves the creation of novel ideas and artifacts. In educational contexts, this kind of *knowledge-creation* (Hakkarainen, Palonen, Paavola, & Lehtinen, 2004; Paavola, Lipponen, & Hakkarainen, 2004) focuses on activities organized around the systematic and deliberate pursuit of advancing shared "objects" (Paavola et al., 2004). Rather than mainly discussing and sharing their opinions of the issues and themes under study, students engage in crystallizing, externalizing, sharing, and developing knowledge artifacts, such as sketches or prototypes, which embody their ideas (Scardamalia & Bereiter, 2006). The view of design learning as knowledge-creation has its theoretical foundations in the pedagogical approaches of knowledge building (e.g. Bereiter & Scardamalia, 2003; Bereiter, 2002; Scardamalia & Bereiter, 1993; 2003; 2006; 2010a), progressive inquiry (Hakkarainen, Lonka, & Lipponen, 1999; 2004; Hakkarainen, 2009a; 2010), and Learning by Collaborative Design (Seitamaa-Hakkarainen, Raunio, Muukkonen & Hakkarainen, 2001; Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010). In the following, these three approaches will be briefly reviewed. Most central to the present study is the Learning by Collaborative Design approach, which partly rests on research on professional designing. Therefore, the two main traditions of design research will be briefly introduced, focusing on those elements and features that inform design education.

Knowledge building is a pedagogical approach concentrating on transforming school classes into inquiry communities focused on improving shared ideas (i.e. conceptual artifacts) with the assistance of collaborative technologies (Scardamalia & Bereiter, 2006). Technology-mediated collaborative learning has been studied since the 1980s, and the pioneering investigations of Carl Bereiter and Marlene Scardamalia (e.g. 1993; 2003; Bereiter, 2002; Scardamalia & Bereiter, 2003; 2006; 2010) have produced several generations of technology-mediated collaborative learning environments, such as the Knowledge Forum (http://www.knowledgeforum.com). The investigations of Bereiter and Scardamalia and their collaborators have indicated that even elementary school students are able to collaboratively advance their ideas. In order to conceptualize the emerging educational phenomena, Bereiter (2002) developed a new theoretical framework for examining schools as knowledge-building communities in which both teachers and students work to build new knowledge and understanding. Knowledge building is aimed at engaging elementary school students in creative work with knowledge through engagement in progressive discourse focused on collectively improving the knowledge artifacts generated. It is further crucial to knowledge building that students learn to re-use the emerging knowledge to solve new problems (Bereiter, 2002). Knowledge building is analogous to innovative processes of inquiry where new conceptual artifacts, such as ideas, questions, and theories, are collectively created and developed so as to enrich and advance the knowledge of the community. Moreover, students' epistemic agency is fostered when they assume cognitive responsibility for the advancement of collective knowledge, rather than merely taking care of their own learning (Scardamalia, 2002; Scardamalia & Bereiter, 2003).

The pedagogy of knowledge building as well as the interrogative theory of inquiry (Hintikka, 1999) lay behind the *progressive-inquiry* approach developed by Hakkarainen and his colleagues (1999; 2004). In progressive inquiry, as with knowledge building, the focal assumption is that inquiry is a process mediated by shared knowledge artifacts (Bereiter & Scardamalia, 1993). Another essential characteristic of progressive inquiry is distributed expertise (Brown, Ash, Rutherford, Nakagava, Gordon, & Campione, 1993; Brown & Campione, 1996), i.e. sharing all the phases of learning among the participants of a learning community. Through sharing expertise, it is possible to gain insights that one would not reach alone (John-Steiner, 2000). From the interrogative point of view, inquiry can be characterized as a question-

driven (problem-driven) process of understanding (Hakkarainen & Sintonen, 2002; Hakkarainen, Lipponen & Järvelä, 2001). It is central to progressive inquiry that students collaboratively set up and advance their own research problems and questions. Particularly important questions arise from problems in understanding and explanation, and thus, explanation-seeking (how and why) questions hold special cognitive value. A critical aim of progressive inquiry is to practice using theories or models to advance, elaborate, and test ideas with which an agent is working (Bereiter, 2002). This may be facilitated by guiding the participants to externalize (draw, diagram, or write) and elaborate their intuitive conceptions, taking these as the objects of collaborative discussion (Bereiter, 2002).

The *Learning by Collaborative Design* approach (LCD) (Seitamaa-Hakkarainen et al., 2001; 2010; Lahti & Seitamaa-Hakkarainen, 2014) is based on progressive-inquiry, and was developed for facilitating design learning processes and students' design thinking. As the LCD approach is informed by inquiry-based learning programs, it shares their common features, such as focus on authentic tasks and expert-like practices, and reliance on computer-supported collaborative learning. The visual LCD model depicts designing as a spiral and cyclical process that is approached iteratively through successive sequences (Figure 1). The model consists of the following phases: (1) creating the design context, (2) defining the design task and related design constraints, (3) creating conceptual and visual (physical) design ideas, (4) evaluating design ideas and constraints, (5) connecting to expert communities and collecting data, (6) experimenting and testing design ideas by sketching, modeling and prototyping, (7) evaluating functions of prototypes and (8) elaborating design ideas and redesigning. However, the phases of the LCD model are not a prescription of rigidly specified design stages; rather, they describe the intertwined facets of the complex and iterative design process.

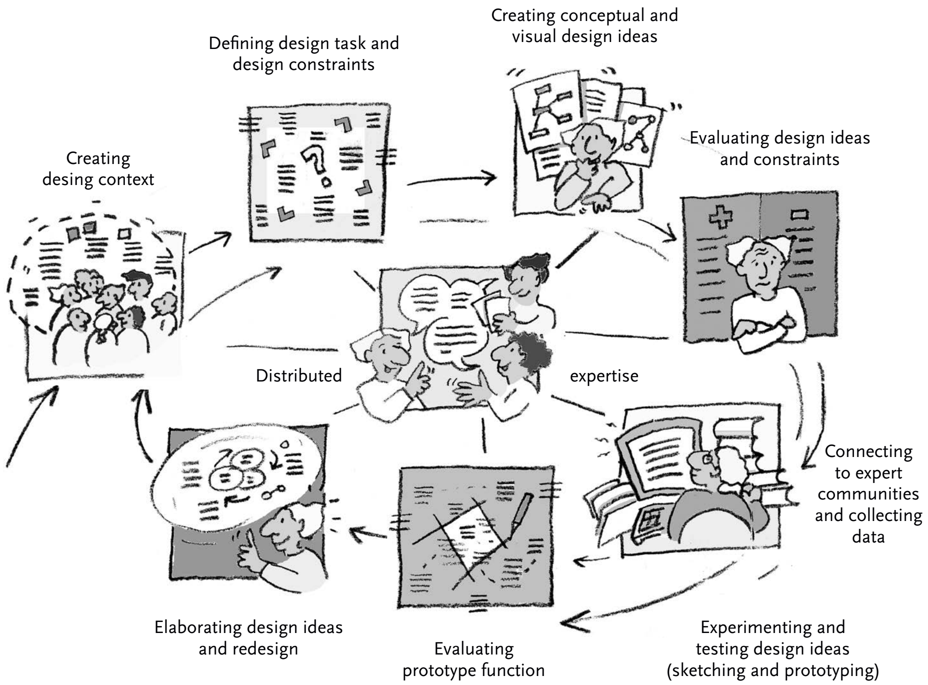

Figure 1. The model of Learning by Collaborative Design (adapted from Seitamaa-Hakkarainen et al., 2010).

Like progressive inquiry, the LCD approach emphasizes distributed expertise and collaboration in all the phases of the process. The participants (students, teachers, and domain experts) share their expertise in creating a meaningful and authentic design context and task for analyzing design constraints and collecting knowledge, as well as providing feedback, in order to develop a shared design object. Furthermore, the model highlights the role of material objects and abstract models as essential parts of the process; the interaction through and around these design elements is primary. Knowledge is dealt through the *design mode* where the focal concern is the usefulness, adequacy, improvability, and developmental potential of all ideas (Bereiter & Scardamalia, 2003). The antonym for the design mode is the *belief mode*, where ideas are considered to be complete. Here, the proper response to ideas is agreement or disagreement, presenting arguments and evidence for or against, and expressing and trying to resolve doubts, whereas the essence of the design mode is a continual, self-aware, improvement in ideas.

Knowledge building, progressive inquiry, and the LCD approach all emphasize the use of expert tools and practices already in elementary education. Knowledge in schools is often imparted through abstract laws, principles and routines separated from their practical contexts, whereas expert knowledge is adapted to its purpose, and facilitates flexible problem-solving (Hakkarainen et al., 2004). In the present study, the focal field of expertise is design; hence, a short overview of the two main traditions of design research will be provided.

On one hand, designing is about giving form to physical things, and design work is centrally concerned with materiality. This is the tradition of craft and professional designing, and remains a dominant view of what designers do: they make things. This research tradition focuses on individual, expert designers working in traditional design disciplines, and considers design ability a form of intelligence (Kimbell, 2011). The purpose of designing is problem solving, and design problems are regarded as ill-structured. The key contributors include Nigel Cross (1982; 1984; 2006; 2011), who coined the phrase “designerly” ways of knowing; Donald Schön (1983), who introduced the concepts of framing and reflection-in-action; Peter Rowe (1987), whose book *Design Thinking* was one of the earliest discussions of the concept; and Bryan Lawson (1997/2006), who studied the practice of designing in a context of multiple design constraints. This research tradition provides characterizations of what individual designers do, how they approach and make sense of their own work, and how they actually execute this work (Kimbell, 2011). Furthermore, it underlines materiality, which is a central concern of design work and a unique feature of design education. Recent research has also shown increasing interest into embodied dimensions of design work, i.e. how the body is actively involved in designers’ thinking and communication processes (Poulsen & Thøgersen, 2011).

The other tradition of design research extends the ideas of Herbert Simon (1969; 1973), who provided a view of design work as abstract, as creating a desired state of affairs. In this context, design does not give form to objects, but concerns action and the artificial (Kimbell, 2011). Following Simon, Richard Buchanan (1992) shifted design theory away from individual designers’ work, towards a more generalized view of design thinking, applicable to nearly anything. Buchanan argues that design thinking is uniquely applicable to the needs of technological culture, where human problems are wicked (Rittel & Webber, 1973). This line of thinking is fairly evident in recent discussions of design and technology education, where the subject is seen as a powerful vehicle for learning various scientific, cultural, and social issues, and where the aim is to generate basic understanding of how design and technology affect the world we live in (de Vries, 2009; Dugger, 2010; Hodson, 2009; Rasinen & Rissanen, 2010; Williams, 2013).

To summarize, the present investigation was originally inspired and shaped by knowledge-building research, and aimed to extend corresponding ideas and methods towards issues relevant to design education. The knowledge building approach focuses on engaging students in productive work with ideas; it is associated with educational efforts to support learning with understanding and promote conceptual change in the context of science education. Likewise, the progressive inquiry approach is linked with science education. The progressive inquiry and LCD models are analogous in nature; both design and inquiry are iterative processes in which new ideas are cyclically developed. Design is, however, foremost focused on creating and developing ideas that are often given a material form. In the design process, prototyping and other forms of materialization play an important role. Furthermore, "designerly" ways of knowing, such as tackling ill-defined problems and employing a solution-focused mode of problem solving, are distinctive and set design apart from other forms of knowing (Cross, 2006; 2011; Goel & Pirolli, 1992).

1.3 Aims and objectives of the study

The progressive inquiry approach is well-established in Finnish science educational research (e.g. Hakkarainen, 1998; Lipponen, 2001; Veermaas, 2004) and, to a certain extent, in general educational practices as well (e.g. Hakkarainen, Bollström-Huttunen, Pyysalo, & Lonka, 2004). However, the LCD approach is still a newcomer in education and educational research, and has been previously applied only in the higher education context (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2003; Lahti & Seitamaa-Hakkarainen, 2014). In order to adapt and study the LCD approach among younger, elementary-level students, a longitudinal study project was designed for the present research.

The *Artifact Project* took place in grades 4 and 5 of an ordinary Finnish elementary school and covered nearly 140 lessons over the course of three terms. The aim was to study the role and diversity of artifacts in Finnish culture, through history-, science- and design- related inquiries. In order to support the students' expert-like practices, a special emphasis was put on fostering connections between the students and various expert communities. In addition to visiting expert sites outside the school (e.g. museums, workshops), a particular innovation of the Artifact Project was to have a professional designer present in the classroom, providing continuous face-to-face guidance and support for the students' design work. The present investigation focused on how and to what extent the expert's authentic design processes, mechanisms, and practices were relevant to the elementary school design learning context.

The Artifact Project saw the first application of the LCD approach to the elementary level of education. The study sought to examine the facilitation provided by the designer, while exploring the nature of the students' knowledge-creation, exemplified by collaborative designing. Furthermore, as the social, material, and embodied dimensions of designing are central to professional design work, the goal of the present investigation was to examine their role in design learning context. The three objectives – (1) students' processes, (2) facilitation, and (3) social, material, and embodied dimensions – were approached through a series of four interconnected sub-studies. These were published in refereed international journals, and they form the second part of the present dissertation. The first part includes the introduction, theoretical framework, research questions, research design, results, and the general discussion of the study, and aims to meet the overall goal of the present dissertation: How can design learning based on the LCD approach be promoted at the elementary level of education?

2 Design in general education

Design learning in general education (i.e. elementary and secondary school) concerns the ways in which human beings modify their environments to better satisfy their needs and wants (e.g. Davis et al., 1997; de Vries, 2009; STL, 2007). The making and use of tools to adapt to the natural environment is a fundamental human aptitude; in other words, we all naturally engage in design (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). However, as with any other form of intelligence, design competence is not a given "talent" or "gift", but can be learned and developed (Cross, 2011). Learning through design (Harel, 1991) is based on a constructionist theory that regards learners as builders of their own knowledge (Kafai, 1996) and sees learning not only as the development of knowledge, but also as the cultivation of ways of thinking and acting. Learning is considered a constant process of active participation in shared activities, through which domain knowledge, practices, terminology, and understanding of the values and tools of the underlying culture are developed (Hennessy & Murphy, 1999). The distinguishing elements of design learning are "designerly" ways of thinking (i.e. "means-ends" reasoning as opposed to "cause-effect" reasoning), the manipulation of tools and materials, and the normative dimension of technological knowledge, which is absent in scientific knowledge (de Vries, 2009). The interaction between thinking and doing is pivotal; as we do things, we also experience, learn, conceptualize and use our knowledge to produce meaning, sensible actions, and products for living (Vrencoska, 2013).

In the following, the practice and research of design learning in Western countries will be introduced. The relationship between design, craft and sloyd will be examined, as well as the use of design as a vehicle for learning science. Finally, aspects of professional designing in educational contexts will be discussed.

2.1 Design as a school subject

Design is a late arrival in education; in most Western countries design education has been developed only in the past two or three decades. The aims, contents, and practices of design education have varied and still vary significantly from one country to another, and even within a single country. In some cases design education is a separate school subject, either compulsory or optional. In others, it has been included in education as a cross-curricular subject, or integrated with other subjects, such as science, mathematics, arts, home economics, or social studies (Davis et al, 1997; de Vries, 2009; Rasinen, 2003). Throughout its history, varying emphases have emerged within design education, ranging from building the character of a child in the 19th century (Olafsson & Thorsteinsson, 2009) to developing an understanding of the designed world (e.g. STL, 2007). Furthermore, design education has been, and still is, included in the curricula under myriad titles, such as: craft, sloyd, arts and crafts, design and craft, design and technology, technology and design, technology, or technology education. Each of these represents the distinct historical, cultural, and political underpinnings of the subject. At present, the trend is generally towards design and technology education in the international context (Rasinen & Rissanen, 2010).

In a broad sense, design can be understood as the modification of the natural world to meet human wants and needs. In many cases, these modifications are realized through or result in various technologies. Therefore, the general aim of design education can be seen as generating a basic understanding of how design and technology affect the world, and how we exist around design and technology (de Vries, 2009; Dugger, 2010; Rasinen & Rissanen, 2010; STL, 2007).

Few reviews of research on design education have been conducted, indicating that most research in the field has been about curriculum, and relatively little research has focused on students and teachers, or the effectiveness of design education (de Vries, 2003; Petrina, 1998; Sherman, Sanders, & Hyuksoo, 2010; Zuga, 1997). More recently, Williams (2013) conducted a review on research published in three journals (published in the US, the UK, and the Netherlands) and presented in four conferences (UK, New Zealand, and Australia) since 2006. In this review of 472 manuscripts (either published or presented), the scope of research on design and technology education was found to be broader than in the past. The most common theme in research was design, including, for example, studies of conceptual foundations and other theoretical perspectives; analysis of elements of students' designs or their design decisions; or examples of design practices in school and in industry. In addition to design, the "hot topics" in research were curriculum, technological literacy, thinking, students' attitudes, teacher training, and teaching.

