THE ARTIFACT PROJECT - HISTORY, SCIENCE AND DESIGN INQUIRY IN TECHNOLOGY ENHANCED LEARNING AT ELEMENTARY LEVEL

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The general objective of the present study was to investigate how elementary school students engage in their knowledge construction processes in computer-supported collaborative learning. We will report a longitudinal case study of a teacher's and researchers' effort to create classroom activities and social practices that support genuine participation in knowledge-creating inquiry. In this curriculum unit, 'The Artifact Project – the Past, the Present, and the Future', the students were asked to analyze artifacts within their cultural historical context, study physical phenomena related to artifacts, examine designs of prevailing artifacts, and finally to design artifacts for the future. We were interested in the nature of questions and explanations generated by the students in the course of their inquiry mediated by Knowledge Forum. While the present investigation was inspired by Marlene Scardamalia's and Carl Bereiter's knowledge building approach, it was focused on examining how pursuit of conceptual artifacts (ideas, concepts, designs, drawings) can productively be integrated with various, materially embodied "hands on" activities, such as taking photos of, drawing, exploring, analyzing, and designing material artifacts. We were, further, interested in the constructive use of students' references to offline activities and expert resources during their inquiry processes. The nature of knowledge generated diverged substantially from one phase of the study to another; a relatively larger percentage of questions and content-related notes produced during the past (history) part of the project was factual in nature in comparison with the present (science experiments) and future (design activities) parts. The results of the present study indicated that conceptual and material aspects of the participants' activities supported one another; the participants were clearly both "minds" and "hands" on throughout the project. It appears that teachers would do well to put students ideas into the centre of educational activity, and also to pursue various materially embodied activities (organizing exhibitions, analyzing and describing, and design). Generally, educators would do well to promote students' undertaking boundary-breaking processes during which connections are forged with expert communities.

Keywords: progressive inquiry, knowledge building, technology enhanced learning, epistemic level of explanation

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1. Introduction

In recent years, the new possibilities of modern web-based technologies have generated expectations of changes in education. These expectations relate to investigators' beliefs that the future knowledge society requires competencies that develop only through participation in the collaborative practices of working with knowledge (Bereiter, 2002; Hakkarainen, Palonen, Paavola, & Lehtinen, 2004). Further, Ference Marton and his colleagues (Marton & Trigwell, 2000), based on their investigations argue, that in order to prepare themselves to solve unforeseen problems, students will need experiences of independently and collectively finding solutions to relatively multi-faceted and complex problems. According to these investigators, working with a wide variety of problems can be seen as the mother of future-oriented learning: educational experiences should be marked by variability, rather than repeated cycles of working with similar procedures, in order to build transferable skills and competencies (Marton & Trigwell, 2000). These considerations suggest that students need, even at the elementary level, experiences of working with challenging tasks and knowledge objects (ideas, theories) across relatively long periods of time.

Correspondingly, Marlene Scardamalia (1999) has pointed out that educational practices are usually organized around relatively simple and discrete tasks and actions that guide and constrain the students' learning. Rather than addressing knowledge objectives of education at all, the participants' educational activity too often becomes reduced to pursuing mere completion of tasks. She proposed that a Copernican revolution is needed in education, in which knowledge objectives in general and students' ideas in particular are placed in the centre of education. In order to provide the students the opportunity to deliberately engage with knowledge objectives of learning, Bereiter and Scardamalia (1993; Scardamalia & Bereiter, 2003) have pursued ground-breaking research on technologies and pedagogies of collaborative knowledge building. Within frames of the knowledge-building approach, learning is treated as analogous to innovative processes of inquiry where new conceptual artifacts, such as ideas, questions, and theories, are communally created, and participants' initial knowledge is either substantially enriched or significantly transformed. A central aspect of knowledge building is to engage even elementary school students in creative working with knowledge through engaging in progressive discourse aimed at collectively improving the knowledge artifacts generated. It is further crucial to knowledge building that students learn to re-use the emerging knowledge for solving new problems (Bereiter 2002). Moreover, students' epistemic agency is to be fostered: their assuming cognitive responsibility for the advancement of collective knowledge, rather than merely taking care of their own learning, a characteristic of a productive knowledge building culture (Scardamalia, 2002; 2003).