In Williams's (2013) review, five areas of research were considered particularly important to the practice of design education (see also Davis et al., 1997). First, a significant amount of research indicates that the design process is both diverse and complex and, therefore, learning and teaching design does not proceed well with pre-described methods or procedures. However, in many cases design is still taught in a simple lock-step manner, ignoring the diversity of students' experiences and reducing the complexity of design to a form of decoration. Second, progress in design develops through the constant interaction of thinking and doing; hence, one of the aims of design education is to facilitate this interaction, to move students between thinking and doing activities (see Kimbell, 1994). Third, creative processes are difficult to carry out within specific pre-determined time frames; students need longer periods of time with proper stimuli to facilitate creative thinking.

The fourth issue in research on design education indicates that most effective learning occurs when students are taught in the time of need (Williams, 2013). According to Williams (2013), there has been debate about whether students first need to learn practical skills and develop understanding of materials in order to be able to develop functional designs, or whether they should be engaged in design activities while concurrently developing practical skills and understandings. The research on design education indicates that the latter approach is more effective. This view is also supported in sociocultural theories of learning (e.g. Brown, Collins, Duguid, 1989; Collins, 2006; Collins, Brown, & Newman, 1989; Lave & Wenger, 1991) which suggest that effective learning takes place through participation in the practices of a culture. The fifth issue highlighted in the research on design education is that the essence of the subject,

the curriculum, and the nature of examination should be in alignment to ensure students' and teachers' mutual understanding of what to study (Williams, 2013).

2.2. **Design, craft, and sloyd**

In many countries design education emerged from an already existing subject, which in most cases was craft (de Vries, 2009). Finland was the first country where craft was accepted as a compulsory school subject in 1866, and the educational value of the subject has been recognized since the beginning (Marjanen, 2012). Craft education (*käsityö* in Finnish), comprising textiles and technical work, still is a compulsory subject for all students in grades 1–7. In addition, students in grades 8–9 can study crafts as an optional subject. The national curriculum for craft education highlights the values and aims that relate to creativity and problem solving, technical and aesthetic skills, independent working skills, and promotion of self-expression. Further, the holistic and iterative nature of the craft process is emphasized; particular attention is given to ideation, testing, and making, as well as the reflective and evaluative aspects of craft (FNBE, 2004; Pöllänen, 2009; 2011).

In a holistic craft process, often referred simply as holistic craft (Kojonkoski-Rännäli, 1998), all phases of the process – ideation, designing, making, and evaluating – are carried out by the same person or group. However, many educators have expressed critical concerns that craft education in Finland puts more emphasis on making than designing (Karppinen, 2008; Pöllänen, 2011). A study on students' and teachers' perceptions of how the holistic craft process is put into practice in secondary school (Hilmola, 2011) reveals that only a little over one third of students feel that they have learned the skills for mastering the holistic craft process often or very often. It is challenging for teachers to understand the concept of holistic craft, and to provide students with the context and activities that support the holistic craft process.

In an effort to realize the concept, Pöllänen and Kröger (2000; 2004; Pöllänen, 2009) have contextualized craft education with the help of four pedagogical models. *Craft as product making* follows the lines of an ordinary, reproductive craft process, where the maker does not influence the design phase, but instead uses a ready-made model and/or instructions. The emphasis is on improving the psycho-motor skills related to basic techniques, materials and tools of the craft process. *Craft as skill and knowledge building* can be positioned in the middle of ordinary and holistic craft, extending ordinary craft from model-based production to the construction of skills and knowledge. When *craft* is regarded *as design and problem-solving* the aim is to provide students with an authentic and meaningful learning context and experience. The main objective is to tackle complex, multidisciplinary, and real-world design challenges with constant iterative cycles of action and reflection. *Craft as self-expression* means expressing one's skills, knowledge, thoughts, experiences, perceptions, and sensations to others by producing crafted items (Karppinen, 2008). The focus is on the personal and active processing of a mental image or association, supporting the self-expressive process. These four pedagogical models depict the way learning occurs in craft education as well as illustrate the shift of focus from the end-product and fluency of skills towards the preparation for future challenges (Pöllänen, 2009).

From an international point of view, craft as a separate and compulsory school subject is a unique phenomenon. Equivalent subjects with similar objectives are, for example, Design and Technology in the UK and Sloyd in Sweden. Sloyd (*slöjd* in Swedish) was introduced as a compulsory school subject in the 1880s, "as a pedagogical system of manual training adopted to develop the child in general, through learning technical skills in woodworking or in sewing and knitting by making useful objects by hand" (Borg, 2006, pp. 35–36). Today, sloyd can be considered as a special form of craft activity, where the objectives lie beyond the mastery of craft competences. Some of the main goals are enhancing the students' self-confidence and promoting their creative abilities, developing students' responsibility for their own learning, and creating awareness of environmental issues and economic aspects of production and consumption (Skolverket, 2000, see also Borg, 2006; Ekström, 2012).

The emphasis on research of sloyd as a school subject has shifted from studies *about* sloyd towards analyses of actual sloyd activities (Ekström, 2012). In a large research project focusing on communication and learning in sloyd (Komolär, 2008), the subject

was regarded as a practice in a sociocultural sense (Borg, 2009). Such social practices involve goal-directed sequences of actions and rely on a socio-historically developed system of knowledge (Scribner & Cole, 1981; see also Hakkarainen, 2009b). The practice was studied, for example, by examining in detail what happens in the sloyd classroom, with a special emphasis on material and embodied aspects of sloyd activities (e.g. Ekström, 2012; Illum, 2006; Illum & Johansson, 2009; 2012; Johansson, 2002, 2006; 2008; 2011). The studies show how learning in sloyd classrooms takes place through several levels of interaction: verbal and non-verbal communication with others; interaction with tools and machines; thinking and communicating through sketches, pictures, drawings, and instructions; and through materials, sloyd products, aesthetic and emotional experiences (Johansson, 2002; Illum & Johansson, 2012).

While Finland and Sweden have acknowledged the educational value of craft and sloyd education for all students since the 19th century, most countries have separated students at a relatively young age into vocational-technical tracks of education. Since the 1990s, many countries have, however, started to recognize the need to provide all students with competencies in design and technology (Davis et al., 1997; Jones, 2009). For example, recent developments of school curricula in Australia, USA, Canada, Europe, South Africa, and New Zealand emphasize the importance of learning design and technology as an area of study in its own right (Jones, 2009).

2.3 Design as a vehicle for learning science

During the past two decades, there has been an increasing interest in using design activities as means to promote science learning (e.g. Harel, 1991; Kafai, 1996; Roth, 1998; Kolodner, 2002; Fortus et al., 2004; Jurow, 2005; Hansen, 2009; Dugger, 2010; Kim, Kwek, Meltzer, & Wong, 2013). Integrating design and science is seen as a valuable process, allowing students to construct a deep understanding of scientific principles. Within the learning through design approaches, science, which deals with and seeks understanding of the natural world, is seen as the foundation of design and technology. For example, in the United States the integration of science, technology, engineering, and mathematics, known as STEM, considers technology and engineering as vehicles for contextualizing science and mathematics curricula (Dugger, 2010; Hodson, 2009). Similar integration efforts have been implemented also, for example, in parts of Europe (Benson, 2009; de Vries, 2009; Ginestié, 2010; Hansen, 2009) and New Zealand (Jones & Compton, 2009). Since design and technology are all-pervasive in the Western contemporary world, it is often easier to understand their social and environmental impacts than it is to see the effects of science (Hodson, 2009).

There are several inquiry-based programs that purposefully use design as a vehicle for constructing new science knowledge; in other programs (e.g. Penner, Lehrer, & Schauble, 1998), design and science are studied sequentially (Fortus et al., 2004). An inquiry approach to the scientific process emphasizes, for example, asking questions, planning investigations, using resources to find information, analyzing data, communicating results, and recognizing and analyzing alternative explanations and predictions. Learning through design encourages students to engage in many of these practices. Learning by Design™ (LBD) (Hmelo, Holton & Kolodner, 2000; Kolodner, 2002; Kolodner et al., 2003; Kolodner, Gray & Fasse, 2003; Puntambekar & Kolodner, 2005) and Design-Based Science (DBS) (Fortus et al., 2004) are programs in which a design challenge provides students a reason for learning science content; engaging in the challenge provides an authentic and meaningful context for using both science and design skills. LBD builds on the literatures of cognitive science and the learning sciences, taking suggestions about classroom practice from case-based reasoning (Kolodner, 1993; Schank, 1982; 1999) and problem-based learning (Barrows, 1985; Koshmann, Myers, Feltovich, & Barrows, 1994), which is an implementation of the cognitive apprenticeship approach (Collins, 2006; Collins et al., 1989). In both LBD and DBS classrooms, the work is built on multiple iterative cycles of constructing, evaluating, and revising models, along with discussion of issues that arise while solving the design challenge. The main distinction between the programs is that in LBD all iterations focus on the same science concepts, but at increasing levels of complexity, whereas in DBS each iteration focuses on a different science concept. However, each cycle also returns to the concepts presented in former cycles, in order to facilitate the development of a deep understanding

of each of the studied concepts. LBD and DBS have much in common with other inquiry-based programs, which all share certain features: they (a) focus on authentic tasks for lengthy periods of time, (b) lead to the creation of artifacts, (c) encourage the use of alternative assessment methods, (d) make use of computer-based technology, (e) build upon collaboration, and (f) view the teacher as a facilitator and a learner along with the students. Research by Kolodner and her colleagues (e.g. Kolodner, Gray & Fasse, 2003) has shown that LBD students have learned science content as well as or better than students learning with more traditional methods. They are able to use the skills of expert scientists and designers in the collaboration, communication, informed decision making, and designing of investigations.

The LBD project team has designed several learning units, each framed by a design challenge requiring the learning and application of science set by the science standards for middle school students; DBS is also based on learning units which define the design challenge as well as the context for designing (Kolodner et al., 2003; Fortus et al., 2004). Thus, learning activities are organized around predetermined scientific concepts, and learning is assessed in terms of the level of adoption of these concepts. Although design is used as a powerful vehicle for understanding underlying scientific principles, these programs do not fully exploit the open-endedness of design processes. Real-world design problems are complex and multifaceted; it is impossible to know the content and phases of the problem-solving process in advance. Neither is it possible to determine beforehand the context for the problem, because in designing it is essential to frame the problem within larger contexts in order to find new ways to deal with the problem and to create unique solutions. Furthermore, even though the programs presented above acknowledge the situated and mediated nature of learning, the question remains as to whether these programs fully make use of the material and embodied dimensions of designing. There are compelling reasons related to the nature of both science and design education that justify the integration of these two learning areas. However, design education could be overwhelmed by science, if it is seen as a mere application of the natural sciences (de Vries, 2009). After all, the goal of LBD and DBS is to engage students in design in order to learn science, not to instruct the students about design.

Although the present study and the underlying LCD approach are in many ways informed by programs using design as a vehicle for learning science, the focal aim is divergent. The main objective is to promote *design learning*, and the investigative activities common to science classrooms can be used as a part of this process. These are rarely used in design education, even though professional designers commonly use them while approaching various components of the design problem at hand. However, designing also includes many stages that cannot be reached through logical reasoning or other methods used in the natural sciences, and seeing design as a mere practical application or extension of science education risks neglecting its unique features. These will be elaborated in the next chapter (2.4).

2.4 **Professional designing in the educational context**

The LCD approach, along with knowledge building and progressive inquiry, emphasizes the use of authentic, professional practices and tools starting at the elementary level of education. The words *authentic* and *authenticity* can have many different meanings in educational contexts (see Shaffer & Resnick, 1999). In the present study, the terms are used to refer to learning activities that are (a) coherent and personally meaningful, and (b) purposeful within a social framework – the ordinary practices of the culture (cf. Hennessy & Murphy, 1999). Research into the learning sciences indicates that when learning is situated in real-world settings, and focused on authentic and meaningful problems, then students develop a deeper understanding of the subject under study (e.g. Bruckman, 2006). In other words, learning is deeper when students engage in activities simulating the practices that professionals employ in their everyday working life (Sawyer, 2006a). Engaging learners in these kinds of authentic practices provides them with a meaningful context that may increase their motivation to learn, and improve their learning by focusing their attention in ways that may enhance their ability to apply new knowledge (Edelson & Reiser, 2006; Kolodner et al., 2003). Furthermore, engaging in authentic practices can help students improve their conceptual understanding by cultivating procedural skills. Of course, as noted by Sawyer (2006a), young students are not

able to act exactly the same as professional designers with extensive training and experience. Therefore, engaging students in authentic practices refers to "developmentally appropriate versions of the situated and meaningful practices of experts" (Sawyer, 2006a, p. 5). The present study has aimed to identify which professional design practices are applicable for elementary students to engage in and learn as well as how to promote age-appropriate design learning without losing the authenticity of professional designing.

In order to bring authentic design practices to classrooms, an understanding – at least on a general level – of the nature of that practice is essential. In the following, two features of the domain that are considered to hold particular importance in the context of design education will be examined: the characteristics of design problems and the nature of design knowledge. Furthermore, the processes of how designers generate and use knowledge will be explored.

Design problems have a special nature and a particular structure, they are inherently different than, for example, problems in the natural sciences (Cross, 2011; Dorst, 2011; Rittel & Webber, 1973; Simon, 1973). Design problems are ill-defined and ill-structured (Goel & Pirolli, 1992; Simon, 1973), that is, they are complex, open-ended, and dynamic; the process of solving the problem is parallel with the understanding of its nature (Dorst & Cross, 2001; Lawson, 2006; Puntambekar & Kolodner, 2005). The types of problems that designers deal with have also been described as *wicked problems* (Buchanan, 1992; Rittel & Webber, 1973), because they are difficult and confusing, and there are no definite criteria or conditions to them. The problem cannot be defined until a solution has been found, and solutions are not true or false, only more or less satisfactory. Furthermore, there is always more than one possible explanation for the problem, and the selection of an explanation determines the nature of the problem and its solution. Every design problem is also an indication of another problem, and the designer dealing with the problem can always try to do better (Buchanan, 1992; Goel & Pirolli, 1992; Lawson, 2006; Rittel & Webber, 1973; Simon, 1969). Creative designing simultaneously develops and refines both the design problem at hand, as well as ideas for its solution, with constant iteration of analysis, synthesis, and evaluation processes (Dorst, 2006; Dorst & Cross, 2001). This kind of work cannot be described as a linear process with a set of stages, nor can it be conceptualized in terms of individual "intelligence"; rather it is an iterative and collaborative learning and working activity, in which design artifacts mediate and organize communication (Perry & Sanderson, 1998) and knowledge-creation efforts (Paavola et al., 2004).

Design is by its very nature a knowledge intensive activity. Because of the special characteristics of design problems, designers must rely on multifaceted types of knowledge. According to Vincenti (1990), knowledge relevant to design consists of both knowledge of *how to do design* and knowledge regarding *how to generate the new knowledge and insights* that successful design requires. Yet, designers produce knowledge in order to complete their design work; thus, it is not an end in itself nor the central objective of the profession. In other words, designers embody knowledge in the form of a dynamic tool to perform a specific task (Perkins, 1986); primarily to design artifacts, systems, or experiences, and secondarily to generate more knowledge. Designing requires both procedural knowledge and descriptive (i.e. declarative) knowledge (Glaser, 1990; see also Vincenti 1990). *Procedural knowledge* (knowing how) is prescriptive, it prescribes how things should be to accomplish a desired end; it is the knowledge of procedure or practice. *Descriptive knowledge* (knowing that) characterizes and describes the state of affairs, i.e. how things are. Part of this knowledge comes from science or other domains, but much of it arises from designing itself, for example, through experimenting and testing.

According to Bereiter and Scardamalia (1993), the distinction between procedural and descriptive knowledge, however, misses the most distinctive features of the nature of expertise in complex domains, such as design. Resting on Polanyi's (1969) concept of *tacit knowledge* (i.e. knowledge that is difficult to explicate or articulate comprehensively), they further conceptualized three kinds of invisible knowledge employed by design experts. *Informal knowledge* is mediated by tools, materials, and objects of the physical world, it is akin to the educated and specialized common sense of experts, that can only be acquired through practice and experience (Bereiter & Scardamalia, 1993; see also Thomas & Brown, 2011). *Impressionistic knowledge* includes decisions, feelings, and the recognition of potential (i.e. identifying promising ideas), whereas *self-regulatory knowledge* refers to knowledge of how to control and manage one's own mental processes. Bereiter and Scardamalia (2003) also later distinguished two principal

modes of dealing with knowledge, *the belief mode* oriented to assess the truth value of knowledge claims, and *the design mode* focused on improving and advancing any ideas generated (see also p. 6 of the present dissertation). As the name suggests, designers mostly use the design mode in order to iteratively improve their design ideas.

Baird (2004), from his studies of scientific instruments, has introduced the concept of *working knowledge*, which is a form of material knowledge, and which sees knowledge as embedded in effective action. Subjectively, working knowledge consists of the skills necessary to work with materials, and objectively, it is the organization of materials, i.e. the tools, materials, and techniques that constitute objects and make their construction possible. Working knowledge is a broader concept than procedural knowledge (knowing how), because it includes also the knowledge that objects themselves embody or encapsulate. According to Baird (2004), such instrumental *thing knowledge* has in many cases been more important than the theories that are used to explain the instruments in question (see also Hakkarainen, 2009b). Design artifacts, such as sketches and models, display the working knowledge of the design process, they embody the ideas of the participants of that process, and further, enable the generation of novel working knowledge. However, as noted by (Vincenti, 1990), the distinctions between various types of knowledge used and created by designers are not definite, and the design practice includes much knowledge that does not fit neatly into just one category. The purpose of defining various types of knowledge is to provide a framework for understanding the complex and specific nature of design knowledge.

How, then, do designers deal with the special nature of design problems, i.e. how do they generate and use knowledge to define a problem and its possible solutions? Designing can be characterized as a dual-space search within two problem spaces (Goel & Pirolli, 1992). Seitamaa-Hakkarainen (2000; Seitamaa-Hakkarainen & Hakkarainen, 2001) has applied the concept of two problem spaces into weaving design, and introduced the idea of a composition space representing visual design and construction space representing technical design. The composition space contains the organization of visual elements and principles, such as shape, pattern and color, which are selected and manipulated during the design process. The construction space is seen as the organization and manipulation of technical elements and principles, such as structure, material, and production methods. Within the composition space, the designer considers how the outcome of the design process will appear, whereas in the construction space she ponders how the object being designed functions and how it will be manufactured. Design moves within and between these spaces both horizontally, i.e. generating several, parallel ideas, and vertically, i.e. developing these ideas further and adding detail (Seitamaa-Hakkarainen & Hakkarainen, 2004; see also Goel, 1995). In the context of design education, the understanding of the two problem spaces, as well as deliberate horizontal and vertical movement within and between them, enhances the quality and versatility of the ideas produced by the students.

In principle, the design problem space could be regarded as infinite, because the number of possible solutions to design problems is unlimited. However, design constraints determine and limit the design problem space (Lawson, 2006; Seitamaa-Hakkarainen, 2000). Such constraints have a central role in the design process; through them a designer is able to construct a rationale for design decisions (Goel & Pirolli, 1992; Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001). For novices learning design, such as elementary students, the infinity of the design problem space can be overwhelming. Supporting students in defining and concretizing the constraints helps them to deal with the ambiguity of the design process, and to focus their attention on relevant aspects of the problem space.

Lawson (2006; see also Seitamaa-Hakkarainen, 2000) divides the design constraints into two main types, those that are *internal* to the system or object being designed, or those that are linked with some *external* factor not under the designer's control. Internal constraints form the basis of the problem solving process, are flexible, and have only an abstract connection to the designed object. External constraints are generated through the needs of participants in the design process; the requirements of the physical environment of the product being designed; or in terms of available resources, among other factors. They are more rigid than internal constraints, and can sometimes determine the whole form of the process. On the other hand, external constraints can be inspirational and compose the very essence of the special, possibly unique, context for designing.

Designing is not about predicting and explaining phenomena in the world, but creating something new, and this calls for various kinds of creative problem solving activities (Goel & Pirolli, 1992). According to Cross (2006; 2011) there are three strategic aspects of design work: (1) taking a *systems approach*, (2) *framing* the problem, and (3) designing from *first principles*. Taking a broad *systems approach* refers to designers' ability to see relationships, rather than settling for a narrow problem definition (Cross, 2006; 2011). Designers spend time determining what the basic, fundamental issue is that needs to be addressed, and consider a wide range of potential solutions through an iterative and expansive process. Besides questioning the problem, designers question the assumptions and the implications related to the problem and its possible solutions (Lawson, 2006; Norman, 2013).

Engagement with the broader context supports the designer in the process of *framing* (Schön, 1983), which refers to the creation of a novel viewpoint from which the problem can be faced and is a special feature of designers' problem solving strategies. Designers take the original problem as a suggestion, not as a final statement; they think broadly about what the real issues underlying the problem might be (Norman, 2013). Although new frame creation often appears to be a random and largely informal activity, research has shown that it is a deliberate strategy, and an important element in the specific patterns of design reasoning (Dorst, 2011). Designing is conducted "backwards," from vague ideas of the wholeness of possibly desirable situations to more detailed proposals (Gedenryd, 1988). These scenarios inspire the creation of solutions because they are outside the immediate design space (Sanders & Westerlund, 2011). Framing, or reframing, as designated by Poulsen and Thøgersen, (2011), is the core of design thinking; to reframe is to transform the understanding of a phenomenon or a problem.

The third strategic aspect of design work refers to designers' either explicit or implicit reliance upon *first principles* in both the origination and development of their design concepts. For example, designers keep looking at the fundamental physical principles behind their concepts, or create innovations where "form follows function" (Cross, 2006; 2011). As noted by Norman (2013), this sometimes means questioning the obvious, "asking stupid questions," in order to redefine existing solutions, approaches, practices, and beliefs.

Reliance upon first principles requires descriptive knowledge that comes from science or other domains, or that is generated within designing through, for example, experimentation (cf. Vincenti, 1990). Moreover, designers aim at constructing a deep understanding of the people for whom they are designing (i.e. user-centered design), which means careful observation and deep empathy with those people.

When considering design education, the nature of design problems and design knowledge, as well as the ways in which designers generate and use knowledge, inform educators in several ways. Competence in design requires acquisition of the knowledge needed to create a design in addition to familiarity with the processes by which a design will be carried out to make a product or system (STL, 2007). Designing is considered a demanding and significant form of expertise, since it involves the integration of various kinds of knowledge, competencies, and capabilities (Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001). Therefore, authentic design work requires extended periods of time, allowing students space for occasional creative side-tracking and various leaps of imagination. Taking a broad systems approach and framing the problem in order to find a novel viewpoint to the problem and its solution is not possible within the usual time frame (from a few hours to a few days) of school projects. Moreover, although designing is a unique way to approach issues, it is closely linked to many other domains and fields of expertise. Creating functional designs requires knowledge of both humanities and science; designers need to know how people and the world they inhabit function. Therefore, design education is inherently interdisciplinary and has relevance across the curriculum; when given the opportunity, students move freely across disciplines (Davis et al., 1997).

3 Facilitating design learning

Design problems are complex and multifaceted, and require more knowledge than any single person can possess. Furthermore, the relevant knowledge is often distributed among diverse areas of expertise (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005). Recent research, moreover, has emphasized the embodied dimensions of design work, i.e. how the body is actively involved in designers' thinking and communication processes (Poulsen & Thøgersen 2011). Hence, there are three key dimensions of design work: social interactions, and knowledge representation and transformation work that takes place through the use of design artifacts (Perry & Sanderson, 1998), and embodied aspects of meaning making. In the following, these three dimensions – social, material, and embodied – of designing as well as their implications to design education will be discussed.

3.1 Social dimension of designing

Like any other form of intelligence, design competence results largely from interaction and collaboration with other individuals; design innovations "emerge from joint thinking, passionate conversations and shared struggles among different people" (Fischer et al., 2005, p. 483). The purpose of these interactions is to share expertise, ideas, resources, or responsibilities in order to work together to accomplish an agreed task or to address an agreed goal (Chiu, 2002). Appropriate socio-technical settings facilitate the participation of individuals for sharing information and organizing design tasks and resources, supports the emergence of a strong commitment to a common goal, and multiplies individual ability rather than simply summing it up (Chiu, 2002; Cross, 2011; Fischer et al., 2005). Furthermore, a participant's constructive influence in team design work is due to the way in which she interacts with others and articulates shared concepts (Dong, 2005); in successful collaboration, the whole pattern of conversation is focused and coherent, and the team members build upon each other's contributions (Cross, 2011). In order to successfully address a design problem, a team must simultaneously deal with the task itself as well as structure and organize their group process (Barron, 2000; Stempfle & Badke-Schaub, 2002).

Likewise, teamwork in professional contexts and collaborative learning in schools mean engaging in coordinated, continuing attempts to solve a problem or otherwise construct common knowledge. Collaboration involves a coordinated joint commitment to a shared goal, reciprocity, mutuality, and the continual renegotiation of meaning (Barron, 2000; Mercer & Littleton, 2007). Drawing on over twenty years of educational research, the learning sciences have consistently proved that successful collaboration supports learning in many ways, for example, fostering deep understanding (see e.g. Sawyer, 2006b). However, according to several studies, it takes time to create a classroom culture that supports collaborative learning. A learning environment, such as a classroom, includes various social structures, all impacting on learning either intentionally or unintentionally. In order to make these structures explicit, Bielaczyc (2006) developed the Social Infrastructure Framework, highlighting four dimensions of classroom social structures. The essence of *The Cultural Beliefs Dimension* is the overall philosophy and norms established among the teachers and students. *The Practices Dimension* concerns the groupings of the participants (individual, small-group, large-group) and the ways in which they engage in offline and online learning activities. *The Socio-Techno-Spatial Relations Dimension* relates to the organization of physical and virtual spaces, and *The Interaction with the "Outside World" Dimension* refers to the ways in which students interact with people outside their classroom learning environment. All four dimensions of the social infrastructure are interdependent, with the cultural beliefs dimension providing the foundation for the other dimensions.

Hennessy and Murphy (1999; Murphy & Hennessy, 2001) have studied the potential of collaboration in design learning. According to them, design education provides rich and unique opportunities for shared thinking and joint decision-making – if the necessary conditions are fulfilled. Leaning on the sociocultural approach to learning (Vygotsky, 1978), and research building upon the Vygotskian framework, as well as Rogoff's (1995) notion of guided participation, Hennessy and Murphy (1999) provide a framework for optimal preconditions for collaboration in design education. The main aspects of the framework are 1) teacher commitment and understanding of

collaboration as a learning mechanism, 2) a task context which sets the conditions for joint decision-making, 3) school and classroom organization that supports small groups, 4) a variety of pedagogic strategies supporting collaboration, and 5) students' perspectives. Hennessy and Murphy's framework shares many features common to other collaboration studies. For example, Mercer and Littleton (2007) emphasize task design and the quality of relationships as necessary preconditions for successful collaboration. Tasks should be open-ended and challenging, have a clear task structure and provision of feedback, and be designed so that students need to work together. Close relationships, with a sense of trust and mutuality, enhance learning. Students should engage with each other in a positive and supportive way, as well as be able to build constructively and critically on each other's ideas. As noted by Hennessy and Murphy (1999), collaborative skills are vital for learning through collaboration, therefore, both need to be facilitated in learning situations.

One of the aims of collaborative learning is to foster students' agency and social capabilities necessary for working creatively and collectively with knowledge. Fischer and his colleagues (Fischer et al., 2005) have suggested that creative work, such as designing, should evolve beyond the isolated image of the reflective practitioner (Schön, 1983) towards reflective communities. They distinguish two types of communities: *Communities of Practice* (CoPs, Wenger, 1998) and *Communities of Interest* (CoIs, Fischer, 2001). CoPs demand practitioners representing certain domain and undertaking similar work. Newcomers enter the community as apprentices, moving from the edges towards the center as they become more knowledgeable; thus, learning takes the form of "legitimate peripheral participation" (Lave & Wenger, 1991). In communities of practice learning is seen as a process of growing up and socializing in a community, and acquiring the skills to communicate and act according to its socially negotiated norms. In the Artifact Project, this was attempted by building connections between the students and various expert cultures. Especially having the professional designer working face-to-face with the students was considered critical for the development of students' design competencies, i.e. learning the processes and activities (rather than just practical skills) in which expert designers are engaged during complex problem solving (cf. Hakkarainen, 2010).

Within this type of *participatory learning* (Jurow, Hall, & Ma, 2008) or *cognitive apprenticeship* (Collins, Brown, & Newman, 1989; Collins, 2006) an important aspect of growing up with an expert culture is the model provided by more experienced members and participation in increasingly demanding activities.

The second type of community, CoIs, consists of stakeholders from different CoPs sharing a collective concern for the solution of a particular problem. The strength of CoPs lies in the shared background and similarity of participants, however, this can also hinder the acceptance of outside ideas. However, the potential of CoIs is in participants' different backgrounds and perspectives which can lead to new insights, although there is a risk of failure in creating common ground and shared understanding. CoIs resemble *affinity spaces* (Gee, 2000; 2003; 2005), which focus on the idea of a space (physical or virtual) in which people interact, rather than on membership in a community. The participants share a common space and, first and foremost, have affinity to the shared object around which the space is organized (and only secondly, if at all, to each other). These types of communities are more common outside the school context, for example, in the collective development of online games. Nevertheless, as noted by Fischer and colleagues (2005), the point of comparing and contrasting different types of communities is not to assign value judgments, but rather to identify patterns of participation in order to map components of successful collaboration. Communities do not have to be strictly of one type or another, they can integrate many forms and change over time as the nature of the work alters.

While CoPs and CoIs illustrate the two types of communities, the *Communities of Learners* model (CoL, Bielaczyc, Kapur, & Collins, 2013) describes the necessary conditions for participation and learning. The essential elements of the CoL model are "(a) a diversity of expertise among its members, who are valued for their contributions and given support to develop, (b) a shared objective of continually advancing the collective knowledge and skills, (c) an emphasis on learning how to learn, and (d) mechanisms of sharing" (ibid., p. 235). Members of the community share their individual efforts toward a deep disciplinary understanding of both subject matter and the ways of working with knowledge. Students learn how to pose disciplinary questions, explore problem spaces within a domain, as well as create, critique

and elaborate possible problem solutions. Furthermore, they learn how to synthesize multiple perspectives, solve problems in a variety of ways, and use each other's diverse knowledge and skills as resources to collaboratively advance their understanding. All the elements of the CoL model are applicable for design learning, and when understood as a form of knowledge-creation, design learning can offer unique opportunities for creating a community of learners.

3.2 Material dimension of designing

In collaborative design activity, various artifacts have a central role as a communicative resource, they function as mediators between individuals or groups (Al-Doy & Evans, 2011; Cross, 2011; Perry & Sanderson, 1998; Welch, Barlex, & Lim, 2000). Artifacts are the objects of interaction, they can be pointed to, talked about, or sketched on; they work as "boundary objects" (Star, 1989), as vehicles for communication (Perry & Sanderson, 1998). Artifacts are externalizations (Bruner, 1996; Vygotsky, 1978) of tacit knowledge (Polanyi, 1969), and support social creativity in many ways. Vague mental ideas evolve to more concrete representations, which makes them more accessible to reflection. Externalizations produce a record of mental efforts and relieve us from thinking our own thoughts. Furthermore, they provide means for others to interact with, react to, negotiate around, and build upon an idea; they contribute to a common language of understanding. The creation and management of externalizations is a central element in developing and maintaining coherence across intersecting social worlds (Fischer et al., 2005; see also Cross, 2011).

Many forms of design representations are available and used in both individual and team design work. Usually sketches are employed as the first step of the process, for externalizing and visualizing ideas at an individual level (Goel, 1995). Next, presentation drawings and physical models are used to communicate with others, and later detailed technical drawings and prototypes are used for communicating details (Pei, Campbell, & Evans, 2010). In a study on collaboration among industrial designers and engineering designers (Pei, Campbell, & Evans, 2010; 2011), a total of 35 different design representations were mapped out; these were classified into four main types of representations (i.e. sketches, drawings, models, and prototypes). Further, two types of information used by the designers were identified: design information concerned with visualization, aesthetics, and usability of the product, and technical information, such as assembly, mechanisms and materials. As noted by Perry and Sanderson (1998), in addition to *design* artifacts, team design work includes *procedural* artifacts, such as forms, memos, letters, and schedules. Design artifacts represent thought about design, whereas procedural artifacts carry information about the process. Advancement of team design work is dependent on the circulation and scrutiny of these artifacts.

Besides supporting interaction between collaborators, design artifacts function as an aid for thinking, reasoning, and reflecting (Cross, 2006; Parkinson & Hope, 2009). Especially sketching has a crucial role in generating, developing, and communicating ideas; it is both a powerful form of thinking and the fundamental language of designing (Seitamaa-Hakkarainen & Hakkarainen, 2004; Welch et al., 2000). Designers make sketches not just to record ideas, but to help generate them; sketches are central to the emergence of new thoughts (Menezes & Lawson, 2006). Further, designers usually work at many levels simultaneously. The best cognitive aid for supporting parallel work is sketching or drawing, because these give the flexibility to shift levels of detail seamlessly (Cross, 2006; 2011). Visual sketches as well as notes enable the testing and exploration of design ideas in development; visualization guides the design process in each phase of its cyclical and iterative progression (Seitamaa-Hakkarainen & Hakkarainen, 2004).

Designing is also material-centric and object-oriented; engagement with and manipulation of physical materials is often an intrinsic part of the design process (Ramduny-Ellis, Dix, Evans, Hare, & Gill, 2010). Designers build various kinds of models to explore their ideas in 3D form, from sketch models to appearance models and functional prototypes (Al-Doy & Evans, 2011; Pei et al., 2010). Material properties affect both the process and the outcomes of design activity, constraining and inspiring the work of a designer (Ramduny-Ellis et al., 2010).

The various design representations, such as sketches and models, are focal in the work of professional designers. However, the function and significance of these representations is not apparent for

school children learning design. Sketching may not be as helpful for students as it is for professionals in the development of new ideas (Menezes & Lawson, 2006), and, if possible, young students tend to move immediately to three-dimensional modeling (Welch, 1998). The formal design representations can become prioritized at the expense of participation and learning (Murphy & Hennessy, 2001) when the purpose and advantages of using them as design tools is not understood (Hope, 2005). Therefore, students should be explicitly taught how to produce various kinds of design representations, and how to use them for storing, developing, and communicating ideas.

3.3 Embodied dimension of designing

The embodied dimension of thinking, i.e. considering the human mind as fundamentally embodied and situated, has gained increasing research attention since the 1980s. Research on *embodied cognition* has been inspired by, for example, philosophical work in phenomenology, theoretical advancements in biology, and developments in cognitive psychology and cognitive semantics, and the work has emerged in an effort to acknowledge the mental as inherently co-defined with the body (Nuñez, 2012). Embodied cognition has been studied in various work settings (for review, see Streeck, Goodwin, & LeBaron, 2011), including design professions, such as architecture (Gedenryd, 1998), blacksmithing (Keller & Keller, 1993; 1996), and industrial design (Poulsen & Thøgersen, 2011; Ramduny-Ellis et al., 2010). Within the learning sciences, research on embodied cognition has concerned, for example, mathematics education (Abrahamson, 2009; Alibali & Nathan, 2012; Hall & Nemirovsky, 2012; Nemirovsky, Rasmussen, Sweeney, & Wawro, 2012), learning through dynamic visualizations (Koning & Tabbers, 2011), early childhood education (Fredriksen, 2011), and sloyd education (e.g. Ekström, 2012; Illum, 2006; Illum & Johansson, 2009; 2012). According to Nuñez (2012), research on embodied cognition offers relatively good descriptions of bodily movements and gestures while speech is being produced, but falls short in explaining how exactly the embodied resources are employed for the enactment of cognitive functions. Streeck, Goodwin, and LeBaron (2011) argue that analysts too often regard verbal production as a base line for understanding interaction, and suggest that they should, instead, attend to what the participants themselves are treating as important.

Based on the research on embodied cognition, Patel (2008), in her study of an artisanal bakery, has created the concept of *embodied thinking* for describing how bodies, the handling of tools and materials, interaction with others, and actions in space are related in the thinking processes. This kind of thinking is visible, for example, in gestures (Hall & Nemirovsky, 2012; see also Alibali & Nathan, 2012; Hostetter & Alibali, 2008), but as Poulsen and Thøgersen (2011) emphasize, embodied thinking cannot be reduced to merely gestures or body language. Drawing on the phenomenology of Merleau-Ponty (1962), namely his notion of the lived body, Schön's (1983) "reflection in action" and Gedenryd's (1998) "interactive cognition," Poulsen and Thøgersen (2011) present a view of embodied thinking in collaborative design activity. They conclude that the lived body is actively involved in the designers' meaning-making processes, serving as the foundation for their interaction and thinking at several connected levels. First, verbal interaction is only an indication of complex and multi-modal dialogue between the designers in relation to the design problem at hand. What is being verbalized "constantly finds its meaning in reference to a tacit level of embodiment which remains unspoken" (ibid., p. 42). Second, the verbal dialogue is also integrated into the use of tools and materials, as well as other items and the surrounding space through an embodied engagement (see also Patel, 2008). In designing, much knowledge is created and communicated without being verbalized; accordingly, design thinking and learning cannot be understood by merely examining verbal interaction (Illum & Johansson, 2009; Poulsen & Thøgersen 2011).

Recent research by Koning and Tabbers (2011) presents a wide range of studies assuming that action, perception, and cognition are closely intertwined with thinking and learning processes. These studies provide strong evidence that cognition is grounded in action, and that there is a strong link between action and comprehension. On the basis of their review of studies of embodiment and grounded cognition (Barsalou, 2008, 2010), Koning and Tabbers offer specific strategies for involving the human body in the learning process. Their study concerns the use of dynamic visualizations in education, but to

some extent the strategies are applicable in design learning as well. First, students should be encouraged to make and observe gestures; in designing, gestures are used, for example, for describing design ideas or demonstrating techniques. Students learning design can also follow the movements of another before testing out new tools or techniques. Second, manipulating and interacting with objects is a focal embodied learning strategy in design education, and is increasingly used in other areas, such as science and mathematics education. In addition to interacting with objects that exist in the learning environment (e.g. tools and materials), students interact with and through the artifacts that they create in situ, i.e. the design representations (cf. Streeck, 2011). Furthermore, a study on deafblind makers' embodied ways of thinking (Groth, Mäkelä & Seitamaa-Hakkarainen, 2013) suggests that an efficient strategy for learning tacit skills is to perform with the student; to take her hands and transfer knowledge tacitly.

To conclude, research indicates that designing is a fundamentally mediated and embodied activity. Thinking, communicating, and meaning making processes in designing include several connected levels of interaction (i) between humans, (ii) between humans, tools, materials, and the surrounding space, and (iii) between mind and body. Accordingly, appreciation of all these dimensions and their relevance to developing students' design competence is essential also in the context of design learning.

4 Research questions

The present study presents a case of design learning, where designing was regarded as a form of knowledge-creation, and where the pedagogical approach Learning by Collaborative Design (LCD) was, for the first time, applied at the elementary level of education. Since design education in general, and LCD in particular, are late arrivals in education and educational research, the general purpose of the present study was to examine the implementation of knowledge-creation learning exemplified by collaborative design at the elementary level of education. The general research question, derived from the overall aim, was formulated as follows:

How can design learning based on the LCD approach be promoted at the elementary level of education?

The overall aim of the study was twofold. On one hand, the study explored the students' collaborative design processes and, on the other hand, it examined the facilitation of these processes. Accordingly, the first research objective was to analyze the contents and progress of the students' processes. The research question related to the first objective was:

What is the nature of elementary students' collaborative design learning process, and how is this process constructed?

The second research objective concerned the facilitation of design learning; in the present study, facilitation was mainly provided by a professional designer. Therefore, the objective was to examine which of his practices were applicable for elementary students to engage in and learn. The research question related to this aspect of the study was the following:

How can elementary students' participation in authentic design practices be facilitated?

In addition to the two main objectives, a third objective related to the first two was set in order to further understand the mediated and embodied nature of the design learning process. In professional designing the social, material, and embodied dimensions of the process are essential; the present study examined their role in the design learning context. Hence, the research question related to the third objective was:

How are the social, material, and embodied dimensions of designing related in design learning processes and their facilitation?

The three objectives of the present dissertation were approached through a series of four, interconnected sub-studies, including several iterative cycles of analysis, in order to meet the overall aim. In the following, the data, methods, results, and conclusions of these studies will be presented.

5 Research design

Research on knowledge building and progressive inquiry has from the outset been oriented towards longitudinal studies; the development of innovative knowledge practices requires iterative efforts across extended periods of time (Ritella & Hakkarainen, 2012). Most research on this area, including the present study, is design-based and characterized by several cycles of design and formative research in complex real-world settings (Edelson, 2002); the goal is to improve the way a design functions in practice (Collins, Joseph, & Bielaczyc, 2004). Design-based research originates in cognitive studies of learning practices and research on computer-supported collaborative learning (Brown, 1992; Collins, 1992). In the early 1990s, it represented a revolutionary change in learning sciences research, since it moved researchers away from their laboratories and controlled experimentation, to the field, to schools, classrooms, and other natural settings of learning. Since then, design-based research has evolved into an accepted approach of educational research (Sandoval, 2014) "as a way to carry out formative research to test and refine educational designs based on theoretical principles derived from prior research" (Collins, Joseph, & Bielaczyc, 2004, p. 18).

Design-based research has been called by various names, such as *design experiment* (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Collins, 1992; diSessa & Cobb, 2004) and *design research* (Bielaczyc, 2013; Cobb, 2001; Collins, Joseph, & Bielaczyc, 2004; Edelson, 2002; Kelly, 2004; Kelly, Lesh & Baek, 2008; Sandoval 2013). In the present study, the term *design-based research* (Barab, 2006; Barab & Squire, 2004; Bell, 2004; Design-Based Research Collective, 2003; O'Neill, 2012; Sandoval & Bell 2004) is used in order to avoid connotations with controlled experimentation (design experiment), and confusion with research concerning design as a professional practice (i.e. design research).

Iterations of design-based research can occur on the macro-level, from one research project to another, or at the micro-level, from one activity, lesson, or project phase to the next (Ritella & Hakkarainen, 2012). At the macro-level, the present study was informed by iterations of research on knowledge building and progressive inquiry; the aim

was to extend the ideas and methods of these approaches towards issues relevant to design education. At the micro-level, the Artifact Project designed for the present investigation consisted of three main phases, as well as several lessons and various activities, as will be elaborated in the next chapter.

5.1 Participants and setting of the study

The present study aims to create and analyze innovative conditions for learning that theory suggests might be productive, but are not yet common (cf. Design-Based Research Collective, 2003; Kelly, Lesh & Baek, 2008). In order to extend the ideas of knowledge building and progressive inquiry towards issues relevant for design education, to address certain challenges related to the research on this field, and to further advance the LCD approach, a longitudinal, elementary-level study project was designed for the present investigation.

The *Artifact Project* was designed in close collaboration with the class teacher, and it took place in her classroom at Laajasalo Elementary School, Helsinki, Finland, in the years 2003–2004. Altogether 32 students (19 girls), aged 10–12 years participated in the project; of these, seven students had linguistic or other educational problems. The project's time span was long, it started at the beginning of the second term of fourth grade and continued over 13 months until the end of the fifth grade. In total, the project encompassed 139 lessons (in Finland one lesson lasts 45 minutes) over three terms.

The practical aim of the project was to study the role and diversity of artifacts as a part of Finnish culture. The general theme – Past, Present, and Future of the Artifacts – was planned by the teacher and the researchers; however, the actual project design emerged through interaction between the organizers and students, without strict pre-determined plans. The various stages of the project were always based on previous stages, and on the students' own ideas of what and how to study. This helped the students' to stay motivated throughout the long project; the topic of learning was almost always authentic and meaningful for them. Further, the micro-level iterations (cf. Ritella & Hakkarainen, 2012) of the project were carefully considered by the research team, and several revisions to the project plan were made in order to better support students' knowledge-creation efforts. The present study focused mainly on the final iteration (i.e. The Future), however, in a parallel dissertation concerning teacher guidance in the project (Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010; Viilo, Seitamaa-Hakkarainen, & Hakkarainen, 2011; 2012; submitted) the development from one iteration to the next is presented.

The structure of the Artifact Project is presented in Table 1. During the first three weeks, the aim was to inspire and engage students in the project, to orient them towards inquiry activities, and practice the use of Knowledge Forum, a networked learning environment (Scardamalia, 1999; Scardamalia & Bereiter, 2003; 2006). In the first actual project phase, The Past, each student team chose one artifact for deeper investigation and studied it within its historical context. Students chose items which they found interesting and which most of them had used: a clock, a spoon, money, a lock and a key, a piece of jewelry, a ball, and a lamp. The historical inquiries of these items led the students towards the second phase of the project, The Present. During this phase, the students explored the physics and chemistry related to the chosen artifacts, such as the movement of a ball, functioning of the lamp, physics of light, and characteristics of metals. Expert-designed science experiments with ready-made toolkits as well as student-created experiments were used for examining these topics.

The students' historical and science-related investigations formed the basis of the project's last phase, The Future, which was oriented towards designing. The students studied and designed lamps, and finally, designed visual representations of their chosen artifacts for the future. The design work was based on what the students had already studied, for example, the use and function of the artifacts. The leadership of the last phase was provided by a professional designer, together with the teacher. The designer was present in the classroom during the whole phase; besides face-to-face guidance, he also interacted with the students online through the project database. The data for the present study was mainly collected from the lamp designing phase, which included the designer's presentations on various issues related to lamp and light designing, students' investigations of existing lamps, students' small team designing through sketching, drawing, and prototyping, as well as students' presentations of their own design ideas, processes, and products.

Table 1. Structure of the Artifact Project.

Phases	Weeks	Main Stages	Connections to expert communities
The Past 12 weeks 53 lessons	Spring 2003 1–3	Orientation: Classifying artifacts; analyzing the design and usability of ladles	
	4–12	Historical development of artifacts	Visiting the National Museum; interviewing grandparents
	8–9	Exhibition in the classroom: Organizing, building, and staffing	
The Present 20 weeks 44 lessons	13–16	Kinetics: Movement and interaction of balls	
	Fall 2003 1–5	Physics of light: Designing and implementing science experiments	
	6–9	Physics of force: Conducting and reporting science experiments with ready-made toolkits	
	10–13	Mechanisms of clocks	Visiting the Museum of Horology
	Spring 2004 1–3	Physics and chemistry of metals and magnetism: Conducting and reporting science experiments with ready-made toolkits	Visiting the blacksmith's workshop
The Future 18 weeks 42 lessons	4–14	Designing lamps: Analyzing existing lamps; sketching, drawing, and prototyping new lamps	Leadership provided by a professional designer
	15–22	Concept designing of future artifacts; exhibition of the lamp designs	

In addition to the participating designer, other connections to expert communities outside the school were created during the project (see Table 1). Visits to museums and to a blacksmith's workshop aimed at breaking the boundaries of traditional schoolwork and fostering the students' expert-like inquiry and design practices.

The technical infrastructure of the Artifact Project was provided by Knowledge Forum (KF, Scardamalia, 1999; Scardamalia & Bereiter, 2003; 2006), which is a networked learning environment designed specifically to support collaborative knowledge building. The core of KF is a multimedia database consisting of knowledge created and organized by the participants. By authoring *notes*, the students contribute, for example, ideas, theories, working models, and reference material to *views*, which are workspaces for various streams of inquiry. The synthesis of knowledge is encouraged by several supportive tools that allow students, for instance, to "build on," or "annotate" their fellow students' notes or create "rise above notes" for synthesizing inquiries completed thus far. In the classroom, the students had ten computers and a scanner, and the teacher had her own computer and a data projector. From time to time, the class had the opportunity to use the school's computer lab, where more computers were available for student use. The database had a critical mediating role in the Artifact Project; the project's various phases and activities were documented there, enabling the anchoring of discussions and learning to previous work. In addition, the database was a shared object of knowledge-creation for the whole classroom community.

5.2 Data collection and selection

As is common in design-based research, various types of data were collected from the Artifact Project (cf. Brown, 1992) in order to understand the complex and multifaceted processes involved in design learning. Traditionally, research concerning knowledge building and progressive inquiry has relied on analysis of database material (e.g. Hakkarainen, 1998; Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007), although more recently analysis of group interaction has also relied on video analysis (Suthers, Lund, Rosé, Teplovs, & Law, 2013). During the Artifact Project, altogether 30 views and over one thousand notes were created in the KF database. In addition to text, the views and notes contained large quantities of visual data, such as sketches, drawings and photographs. The material produced in the database was used as the primary data source in the first sub-study of the present dissertation, and as additional data in the third sub-study.

In the Artifact Project, large quantities of video data were collected; in total, 56 lessons were recorded during the project. Video data was considered essential to understanding the process of knowledge-creation and the collaborative emergence of knowledge practices, including their various social, material, and embodied dimensions. Consequently, the present study relied heavily on video material collected during the Artifact Project; video data from the lamp designing phase (approximately 16 h) was used as the primary data source in sub-studies II, III, and IV.

In addition to the database and video material, the Artifact Project's data set included the teacher's weekly diaries, however, the analysis of the diary data has been reported in the parallel dissertation (Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010; Viilo, Seitamaa-Hakkarainen, & Hakkarainen, 2011; 2012). The diaries included a structured part where the teacher described classroom activities, and a reflective part where she wrote her own impressions of the process; the aim was to support the teacher in reflecting on her teaching in a systematic fashion.

In the present study, the database and the video material both formed large bodies of data. The challenge was to make systematic and justified selections for the analyses. The selected samples had to be representative of the whole data set, small enough to be manageable, but large enough to allow systematic analysis. In order to form a coherent impression of the whole Artifact Project, the database was first analyzed quantitatively by using the Analytic ToolKit, which underlies KF. This analysis revealed the frequency of computer postings (i.e. notes, annotations, views, rise-aboves, build-ons) as well as note reading activity, and served as a basis for the selections of further, qualitative analysis (Figure 2). Two views from each phase of the project were selected for examining how the use of KF mediated students' historical, science-related and design inquiries. The six selected views involved various learning activities and were directly linked to the phases of the project. They also formed continua of student inquiries, for example, investigations of clocks from the historical perspective, to the mechanics of clocks and designing of clocks in the future. These analyses and their results were reported in Publication I. One of the selected views, the "Lamp Designing" view, was also further analyzed for Publication III, in order to more closely investigate KF's role in the design process.

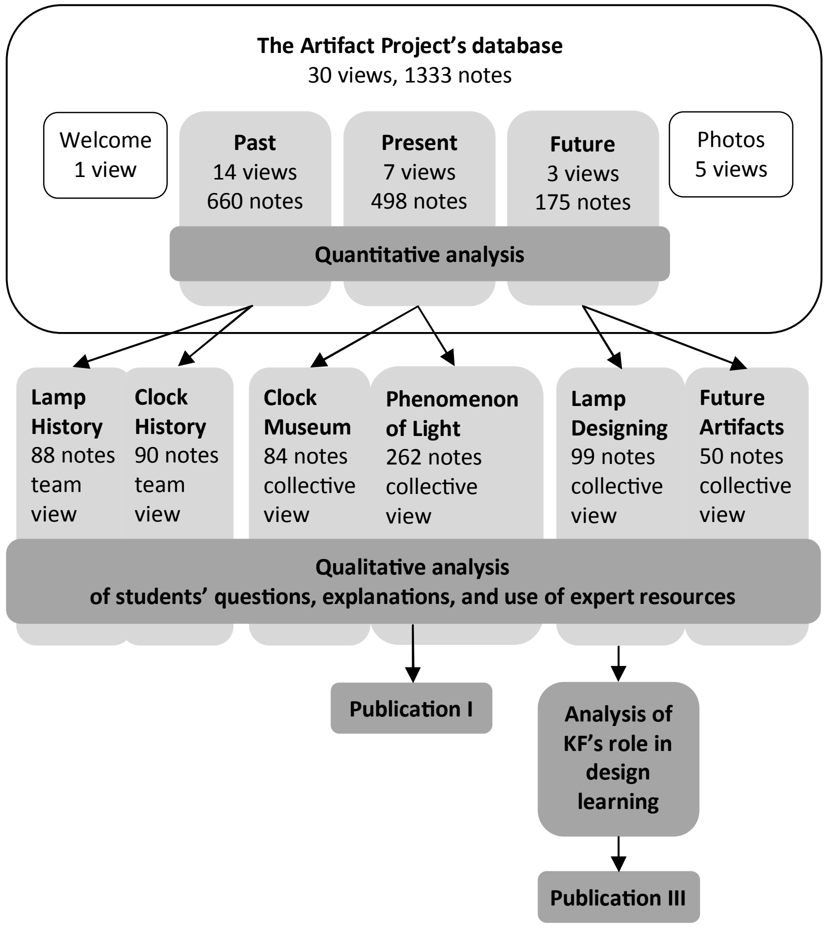

Figure 2. Selections made for the analyses of the KF database.

The material in the KF database accumulated throughout the project, and selections needed to be made for analysis of this data. Conversely, with the video data, careful choices needed to be made already in the data collection phase. Systematic selection was necessary for determining when to record and which elements of the complex learning environment should be recorded (cf. Derry et al., 2010). Since the Artifact Project covered 139 lessons over three terms, it was neither meaningful nor possible to record the entire project. Decisions on when to record were made with the teacher, who had the most extensive knowledge of the project as a whole.

Approximately one third of the lessons from the first two project phases, the Past and the Present, were recorded (Figure 3). However, since the present study focused on design learning, 66.7% of the lessons

of the last phase (i.e. the design phase) were recorded. The majority of these recordings were made during the lamp designing stage for two reasons. First, having a professional designer working with the students face-to-face in their classroom for several weeks was an innovation implemented especially for this research project; the aim was to provide the students with direct and continuous access to the skills, problem-solving abilities, knowledge and language of designer practitioners (cf. Hsu & Roth, 2009; Roth, 1998) in order to support their expert-like designing. The video recordings of the lamp designing process captured the students' experience this kind of direct interaction for the first time in their learning history. Secondly, diverse design activities (writing, sketching, drawing, model-making) were deliberately included in the lamp designing stage, thus depicting the socially and materially mediated, as well as embodied, nature of the design process.

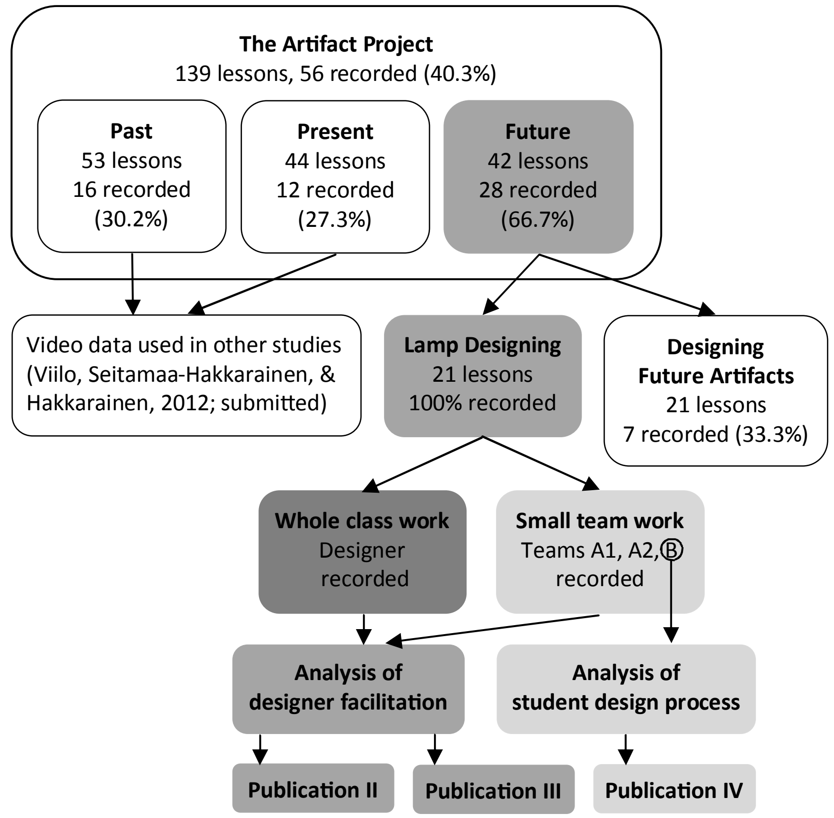

Figure 3. Selections made for the analyses of the video data.

In total, the lamp designing phase spanned approximately 21 lessons, all of which were recorded with a single camera by the present researcher. In meetings with the whole class, the designer's activities were recorded, and during work in small teams, three student teams were followed. During almost half of the design sessions, the class was split into two (large groups, A and B), which is a standard scheduling procedure in the school. For example, the Group A teams started developing their design ideas on Thursday, while the Group B teams did the same on Friday. The activities of two Group A student teams were recorded, and one Group B team was followed. An external microphone was attached to the camera to record the discussion in the small teams; during activities with the whole class, we relied on the internal microphone of the camera. The video recordings from the lamp designing stage were used as the primary data in the original Publications II, III, and IV; further selections, segmentations, and analyses of the video data will be elaborated in the next chapter (5.3). Systematic selection was essential for deciding which parts of the extensive video corpus were to be chosen as representative samples, and appropriate analytical frameworks and practices needed to be developed or applied to address the research questions (cf. Derry et al., 2010).

In a sense, the present study has features of educational ethnography, in that it includes relatively long periods of fieldwork, a versatility of data, methods and analytic frameworks, as well as participant observation and video recording as the focal data collection methods (cf. Atkinson, Coffey, Delamont, Lofland, & Lofland, 2001; Lappalainen, 2007). Furthermore, it attempted to produce rich descriptions of events that occurred in the learning context, in order to understand what was happening and why (cf. Atkinson et al., 2001; Delamont & Atkinson, 1995). Educational ethnography can be defined as "research on and in educational institutions based on participant observation and/or permanent recordings of everyday life in naturally occurring settings" (Delamont & Atkinson, 1995, p. 15; see also Gordon, Holland & Lahelma, 2001; Lahelma & Gordon, 2007). However, ethnography is a theoretical approach in its own right rather than merely a research method (Delamont & Atkinson, 1995); the result of an ethnographic study is a theorized account of the culture studied (Delamont, 2006). Moreover, in ethnographic research there is no attempt to change educational practice, as in design-based research (Collins, Joseph, & Bielaczyc, 2004).

5.3 Four iterations of qualitative content analyses

As design-based research is mainly defined in terms of certain epistemic commitments rather than the use of particular methods (Sandoval, 2014), a pragmatic stance towards methodological options was adopted in the present study. At the pragmatic level of making concrete methods decisions, the point was to select appropriate methods for this particular research context in order to iteratively achieve the research objectives (cf. Patton, 2002). The data collected from the Artifact Project was approached and analyzed with four gradually deepening iterations, corresponding to the four sub-studies of the present study. Further, each of these iterations included several cycles of selection and segmentation of the data.

The analyses conducted represent qualitative content analysis (Chi, 1997), focusing on identifying the relevant issues in promoting design learning in elementary education. As in sociocultural research of learning, the interest of the present study was in the content and functions of interactions, i.e. the ways shared understanding was developed within a learning environment (cf. Kumpulainen & Wray, 2002; Mercer & Littleton, 2007; Mercer, Littleton & Wegerif, 2009). However, besides emphasizing the situated nature of learning (Lave & Wenger, 1991; Palinscar, 1998), the present study underlines learning as an object-oriented process where activities are organized around the collective creation and elaboration of shared knowledge objects (cf. Hakkarainen, 2009a; 2009b; Paavola et al., 2004). Further, in order for these objects to be truly shared and improvable, they need to be materialized in some form or another. Therefore, the analyses conducted in the present study concerned not only social, but also material and embodied interactions taking place in the processes by analyzing lengthy periods of design learning activities, acknowledging both the details and the overall context of the activity. A combination of theory-based and data-driven approaches was used for developing the coding frameworks (cf. Saldaña, 2009); they were created on the basis of (a) preliminary analyses of the data, and (b) reflection on the data in relation to the theoretical outlining of the studies. Combining issues emerging from the data with theoretical knowledge assisted in identifying the aspects considered relevant for design learning (cf. Seale, 2006). An overview of the four content analyses is presented in

Table 2. Publications I, II, and IV also included quantitative descriptions of the data; these descriptions were mainly used for providing an overview of the phenomena under investigation.

Table 2. Overview of the content analyses conducted in the original publications.

Original publication	I	II	III	IV
Data	KF database, 6 views	Video data	Video data, KF database "Lamp Designing" view	Video data
Unit of analysis	Student's written note or annotation	Design event	Design event	Verbal statement
Focus of qualitative analysis	Students' questions, explanations, and use of expert resources	Social settings, design inquiry phases, designer's facilitation activities	Designer's facilitation activities and strategies in implementing design practices	Students' design activities: focus of discourse; use of tools, materials, and gestures
Inter-coder reliability	.81 all content categories	.88 content categories of designer's facilitation activities	.88 content categories of designer's facilitation activities	–
Quantitative description	Frequency distribution	Frequency distribution Temporal distribution	–	Frequency distribution Temporal distribution

The first qualitative analysis (Publication I), conducted on the Artifact Project's database, focused on the nature of knowledge generated by the students through their design inquiry in relation to their historical and science inquiries. On the basis of the quantitative analysis of the whole database, two views from each phase of the project, representing different kinds of inquiry (i.e. historical, science, and design inquiry), were selected for the analysis (see Figure 2, p. 42).

The students' written notes and annotations on these selected views were coded according to (a) the type of questions proposed, (b) the type of explanations provided, and (c) the knowledge resources used. The coding categories for the students' questions were adapted from the analysis framework developed by Hakkarainen (1998, see also Zhang et al., 2007). For coding the explanations, Hakkarainen's (1998; 2003; Hakkarainen, Lipponen & Järvelä, 2001) scale for rating the epistemic level of explanations was adapted, whereas a data-driven approach was employed for coding the use of knowledge resources. The first analysis of the project database did not seek to reveal what was actually happening in the classroom, nor did it display the activities that the students and the designer were engaged in or the role of design artifacts in these activities. These issues were addressed through the analyses of video data in the subsequent studies (Publications II–IV).

In order to process the large and rich corpus of video data, it was first necessary to delve into what was happening in the video recordings, in other words, to identify precisely what was being done and how (cf. Korvela, 2003). With these initial viewings of the data, the various social settings began to stand out from the classroom activities; either 1) the designer or 2) the students were giving presentations and having discussions with the whole class, or 3) the students were designing in small teams (Figure 4). Identifying these three types of social settings was the first iteration of organizing the data into meaningful segments. These segments were, however, too large for analysis. Thus, the second iteration focused on segmenting the data into more manageable episodes.

The various forms of interaction were the basis of the second segmentation: either the designer was interacting with the whole class or small teams, or the students were interacting with each other within the small teams. At this point, it began to seem beneficial to distinguish two branches of analysis, as the aim was to examine two large and complex phenomena. On one hand, the goal of the present study was to investigate the nature of the *students' design process*, and on the other hand, the aim was to explore the *facilitation of this process*. Examining these separately enabled more thorough and in-depth analyses on both.

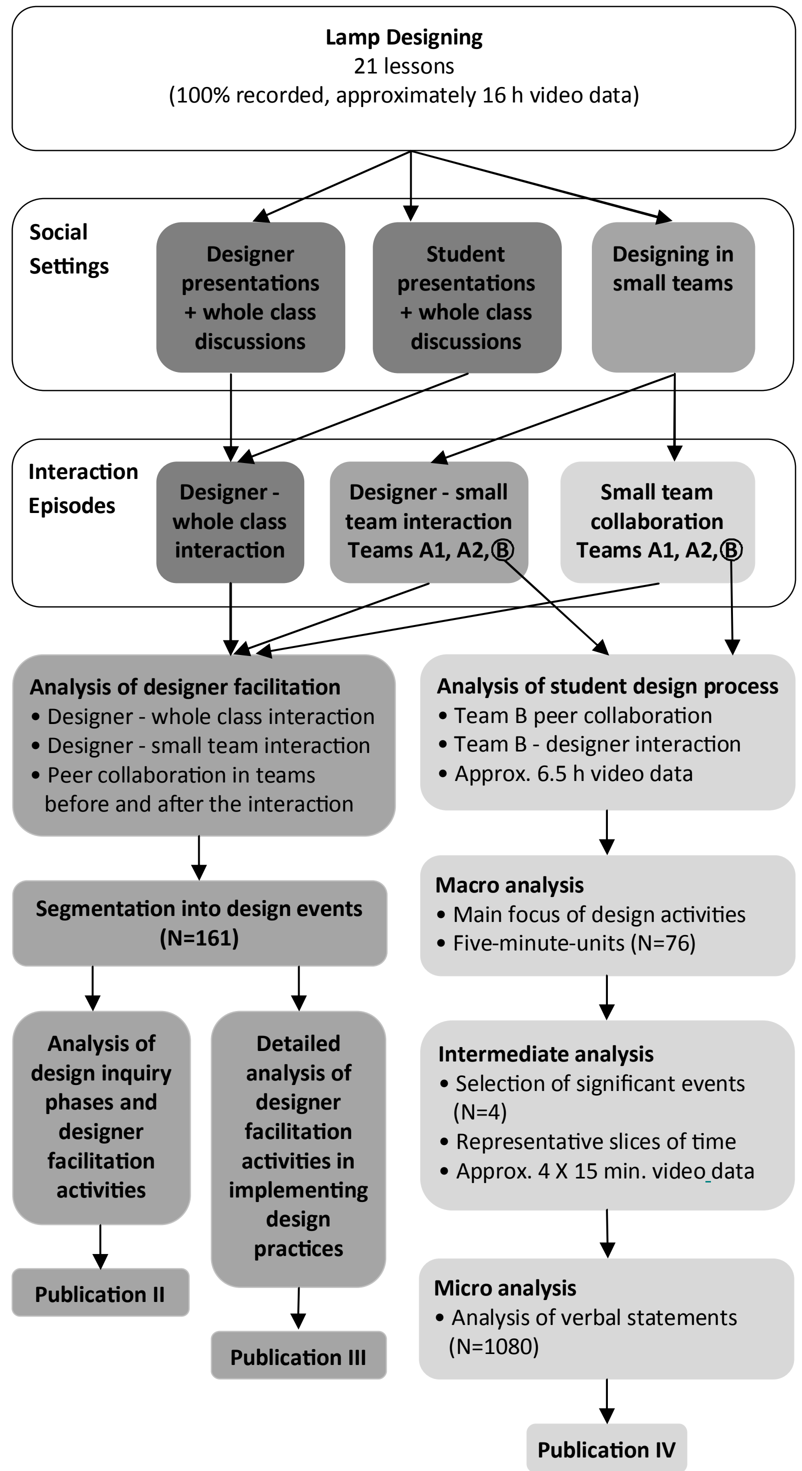

Figure 4. Segmentation and analyses of the video data.

In order to investigate the designer facilitation, three types of interaction episodes were selected for further segmentation and analysis. Designer-whole class interaction episodes and designer-small team interaction episodes were selected in order to analyze the various forms of facilitation that took place during the assorted activities in the classroom. Small team collaboration episodes immediately before and after interaction with the designer were selected in order to analyze how students applied support from the designer. For the analysis, the selected episodes were further segmented into smaller design events, each distinguishable from the others on the basis of the noticeably different content or context (cf. Chi, 1997; Derry, 2007; Seitamaa-Hakkarainen, 2000). The outcome was 161 events, varying from a few minutes to over 15 minutes in length.

Analysis of these events focused on determining the design inquiry phases of the lamp designing process and the designer's activities during all the various phases. The design inquiry phases were determined in accordance with the LCD-model (Seitamaa-Hakkarainen et al., 2001; 2010), whereas a data-driven approach was employed for categorizing the designer's activities. This analysis and its results were reported in Publication II. The analysis revealed that the focal activity during the lamp designing process was the implementation of design practices through the students' small team work. The subsequent studies, therefore, focused on analyzing this activity further. Content analysis taking place in the third sub-study (Publication III) aimed at defining at a more detailed level the designer's facilitation activities and specific supporting strategies during students' practical team work. In addition to the analysis of the video data, the KF "Lamp Designing" view was further analyzed in this sub-study, in order to understand the role of the networked learning environment in the lamp designing process.

For a closer look at the students' processes, content analysis of the fourth sub-study (Publication IV) was conducted on the activities of one student team, from the beginning to the end of their lamp designing. The team was from the large group B, and was selected because their whole design process was recorded on video. The team's peer collaboration episodes, as well as the episodes in which they interacted with the designer, were selected, producing approximately 6.5 hours of video data.

Furthermore, the fine-grained analysis of student design activities that was the objective in Publication IV called for more detailed data selections. In order to make the selections systematically, Ash's (2007) three-level methodology – macro, intermediate, and micro – was adapted. First, the selected episodes were divided into five-minute units, and the main focus of activity in each unit was defined (macro-level). Second, based on this definition, as well as former knowledge of the data, four events, each averaging 15 minutes, were selected (intermediate level) for the micro-level analysis. The selected events provided representative slices of time (cf. Ash, 2007) from different phases of the project, exemplifying various kinds of activities. The micro-level analysis was a structured investigation of students' verbal utterances, i.e. statements, as well as their use of tools, materials, and embodied activities.

As an analysis tool, CORDTRA (*Chronologically-Oriented Representations of Discourse and Tool-Related Activity*) diagrams (Hmelo-Silver, 2003; Hmelo-Silver, Chernobilsky, & Jordan, 2008; Hmelo-Silver, Chernobilsky, & Nagarajan, 2009a; Hmelo-Silver, Liu, & Jordan, 2009b; Hmelo-Silver, Jordan, Liu, & Chernobilsky, 2011) were used in Publication IV, enabling the combining of the chronological picture of the coded discourse with other learning activities. CORDTRA diagrams provide one way of generating information about how social interaction and other learning activities serve as tools for students' collaborative thinking; the diagrams support analysis that extends beyond coding individual speech acts (Hmelo-Silver, 2003; Hmelo-Silver et al., 2008; 2009a; 2009b; 2011).

The technique was originally developed by Luckin and colleagues (2001; Luckin, 2003) and called the *Chronologically Ordered Dialogue & Features Used* (CORDFU) method. It was initially used in a traditional, single-learner context and further developed for use with teams and novel learning technology. Hmelo-Silver (2003) generalized the technique, and used the diagrams to understand how producing a drawing mediated learning in face-to-face collaboration. Hmelo-Silver and her colleagues later expanded this work to study online collaborative learning (Hmelo-Silver & Chernobilsky, 2004; Chernobilsky, Nagarajan, & Hmelo-Silver, 2005; Hmelo-Silver, Chernobilsky, & Jordan, 2008; Hmelo-Silver, Chernobilsky, & Nagarajan, 2009a; Hmelo-Silver, Liu, & Jordan, 2009b; Hmelo-

Silver, Jordan, Liu, & Chernobilsky, 2011). In addition, Puntambekar, Stylianou, and Goldstein (2007) have used CORDTRA diagrams for examining the face-to-face classroom enactments of two teachers, in order to understand the differences in the learning outcomes of their students. More recently, Ioannou (2011) has used CORDTRA diagrams for studying the affordance of wikis to support collaborative learning, and Ioannou and Georgiou (2010) have discussed the strengths and limitations of the CORDTRA method and provided recommendations for its improvement. They suggest that an automated process for generating the diagrams should be developed, and that they should have "zoom in" functionality for exploring interesting patterns of activity.

The CORDTRA technique allows examination over extended periods of time (hours to days) but also supports micro-level of analysis (Hmelo-Silver, Liu, Jordan, 2009b). One potential difficulty in constructing the diagrams lies in including the appropriate amount of information (Hmelo-Silver, 2003; Ioannou & Georgiou, 2010). Creating the diagrams is a labor-intensive process, and their interpretation can be difficult. Yet there should be enough information for the diagrams to be useful. When using the diagrams for analyzing face-to-face collaboration from video data, as in the present study, the data is usually dense, non-linear, and messy, and comes in large quantities. Careful and systematic selection is needed for choosing samples for analysis, as well as the appropriate coding categories. In the present study, where mainly three participants were involved in a complex and open-ended collaborative design task, events averaging 15 minutes appeared to be interpretable, yet still informative. The diagrams were interpreted together with the corresponding discourse and video data; zooming in on interesting patterns on the diagram and alternating between the diagram, the coded discourse, and the video material (cf. Hmelo-Silver et al., 2009a; 2009b; 2011).

6 Main findings of the study

The iterative cycles and the main results of the four sub-studies are summarized below. Further details of the studies are available in the original publications.

6.1 The Artifact Project. History, science and design inquiry in technology enhanced learning at elementary level *(Publication I)*

The aim of the first sub-study was to examine, through analysis of the KF database, the nature of knowledge generated by the students within their design inquiry in relation to their historical and science inquiries. Two views from each phase (i.e. past, present, and future) of the Artifact Project were selected for the qualitative analysis, in which the students' questions, explanations, and use of expert resources were examined.

Analysis revealed that the nature of knowledge generated clearly changed from one phase of the project to another. During historical inquiry, the students' questions and explanations were mainly factual in nature; the structure of fact-seeking questions and short fragmented responses implied clear question-answer pairs. In comparison, during science-related investigations the questions changed towards explanation-seeking questions, whereas in the design inquiry phase all student questions represented design challenges, i.e. questions seeking for definitions of the purpose, goal, or constraints related to the artifact being designed.

While the students' explanations in the historical phase were characterized mainly as isolated facts, the epistemic level of the explanations clearly matured towards the end of the project. In science inquiry, knowledge chains were created with build-on notes and annotations; advances of understanding led to further questions and more abstract levels of knowledge. In the last phase of the project, the students' design ideas were explained either in a descriptive or explanatory manner. The students either merely described their ideas with factual, yet connected pieces of information, or additionally

provided explication, elaboration, and justification of their ideas.

The use of different knowledge resources was studied by identifying the notes that referred to museum visits, reading material or the Internet, experiments, or the designer. The number of notes with these explicit references was small, and the students mainly referred to the source with their own words, without going beyond the resource material. However, qualitative analysis of student notes indicated that the designer's participation was central and his feedback supported the students in engaging in several iterative cycles of design inquiry. In many cases, new or improved ideas were presented immediately after the designer's contributions to the database; further, these improvements resembled the designer's suggestions.

The results of Publication I indicated that, when provided with an authentic and meaningful design task, elementary students are able to deepen their design inquiries through (a) questions seeking for definition of the purpose, goal, or constraints related to the artifact being designed, and (b) explanations providing either descriptions of their design ideas, or explication, elaboration, and justification of the ideas. Furthermore, the results indicate that in order for the students' inquiries to succeed, careful facilitation is needed. In the present study, the use of KF facilitated students' in-depth inquiry by supporting the sharing and visual organization of knowledge. Furthermore, the various KF functions (build-on, rise-above, annotations) enabled deepening cycles of inquiry and continuous idea improvement. This, however, also required continuous monitoring and participation from the teacher and the designer.

To summarize, the results of Publication I revealed important aspects of the iterative nature of the students' design processes, as well as the role of facilitation in these processes. However, as the analysis was conducted on the database material only, it did not reveal what was actually happening in the classroom. In order to understand the processes of knowledge-creation and collaborative emergence of inquiry and design practices, as well as the role of material and embodied activities, the subsequent studies focused on the analyses of the video data.

6.2 Figuring the world of designing: Expert participation in elementary classroom

(Publication II)

Publication II examined the designer's face-to-face facilitative activities during various phases of the lamp designing process, and during various social settings used in the classroom. The concept of figured worlds (Holland, Lachicotte, Skinner, & Cain, 1998) was operationalized in an effort to understand how professional ways of thinking and acting could be made applicable for elementary students' engagement and learning. Video recordings from the lamp designing phase constituted the data source in Publication II. For the analysis, the designer-whole class and the designer-small team interaction episodes were selected, as were the student teams' peer collaboration episodes before and after interaction with the designer. These were further segmented into smaller design events (N=161).

Three distinctive foci of the participants' activity were identified in the study: (1) Design Rationale, (2) Design Practices, and (3) Design Community. All of these were visible throughout the lamp designing, and each highlighted different aspects of the multifaceted process. The first focus, Design Rationale, included the creation of the design context and the definition of the design task, which took place mainly during the designer's presentations and the whole class discussions during and after the presentations. The designer made his own expertise more accessible for the students verbally and by bringing several visual and material design artifacts to the classroom. He also anchored this new knowledge to students' prior conceptions and more common experiences.

The second focus, Design Practices, took place during small team work, which included the creation and elaboration of the design ideas, as well as the experimenting and testing (sketching and prototyping) of the ideas. The designer supported the externalization and envisioning of the students' design ideas, facilitated their idea elaboration, and supported the use of professional techniques of external representation. The role of domain language, tools, and materials was central in all of the designer's facilitation activities, the designer supported the students in using them for storing, representing, mediating, and developing their emerging ideas.

The third focus, Design Community, was most apparent in the students' presentations, which were given regularly throughout the process. It was challenging for the students to recognize, explicate, and share their design knowledge; the designer facilitated the reflection and evaluation of the students' design ideas, processes, and products by providing support and feedback during the presentations. He also summarized central knowledge presented by the students, as well as invited others to participate in evaluation and reflection. Towards the end of the project, the students were better able to articulate their ideas, justify their solutions, and evaluate their own and each other's projects, both verbally and visually.

The results of Publication II revealed the focal role of the designer's facilitation in the lamp designing process; his support of the students was essential throughout the process. Identification of the three foci (Design Rationale, Design Practices, Design Community) illustrated the various facets of the process, which each required differing facilitation activities from the designer. The results indicated that elementary students needed support in understanding the rationale directing the design practice, in actually engaging in these practices, and in reflection and sharing of design knowledge within their design community. Moreover, the analysis revealed that the main activity during the lamp designing process was implementing design practices (59% of the total time). Thus, the following studies focused on analyzing this activity further.

6.3 Design expert's participation in elementary students' collaborative design process

(Publication III)

Publication III explored the social and material facilitation provided by the designer during student teams' practical work, in order to provide insights into how disciplinary expertise might be infused into design learning. The video events selected and segmented for Publication II were used as a data source also in Publication III. Obstacles faced by the students were also identified in order to underpin analysis of the designer's facilitation activities. In addition, the teacher-student and teacher-designer episodes were included in the analysis in order to examine the teacher's role in the process. Furthermore, the contents and use of the KF "Lamp Designing" view was analyzed in order to explore the role of the networked learning environment.

As described above, implementing design practices was the focal activity during the lamp designing process; while working in small teams, the students created and elaborated their design ideas, as well as experimented and tested these by sketching, drawing, and building models or prototypes. In the analysis, four obstacles and four facilitation activities were identified; further, each of the facilitation activities included several specific facilitation strategies.

First, the students had difficulties in identifying meaningful patterns in the complex and open-ended design task, and the designer provided structure by focusing students' attention on the user needs, and by identifying the design constraints together with the students. Second, it was challenging for the students to externalize (verbally and visually) and envision their design ideas. The designer supported students by providing professional terms for describing ideas as well as tools and materials for visualizing the ideas, and by demonstrating how to use sketches and various artifacts for visualization. Third, elaboration of the ideas was difficult for the students, because of their lack of knowledge of what was possible, relevant, and productive. The designer facilitated idea elaboration by focusing students' attention on details that needed elaboration, by providing domain knowledge, language, and tools to support elaboration, and by modeling alternative solutions. Fourth, the students lacked knowledge of the basic representation techniques of designing and the skills to use them as tools for developing design ideas. The designer supported the use of these techniques by guiding the students to use real measurements while sketching or prototyping, by providing tools and materials for drawing and prototyping, and by providing hands-on support for handling the tools and materials.

In addition to the obstacles faced by the students and the designer's facilitation activities, the teacher's role and the use of KF were analyzed in Publication III. However, these were described at a general level, in order to provide an overall view of the lamp designing process. The teacher's role was to act as an organizer, as a support for the designer and the students, and as a KF expert. She provided her knowledge and experience of the students, their learning processes,

the classroom practices, and school resources. The KF database was mainly used for storing and sharing designs, rather than as a genuine discursive knowledge building environment. Nevertheless, the shared view (the teacher's computer screen shared through a data projector) was used throughout the process, for promoting the collective design knowing of the class.

To summarize, Publication III deepened and complemented the analysis carried out in Publication II by examining the designer's facilitation activities at a more detailed level in the main phase of the lamp designing process. In addition, Publication III provided an overview of the roles of the teacher and the networked learning environment. However, the analyses in Publication II and III provided only a partial view of the students' processes and, therefore, an in-depth analysis on these was the focus in the last sub-study of the present dissertation.

6.4 Design thinking in elementary students' collaborative lamp designing process *(Publication IV)*

The aim of Publication IV was to explore the multimodal nature of elementary students' design thinking. As a systematic examination was the target of the study, the entire lamp designing process of a single student team was selected for analysis. The selection included the peer collaboration episodes of the team, as well as the episodes in which students interacted with the designer, all of which were unfolded through a three-level analysis method (Ash, 2007). The final level of the analysis was a structured, micro-level examination of the students' verbal statements and their use of tools, materials and gestures. In the study, CORDTRA diagrams (Hmelo-Silver, 2003; Hmelo-Silver et al., 2008; 2009a; 2009b; 2011) were created, enabling the juxtaposition of the collaborative design discourse with the use of materially mediated and embodied activities, all in chronological order.

The analysis revealed that the team's discussion was mainly related to the visual or technical aspects of their design, to the design constraints limiting the problem space, or to the design representations they produced. In the early stages of the process, when the team was generating their first design ideas, as well as choosing and elaborating their final idea, the visual aspects of the ideas dominated the discussion. As the team progressed to a more detailed level of designing, the technical aspects began to govern their interaction. Towards the end of the project, the team's various design representations became increasingly central to their discussion.

To support their idea generation and communication, the team used hand gestures and various tools, such as sketching and measuring tools, and the shared view. The embodied dimensions of their thinking, i.e. handling of tools and materials and using dimensions of body and space, became more evident as the designing progressed, facilitating the students in the type of knowledge-creation not apparent in the earlier phases of the process. Issues that had been too challenging for the students to manage through discourse and sketching were solved by building and handling the physical lamp model.

The results of Publication IV revealed that, when provided with sufficient social, material, and embodied facilitation, the students were able to perform many genuine design activities that simulate professional design work. They were able to solve an authentic and challenging design task by creating several design ideas, elaborating many of these further, and by considering both visual and technical features, as well as the constraints related to the ideas. External representations (sketches, drawings, models) were used for illustrative and communicative purposes, and as tools for developing the design ideas both horizontally and vertically. Equal participation and the emergence of a shared design idea were essential for the progress and the success of the process. Further, engaging in embodied activities facilitated the students' advance into innovative, real-time design thinking processes that were otherwise beyond their capabilities. To summarize, the results indicate that knowledge-creation in the context of design learning relies heavily on socially and materially mediated, as well as embodied dimensions of thinking and acting.

Publication IV also aimed at developing and applying new methods for analyzing longitudinal, complex, and iterative design process in a structured and detailed manner. The CORDTRA diagrams provided the means to capture both the details and the overall context of the process. Furthermore, the diagrams enabled the examination of verbal discourse simultaneously with material and embodied activities, which is essential when studying a multimodal activity, such as design learning.

6.5 Summary of the findings

The general objective of the present study was to examine how design learning could be promoted at the elementary level of education. This objective was two-fold; on one hand, the present study investigated the nature of students' collaborative design learning processes, and on the other hand, the facilitation of these processes. Further, the study explored the role of social, material, and embodied dimensions of designing in the learning processes as well as in their facilitation.

In the present study, designing was regarded as a form of knowledge-creation, and the Learning by Collaborative Design (LCD) approach was, for the first time, applied at the elementary level of education. Thus, previous research could only provide certain hints of the success or failure of this type of approach. The main finding of the present study, therefore, was that when provided with adequate and appropriate support, *elementary students are able to engage in and learn creative knowledge-creation exemplified by collaborative designing*. In what follows, the nature of the students' knowledge-creation and design processes, as well as the elements of facilitation that promoted the processes, will be summarized. In addition, the nature of the design knowledge generated and used by the students will be discussed in light of the findings, although a systematic analysis or assessment of the knowledge is not within the scope of the present study. The summary is structured in accordance to the LCD approach (see Figure 1, p. 6) and the three distinctive foci of the participants' activity (i.e. design rationale, design practices, and design community) identified in the present study.

An *authentic design task* situated in a *meaningful context* was the foundation of the whole design process, providing the **rationale for students' designing**. For professional designers, the task and its context are usually presented in a design brief provided by a client; the design brief is, therefore, a critical part of the process. In schools, the context and the task can be found, for example, from current issues in school subjects other than design, from students' interests outside school, or from connections to expert communities. A design brief could be formulated by the teacher or composed together with the students in order to make the design learning process more authentic. In the present study, the idea of lamp designing originated from the previous phases of the Artifact Project, where the students had studied, for example, the history and function of lamps, light, and electricity, and visited museums and workshops. The studies were stored and developed in the project's KF database; the designer was consequently able to refer to them while laying the groundwork for the students' design work in his presentations on various issues related to lamp designing. This enabled the students to participate in creating the context for designing, which helped them to understand the meaning of the activities in which they were engaging. Their previous investigations also enabled them to rely on the first principles (cf. Cross, 2006; 2011) behind lamp designing, such as issues related to the dispersion of light or supply of electricity. Furthermore, defining the larger context for lamp designing simulated professional designers' practices of framing (cf. Schön, 1983) and taking a systems approach (cf. Cross, 2006; 2011), which are essential in creating a novel viewpoint of a design problem. Naturally, the students were not expected to create novel ideas in a historical sense, but to create ideas and knowledge that were new to them and to their classroom community and, thus, to transform their understanding of the designed world.

The context was further defined and the design task grounded through students' evaluations of existing lamps. In a whole class discussion guided by the designer, the relevant factors of the evaluation were mapped out, i.e. the students were led to consider the *design constraints* determining the design task. Many learning scientists agree that the most effective learning environments are highly constrained, while still allowing the students to engage in authentic practices (Sawyer, 2012). In the present study, the students had an active role in defining the design task and related constraints together with the designer. Making the constraints explicit through discussion and the students' own investigations helped them to see structure in the complex and open-ended task, and to focus their attention to the relevant aspects, such as user needs, of the design problem space. Moreover, it supported them in moving beyond their familiar patterns and in carrying out multidimensional (i.e. visual and technical, vertical and horizontal) reflection of the design ideas.

The knowledge that the students used and created while defining the rationale for their design work was mainly descriptive in nature (cf. Glaser, 1990). It consisted of knowing various features and functions of lamps and their usage, including both historical and

present-day perspectives. This knowledge was based on the students' inquiries in the earlier phases of the Artifact Project, and was further refined with the knowledge provided by the designer. The first steps towards creating students' working knowledge (cf. Baird, 2004) were also taken. The students were, on one hand, led to consider how to determine the criteria for evaluating existing lamps, and, on the other hand, how to use this new knowledge to constrain the design problem space and to give structure to the design problem. In other words, they learned how to transform their descriptive knowledge of the features and functions of lamps into a more dynamic working knowledge of the process of designing new lamps.

The design context, the task, and related constraints were further specified, and more working knowledge was generated throughout the students' practical team work. The **design practices** were implemented by *creating and elaborating the design ideas*, as well as *experimenting and testing the ideas* through sketching, drawing, and prototyping, i.e. by simulating many practices of professional designing. The results of the present study indicate that competence in design develops through interaction on several connected levels: between humans; between humans and tools, materials, and the surrounding space; and between body and mind. Communicating with each other and with the designer, with and through tools, materials, and design representations, and using dimensions of body and space enabled the emergence and constant improvement of a shared design idea. This, however, required careful facilitation; students needed support at all levels of interaction and in moving between levels. They needed to learn, for example, how to collaborate constructively, how to use the tools and materials, or how to produce and use design representations for storing, developing, and communicating ideas. Making the various design practices, tools, and terms explicit and available was essential for the students to be able to use them and to understand their purpose. Furthermore, the results of the present study are in line with other recent studies of design education (for a review, see Williams, 2013), which indicate that even young students are able to create functional designs while developing practical design skills. The students participating in the present study were 10–12 years old and had never before engaged in a design process. Nevertheless, they produced creative and practical lamp designs while still learning the basic skills of designing.

During their practical team work, the students had to learn, employ, and create a vast amount of working knowledge (cf. Baird, 2004), which in many cases was tacit (Polanyi, 1969) or informal (Bereiter & Scardamalia, 1993) in nature. Through iterative cycles of personal and joint experience, and through socially and materially mediated as well as embodied knowledge practices, the students learned how to produce sketches, drawings, and models that bore their working knowledge. Further, they learned how to use these design artifacts for creating, developing, and communicating their design ideas. While learning the basic skills of designing and working with materials, students were also generating new knowledge of how to do designing (cf. Vincenti, 1990). Their impressionistic and self-regulatory elements of knowledge were evolving; they, for example, were better able to make their own design decisions and organize their work (cf. Bereiter & Scardamalia, 1993).

Many challenging issues needed to be dealt with during the lamp designing process. Therefore, the students were encouraged to *distribute* their *expertise* and to *evaluate the design ideas, process, and products*. Besides distributing and evaluating within the teams, the students were regularly asked to give presentations to support interaction between teams, and in order to create a **design community** within the classroom. This also simulated the professional designers' practice of presenting their ideas to clients; likewise, the students presented their ideas and justified their decisions both verbally and visually through their sketches and models. In addition to practicing the concrete skills of presenting and providing constructive criticism, the purpose of the presentations was to support collective sharing and advancement of design knowledge. This was also supported through the use of KF and the shared view; throughout the project technology had a critical mediating role in creating, improving, documenting, and sharing knowledge within the classroom community. The sum of students' descriptive and working knowledge acquired so far was used to collectively generate the new knowledge that learning how to design requires. The designer's facilitation during the presentations was particularly aimed at providing support for joint idea improvement, and for respect and value for the students' contributions and diversity of expertise. Hence, the resulting classroom community represented a community of learners (cf. Bielaczyc, Kapur, & Collins, 2013) where

deep disciplinary understanding of both the subject matter and ways of working with knowledge was fostered on both individual and collective levels. Furthermore, this resembled a community of practice (cf. Wenger, 1998), where students were learning the professional designer's tacit knowledge, practices, and skills, as well as the values and identity he modeled for them. The students were growing up in and becoming socialized to the culture of designing, as well as developing their understanding of the designed world.

To conclude, the results of the present study indicate that the pedagogical LCD approach structured and supported the elementary students' design and knowledge-creation processes in many ways. When provided with lengthy periods of time and adequate facilitation, young students were able to engage in and learn all the essential elements of designing illustrated in the LCD model, simulating many professional design activities. The nature of the students' lamp designing process can be characterized as an iterative, object-oriented, and in-depth process of knowledge-creation, where the socially and materially mediated and embodied dimensions of thinking, interacting, and meaning making were essential. Furthermore, the three foci of participants' activity identified in the present study portray the complex and multifaceted nature of the design process: In order to engage in genuine design inquiry, students need support in understanding the rationale directing the design practice, in actually engaging in these practices, and in the reflection on and sharing of their emerging design knowledge. In real classroom settings, the three foci are to a great extent overlapping and interwoven. However, awareness of these foci might help appreciate and best exploit both the complexity of the design process and the diversity of students' expertise. The design knowledge generated and used by the students can be roughly defined in three categories according to the three foci. While defining the design rationale, the students' knowledge was mainly descriptive (cf. Glaser, 1990) of the features and functions of lamps. During the implementation of design practices, the development of students' working knowledge (cf. Baird, 2004) was facilitated in order for them to learn how to do design at the practical, material level, and to use their design artifacts as representations of their knowledge. The working knowledge generated and used included many tacit and informal aspects, as well as some impressionistic and self-regulatory features (cf. Bereiter & Scardamalia, 1993; Polanyi, 1969). While creating the design community, the descriptive and working knowledge of the whole class was deliberately drawn together, in order to collectively learn how to generate the new knowledge that practicing design requires. Like the three foci, the categories of knowledge are neither discrete nor unconnected, but rather provide a framework for understanding the variety of knowledge needed in design learning.

7 General discussion

The present study investigated a case of elementary students' design learning, where designing was considered a form of knowledge-creation, and where the LCD approach was applied. In the following, the limitations of the study will be discussed, and four pedagogical implications supported by the findings will be presented. Further, suggestions for future studies will be provided.

7.1 Limitations of the study

The present study examined creative knowledge-creation exemplified by collaborative designing at the elementary level of education. The results indicate, that (i) elementary students are able to engage in and learn creative knowledge-creation and design processes, and (ii) the processes can be structured and supported with the pedagogical LCD approach. Since design education in general, and LCD in particular, are newcomers in education and educational research, the present study can, however, provide only a tentative drafting of how design learning could be implemented and promoted in elementary education. Further, the present study provided evidence that the LCD approach worked well in the particular case of lamp designing. Due to the qualitative nature of the analyses conducted, the study does not, however, prove that the approach can always be successfully applied in elementary education. There is a need for more quantitative research in order to form greater insight into the generalizability of the outcomes.

The data source of the present study was the longitudinal and multifaceted Artifact Project, during which large quantities of various types of data were collected. Only parts of the project and data were within the scope of the present study; however, the selections of what and how to study were made systematically and in accordance with the research questions through several iterative cycles of research. Video data from the lamp designing phase constituted the main data source of the present study, in addition, selected views from the project's database were analyzed. Due to limited resources, only one video camera with one external microphone, and one person (the present researcher) operating them were present in the classroom. Overall decisions of what and how to film were made in advance, but in complex real-world settings, such as the classroom, some quick decisions had to be made in situ. In a few instances this resulted in situations where the most interesting activities were happening beyond the camera's reach, or sound quality was insufficient for the analysis. However, the overall quality of the video data was good, providing a rich data source not only for the present study, but for other studies as well. The parallel dissertation concerning teacher guidance in the Artifact Project (Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010; Viilo, Seitamaa-Hakkarainen, & Hakkarainen, 2011; 2012; submitted) included data that was not used in the present study (i.e. teacher diaries, and residual video and database material), but the analysis of this data provided additional information for the present study as well. Moreover, in the year following the Artifact Project the same students and the designer participated in another project, concerning architectural designing (Seitamaa-Hakkarainen, Kangas, Raunio & Hakkarainen, 2012a; Seitamaa-Hakkarainen, Kangas, Raunio & Viilo, 2012b), in which the LCD approach was again implemented. The Architecture Project was largely informed by the implementation and analyses of the Artifact Project, and provided further indication of the feasibility of the LCD approach.

Methodologically, the present study represents design-based research. Even though this approach has become widely accepted in educational research, there are certain challenges that still need to be addressed. Because design-based research is set in complex real-world settings, there are many variables that cannot be controlled; the enacted design is usually quite different from the intended design. Yet there is a need to observe carefully and analyze systematically the interdependence of the elements of a design (Collins, Joseph, & Bielaczyc, 2004). Another challenge is related to the desired learning gains; how is it possible to define what counts as success or evidence of the development of complex cultural practices that may take several years to become fully articulated (Hakkarainen, 2009b; Muukkonen & Lakkala, 2009)? Throughout the Artifact Project, it appeared that the students' learning processes were exceptionally deep and wide-ranging. For example, topics from 7th grade physics were covered in the 5th grade. Furthermore, the students seemed to develop a strong

sense of identity and agency, which enabled them to see themselves as capable of improving ideas and creating knowledge, instead of merely assimilating textbook knowledge. However, the present study could only provide indirect information of such development and its transferability.

There is also a methodological concern that design-based research lacks an argumentative grammar, "the logic that guides the use of a method and that supports reasoning about its data" (Kelly, 2004, p. 118). To address this challenge, Sandoval (2014) suggests a technique for distinguishing and mapping *design conjectures* (i.e. how a design functions) and *theoretical conjectures* (i.e. how those functions produce learning), in order to specify explicitly and concretely the commitments of design-based research. These two types of conjectures are related to the basic two-fold objective of design-based research: the simultaneous commitment to educational change and theoretical development. Mapping the conjectures facilitates systematic consideration of high level presumptions, implementation, mediating processes, and expected outcomes of a design-based research endeavor, focusing attention on the elements and functions that need to be studied (Sandoval, 2014). The iterative pursuit of a series of refined design research studies might produce principled, practical knowledge about implementing genuine knowledge-creation and design practices in education by revising initial designs on the basis of experiences.

In designing, the social, material and embodied dimensions of activity have a central role. Teamwork, group interaction, collaboration, and other aspects of the social dimension have been intensively studied both in research on professional designing as well as in the learning sciences. Further, sketching and drawing have been studied in both areas. The role of material exploration and experimentation has not, however, received much research attention. Visualizations and sketches are used to plan the work, but they are altered during the process, by the choice of materials and tools related for the specific context (Mäkelä & Nimkulrat, 2011; Kosonen & Mäkelä, 2012). This involves parallel working through conceptual reflection and material experimentation and implementation (Ramduny-Ellis et al., 2010; Seitamaa-Hakkarainen et al., 2012a). Although the theoretical and conceptual work on embodied cognition is sophisticated, there is still little empirical research applying these to documented design practices, where concrete dimensions of embodied knowing apparently play a crucial role.

In the present study, new kinds of methods for analyzing material mediation and embodiment needed to be applied and tested. CORDTRA diagrams provided the means to relate discourse interaction with materially mediated and embodied dimensions of design learning, thereby supporting chronological analysis beyond coding individual speech acts. However, as this was the first attempt to use the CORDTRA method in the context of design learning, the analysis of embodied dimensions of designing in particular remained rather cursory. As in previous studies, which used the method for analyzing video data (e.g. Hmelo-Silver, 2003; Puntambekar, Stylianou, & Goldstein, 2008), the unit of analysis was a verbal statement, thus employing verbal discourse as the basis for understanding interaction (see Streeck et al., 2011). However, in the lamp designing process much activity was carried out in the absence of discourse, and the analysis could only provide hints of the materially mediated and embodied dimensions of designing and knowledge-creation. A new possibility for investigating these issues is the multidisciplinary research project *Handling Mind* (http://blogs.helsinki.fi/handling-mind/), which aims to develop and test neuroscientific research methods for studying creative embodied processes and skill learning in the field of design research (for initial results, see Groth, Mäkelä, Seitamaa-Hakkarainen, & Kosonen, 2014; Seitamaa-Hakkarainen, Huotilainen, Mäkelä, Groth, & Hakkarainen, 2014). In the project, for example, the role of motoric training on skill learning process and its neural basis is studied through the examination of brain responses. The Handling Mind research project is situated in the higher education context, but most likely it will also provide new directions for studying design learning at lower levels of education.

7.2 Implications of the study

In the present study, design learning is regarded as an object-oriented process of knowledge-creation (cf. Paavola et al., 2004; Hakkarainen, 2009a; 2009b), where the participants organize their activities

around continuous and deliberate advancement of knowledge artifacts that embody their ideas. Creating knowledge is seen as a fundamental future competence; productive participation in the emerging innovation-driven knowledge-creation society will require cultivation of sophisticated creative competencies by all citizens. Creativity and innovation have become the recognized hope for solving employability, personal, and societal crises at the country, organizational, and individual levels and, therefore, it has been argued that schools need to nurture creativity and innovation deliberately and systematically, across all disciplines (Schleicher, 2012). In order to prepare students to function productively in the knowledge-creation society, they have to be socialized to creative practices of working with knowledge from an early stage of their education. The practices of designing provide many possibilities for knowledge-creation, since they, from their very premise, aim to create something new. Further, since the objects and effects of design are daily apparent all around us, engaging in and comprehending design processes provides a means of developing a deep understanding of the less tangible issues affecting us humans and the world we inhabit.

New curricula that are coming to Finnish schools strongly emphasize both the integration of school subjects and the use of investigative methods for socializing students to productive and creative use of knowledge. Pedagogical models are needed that will guide and structure teachers' personal and collaborative efforts to implement knowledge-creation practices at school. The findings of the present study indicate that the pedagogical LCD approach provides a fruitful basis and a functional structure for developing and implementing knowledge-creation practices in the context of design learning in elementary education. LCD emphasizes participants' creative thinking by engaging them in collaborative generation, externalization, visualization, and prototyping of ideas so as to create innovative and functional designs. Further, it promotes integrating design with various school subjects, such as science. Designing aims to develop one's ability to see possibilities, to experiment with new ideas by sketching and prototyping, to make leaps of imagination as well as to systematically analyze, generalize, and synthesize observations.

Previous research on design learning has identified several issues considered important to the practice of design education; four of these pedagogical implications are also supported by the findings of the present study. First, **creative knowledge-creation and design processes evolve through extended periods of time**. The Artifact Project spanned three school terms (i.e. 13 months) of which the lamp designing phase took ten weeks. Further, the students were able to work on the project for several consecutive lessons or even a whole school day. Conventional school projects rarely give students the opportunity to spend several weeks or months on a complex project; thus, most students have little experience of authentic designing, that is, planning, problem solving, investigating, experimenting and testing, dealing with constraints, elaborating ideas, and bringing everything together into one project (Kafai, 1996). For example, Buechley and her colleagues (Buechley, Eisenberg, & Elumeze, 2007; Buechley, Eisenberg, Catchen, & Crockett, 2008) have conducted a series of studies in which students participate in workshops or courses for designing, constructing, and programming wearable computers (i.e. e-textiles). Based on their own experiences and on the students' feedback, the research team proposed that the course schedule should allow for meeting times of at least 90 minutes each and should provide at least 20 hours of total class time (Buechley et al., 2007). Naturally, this is a recommendation, and the time needed depends, for example, on the nature of the project and on the ages of the participants. However, studies by Buechley and colleagues (2007; 2008) as well as several other studies concerning design learning (for review, see Williams, 2013) are in line with the results of the present study, indicating that creative processes are difficult to realize within specific pre-determined time frames, and longer periods of time are needed to facilitate genuine knowledge-creation and designing.

Second, **design is inherently interdisciplinary and calls for not only design knowledge, but also knowledge of science and the humanities.** Designing is about modifying the natural world to better meet human wants and needs and, therefore, the design process is informed by both science, which deals and seeks an understanding of the natural world, and the humanities, which study human culture and the social world. Since design is all pervasive, its objects all around us, and its effects daily apparent, it provides a fruitful ground for integrating school subjects in a way that facilitates deep learning. The Artifact Project integrated several school subjects, such as history,

science, Finnish, art, and design, which enabled the students to approach the issues under study from various viewpoints. During lamp designing, they were able to consider, for example, the physical principles and user needs related to their design ideas.

Around the world, efforts to integrate design with various school subjects have emerged within the last two decades. For example, educators concerned with students' disengagement from STEM (science, technology, engineering, mathematics) subjects have started to realize the need to integrate art and design into the curriculum as well; the abbreviation STEAM (see e.g. http://stemtosteam.org) is beginning to replace STEM. STEAM integrates and uses the arts in the STEM curriculum to help students express their understanding of STEM concepts in creative and innovative ways. Design is seen as the core problem solving process where the concern lies beyond the usability (i.e. technological design) and aesthetics (i.e. artistic design) of a product or a system. Experience is essential; the primary interest in designing is in human experience, instead of technology or aesthetics as such (see, e.g. Battarbee & Koskinen, 2005). Furthermore, the arts encourage imagination in addition to creativity, which is key to novel innovations. As argued by John Seely Brown (Chaplin, 2014): "Once I imagine something new, then answering how to get from here to there involves steps of creativity. So I can be creative in solving today's problems, but if I can't imagine something new, than I'm stuck in the current situation."

Integrating design with other subjects is, however, not unproblematic. Work-related studies have shown that, over the past decade, designing has gained increasing attention in a wide range of contexts beyond the traditional fields of designers, for example, in business, medicine, and IT (Dorst, 2011; Kimbell, 2011, Stewart, 2011). The designerly ways of problem solving are seen as valuable for firms and organizations trying to innovate or effect change. Nevertheless, several recent studies (e.g. Cross, 2010; Dorst, 2011; Kimbell, 2011; Tonkinwise, 2011) underline how these popular accounts of designing ignore the extensive research conducted by design researchers. Kimbell (2011) noted that, today, designing is most often related to the challenges facing organizations, especially businesses, and expressed concerns with design's place in the world, if its larger social and political contexts are lost. She identified three alarming issues in the popularized accounts of designing: common reliance on a dualism between thinking and doing; the idea of a generalized design thinking, which ignores the diversity of designers' practices and their historical situatedness; and resting on theories that entitle the designer as the main agent in designing. Especially issues one and three apply also to educational contexts, as will be elaborated in the following chapters.

Third, **design competence develops through several connected levels – social, material, and embodied – of thinking, interacting, and meaning making**. Authentic design tasks are challenging and require distribution of expertise in various ways: between humans; between humans, tools, materials, and the surrounding space; and between mind and body. Further, designing requires the generation and use of various kinds of knowledge in order to know, on one hand, how to do design, and, on the other hand, how to generate the new knowledge that such doing requires. Much design knowledge is tacit (Polanyi, 1969) and informal (Bereiter & Scardamalia, 1993) in nature, and therefore, it is non-transferable and can only be learned through personal and joint experience and experimentation that engages both bodies and minds (Thomas & Brown, 2011). This type of knowledge is intertwined with the objects and practices of the physical world; through them it can also be made visible and accessible. Sophisticated instruments and practices of generating and using knowledge help young students to expand their intellectual resources in a way that makes the pursuit of knowledge creation feasible (Ritella & Hakkarainen, 2012). Using sophisticated instruments for creating artifacts enhances thinking through doing and elicits the gradual emergence of the "thing knowledge" that is critical in the creative application of knowledge (Baird, 2004). During the lamp designing process, the co-evolution of conceptual, material, practice-related, and physically embodied artifacts and activities was essential for the advancement of students' design ideas. Moreover, the present study provided tentative indications that the artifacts created and practices enacted changed the environment of participants' activity in a way that made the pursuit of more demanding objects accessible for subsequent activity (see Hakkarainen, 2009b).

The pedagogical LCD approach underlines iterative cycles of activity, as well as the socially and materially distributed nature of design knowledge. However, the approach could be developed further

by acknowledging more strongly the embodied dimensions of designing, i.e. the interaction between mind and body. Such efforts are, in fact, under way in the Handling Mind research project (see chapter 7.1, p. 68), where new methods to study creative embodied processes are being developed and tested.

Fourth, **collective and participatory learning facilitates designing and knowledge-creation**. During the lamp designing process, collective learning was supported in various ways. Firstly, the students generated their designs through peer collaboration in small teams and, secondly, the shared design knowledge of the classroom community was developed and distributed through presentations and the database. The class included several students with various learning difficulties, and the teams intentionally comprised students with varying levels of ability. According to Page (2007), diversity overcomes ability; a group consisting of heterogeneous but competent participants can solve complex and open-ended problems systematically more effectively than a group consisting of only the most intelligent persons. Since the "best" tend to resemble one another, they may lack the diversity of perspectives, interpretations, heuristics, models, and identities, i.e. the ability to think differently.

In addition to valuing diversity among the students, creative contributions during the lamp designing process were promoted by adopting the practices and tools of professional designing. The findings of the present study are in line with previous studies that indicate that boundary-breaking between school work and professional work significantly supports students' activities and deep learning. Such long-term, continuous, face-to-face interaction between the designer and the students, such as that which took place during the lamp designing process, is, of course, exceptional and demanding of resources. However, previous research in this area has illustrated other means to support partnerships between students and experts. For example, studies have reported projects where students have worked with scientists in their laboratories (e.g. Barab & Hay, 2001; Bell, Blair, Crawford, & Lederman, 2003; Charney et al., 2007; Hsu & Roth, 2009), professionals have visited single lessons (Jurow, Hall, & Ma, 2008), or experts have provided online feedback and support (Lahti, 2008; O'Neill, & Polman, 2004).

All the four pedagogical implications described above link up with the *maker movement* or *maker culture*, which is an emerging global movement underlining innovation and learning through social making (e.g. Anderson, 2012; Sharples et al., 2013). Maker culture has been listed in the TOP-10 phenomena that will profoundly change education in the next ten years (Sharples et al., 2013), and, moreover, it has been called the new industrial revolution that will bring about broad social and economic changes through an ideological shift in the design and production of artifacts (Anderson, 2012). The maker movement highlights shared social ideation and DIY, do-it-yourself ethos in construction of various artifacts ranging from robots and 3D-printed models to clothing and more traditional crafts.

Two factors have been associated with the emergence of maker culture: 1) the rapid evolution of networking technologies, and 2) the recent proliferation of affordable computing hardware, available open-source software, and rapid prototyping technologies, such as 3D printers and laser cutters (e.g. Anderson, 2012; Sharples et al., 2013). Proponents of the maker movement argue that the recent developments in networking technologies and hardware have enabled wider dissemination and sharing of ideas; moreover, they dissociate the maker culture from more traditional construction-centered hobby pursuits (Sharples et al., 2013). Maker culture "encompasses not only the process of creating specific objects, but also the social and learning cultures surrounding their construction" (ibid., p. 33).

Participation and collaboration are seen as the cornerstones of maker culture, whether these occur face-to-face or through networked technologies. It has even been argued, that making *is* connecting, meaning that through making things people engage with the world and eventually change it (Gauntlett, 2011). *Makerspaces* (i.e. workshop spaces equipped for maker groups), for example, *FabLabs* (Gershenfeld, 2005; Walter-Herrmann & Büching, 2013; see also Anderson, 2012), informal gatherings (e.g. knitting cafes), organized events, such as *Maker Faires* (see http://makerfaire.com/), and online spaces (e.g. wikis, social media) enable sharing and the collective creation of ideas and artifacts. The origins of the maker movement can be traced to the launch of the MAKE magazine (http://makezine.com/) in 2005, and to the first Maker Faire held in San Francisco in 2006. In Finland, a large-scale Maker Faire, *WÄRK:fest* (http://www.warkfest.org/en/), was for the first time organized in 2012 and sparked considerable interest within the Finnish maker community.

7.3 Suggestions for further studies

The present study has provided the first conclusions of how to promote design learning and knowledge-creation at the elementary level of education, and how these processes could be structured with the pedagogical LCD approach. In the future, more research is needed that, beyond showing that young students are able to productively participate in creative knowledge-creation exemplified by collaborative designing, provides evidence that such activities will lead to measurable advancement in depth of understanding of the design inquiry process, mastery of associated methods and practices, intellectual engagement as well as an enhanced sense of being able to contribute to collective knowledge-creation efforts. As the present study provided some general information about the types of knowledge that elementary students are able to generate and use while designing, further studies could more systematically analyze the nature and quality of this knowledge.

Maker culture has attracted the interest of educators in hopes of finding new pathways for making school subjects more authentic and meaningful for students. According to Sharples and colleagues (2013), maker culture applied to educational contexts represents a form of learning by doing, which might appear to echo the earlier formal apprenticeship model of learning, but instead emphasizes informal, networked, peer-led, and shared learning activities in a community of practice. It underlines experimentation, innovation, and the testing of theory through practical, self-directed tasks and production of tangible artifacts, and is seen as having the potential to contribute to a more participatory approach to learning. Many of these elements were put into practice during the Artifact Project, however, more research is needed that involves the utilization of maker technologies. Rapid prototyping tools (e.g. 3D printers, laser cutters) allow elements of a design to be easily changed and manipulated, enabling multiple iterations of testing and making models, and encouraging students to take risks in exploring novel solutions. Mistakes and failures are seen as natural parts of the process, providing opportunities for reflection and further advancement of learning.

As noted by Blikstein (2013), the ideas behind the maker culture are, in fact, at least a century old, and can be traced back to the ideas of experiential education, constructionism, and critical pedagogy underlined by John Dewey, Seymour Papert, and Paulo Freire, among others. In 2008, Blikstein created the Fablab@School project (http://fablabatschool.org/), which is a growing international network of educational digital fabrication labs providing students with a place for making, building, and sharing their creations. Blikstein (2013) has identified five principles, that are considered important when bringing maker culture and technologies to schools; most of these are also emphasized in the present study. The first principle encourages educators to push students to work on complex projects, rather than use quick demonstration projects to produce aesthetically-pleasing products with little effort. The second principle comes from "the power of despair and visceral involvement" (ibid., p. 219), since FabLabs enable multiple, iterative cycles of design, as well as levels of both frustration and excitement that are not common in school work. Third, FabLabs enable powerful inter-disciplinary projects and, fourth, they make the learning of abstract concepts highly meaningful, engaging, and contextualized. Fifth, rather than replacing students' existing and familiar practices, FabLabs encourage the conceptualizing and re-evaluation of these practices.

The origins and largely also recent embodiments of the maker movement include mostly tech-savvy tinkering with hard-surface materials, such as programming and constructing robots. However, novel materials, such as conductive fibers combined with accessible embedded computing platforms, have made it possible to explore the intersections of traditionally separated domains. *E-textiles* (i.e. electronic/computational textiles, smart textiles, or wearable computing/electronics) extend and combine the landscapes of fabric and electronic crafts, and provide also interesting new prospects for design education (Buechley et al., 2007; 2008; Buechley, Peppler, Eisenberg, & Kafai, 2013). For example, the *LilyPad Arduino* is "a fabric-based construction kit that enables novices to design and build their own soft wearables and other textile artifacts" (Buechley et al., 2008, p. 423). *OpenKnit* (http://openknit.org/) is an ongoing project developing an open-source electronic knitting machine and related software, *Knitic* (http://www.knitic.com/), for designing and making knitted items, such as clothes and accessories. Ultimately, the project aims to provide instructions for how to construct a knitting machine, including, for example, a circuit diagram and STL files (i.e. the file

format used by Stereolithography software to generate information necessary in the production of 3D models) for a 3D printer. According to the maker ethos, the project is open for anyone interested in integrating textile fabrication with digital manufacturing, i.e. "soft digital fabrication" (Varvara & Canet Sola, 2013).

Networking technologies provide a way to access unlimited informational resources, and to participate in collective knowledge-creation activities free of cost and without limitations on time and place. This has brought about the emergence of various online collectives where myriad creative activities are taking place. Online communities dealing with issues related to any topic or school subject can be found, ranging from medical forums to gaming, from Wikipedia to Ravelry (a knit and crochet community). Participation in these collectives is usually free, open sharing of ideas is strongly supported, and a diversity of expertise is highly valued. Although students' online activities are mostly social and recreational, they are important starting points for experimenting with digital media creation and self-expression; formal education could be positioned to step in and support moments when students are motivated to move from friendship-driven to more interest-driven forms of activity (Ito et al., 2008). According to Thomas and Brown (2011), online collectives represent a new culture of learning, where learning emerges from the environment and grows along with it. This kind of learning is suited for our world of constant change, because it comprises two important elements: A massive information network providing almost unlimited access and resources to learn about anything, and a constrained and structured environment that allows for unlimited agency to build and experiment with anything within the boundaries of that environment.

The design activities carried out in the present study represented the traditional design of material objects, where the user-centered approach was utilized to deal with problems and constraints related to lamp designing. It is becoming increasingly apparent, however, that the user-centered approach cannot address the breadth and complexity of the design challenges faced today. Simply designing products for users is rapidly evolving towards "designing for the future experiences of people, communities, and cultures who are now connected and informed in ways that were unimaginable even 10 years ago" (Sanders & Stappers, 2008, p. 10). While the traditional design disciplines focus on designing *products*, the emerging fields of design work focus on designing for a *purpose*, such as for experiencing, emotion, or sustainability. The evolving design practices will change what is being designed, how it is designed, and who is designing (Sanders & Stappers, 2008). These changes will greatly extend the boundaries of the designed world, influence our daily life more profoundly, and more strongly emphasize the significance of design learning from the early stages of education.

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