The pedagogy of knowledge building, as well as the interrogative theory of inquiry (Hintikka, 1999) lay behind the "progressive-inquiry" model developed by Hakkarainen and his colleagues (1999; 2004). The progressive inquiry approach shares with the knowledge building approach an assumption that inquiry is a process mediated by shared knowledge artifacts, such as questions, explanations, plans, and ideas (Bereiter & Scardamalia, 1993). An essential characteristic of progressive inquiry is distributed expertise (Brown et al., 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 accomplish insights that one would not be able to gain 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 in progressive inquiry that students set up their own research problems and questions, and engage in joint advancement of them. Particularly important questions arise from problems in understanding and explanation and thus explanation-seeking (how and why) questions have a 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; Carey & Smith, 1995). 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).

While the present investigation is inspired by the knowledge-building approach, the present investigators are elaborating the progressive inquiry approach in the direction of understanding the fundamental role of social practices and material culture in technology-enhanced learning. Knowledge building, in its fullest sense, is not only a process of playing creatively with ideas or merely conceptual activity in nature; it defines certain social practices as well. In order to create successful inquiry culture within a classroom, we need to create local classroom practices that direct and channel the students' activities in a way that elicits in-depth inquiry. The teacher has to cultivate within his or her classroom certain innovative practices of working productively with knowledge, including with the hybrid and material artifacts involved. Such "knowledge practices", necessarily, are deeply embodied in the physical and cultural environment of learning, available tools and instruments, as well as rich material culture in general (Hakkarainen, 2003). Hakkarainen and his colleagues have argued that technology enhances meaningful learning and instruction only through transformed social practices (Hakkarainen et al., 2006). In order to genuinely elicit educational transformations, it is necessary to put social practices into the middle rather than the periphery of discussion. The social and technical aspects of technology-enhanced learning co-evolve by way of novel technological instruments providing new affordances for educational activity, and developing practices affecting directions of subsequent technology use. The practices of progressive inquiry described above appear to rely on hybridization of knowledge practices between educational and research communities through involving students in research-like practices of pursuing their own inquiries, and corresponding questions and explanations. In order to truly appropriate expert-like practices of working with knowledge, students need to have strong, reciprocal networking relations with various expert communities. Consequently, the study to be reported involved boundary-breaking processes during which students interacted with various domain experts as well as functioned under the guidance of a professional designer.

Investigations regarding creative expertise indicate that experts always function in a rich heterogeneous actor network consisting of artifacts and people (Latour, 1999). It appears to us that in order to engage in productive working with knowledge students have to, in parallel, be both "minds on" (working with ideas) and "hands on" (implementing or prototyping ideas by creating materially embodied artifacts). Many abstract principles that are difficult to learn from text become easier, more engaging, and motivating when approached through a design process (Roth, 1998). Learning by design has been used intensively in science and technology education (Harel, 1991; Roth, 1998; Kolodner 2002; Hennessy & Murphy 1999; Kafai, Franke, Ching & Shih, 1998). Empirical studies indicate that learning by design can enhance learning of complex problem solving skills and lead to better results than traditional instructional practices. Students who are themselves designing and exploring artifacts tend to have a deeper understanding of their working principles, even if they sometimes have gaps of knowledge or misconceptions. In science education, the cultural artifacts, such as oral and written language and laboratory equipment, are seen as providing a shared semiotic system for social interaction and modes of thinking (Säljö, 1999). Students' first-hand observations, experimentations, and design experiences are important parts of their scientific inquiry. The instructional setting should engage the students in authentic research-like knowledge practices, i.e., pursuing their own investigations, gathering and interpreting results, carrying out experiments, providing explanations, and communicating and negotiating about their finding with their fellow students.

Moreover, designing objects is an active, distributed, and socio-culturally mediated process of meaning making (Cole, 1996; Wertsch, 1998). Research on social creativity suggests that the core of humans' intelligent activity is not the individual mind, but the groups of minds in interactions among one another and with tools and artifacts (Fisher et al., 2005; John-Steiner, 2000). Experiences of collaborative designing appear to cultivate both participants' creativity and the agency required for adventuring with one's fellow inquirers in elaboration of exciting design ideas (Seitamaa-Hakkarainen, Lahti & Hakkarainen, 2005). It appears essential to provide students with experiences in solving complex design tasks throughout education, tasks that engage them in iterative improvement of their ideas and the artifacts embodying them. Designing has conceptual and material aspects: It is not only focused on developing the participants' ideas through taking part in knowledge-seeking inquiries, but also has a practical component, creating design prototypes and material products. The efforts of the participants are organized toward developing shared design ideas (conceptual artifacts), embodying and explicating those ideas in visual sketches (graphic artifacts or inscriptions), and giving the ideas a material form as prototypes or end results (e.g., mass produced products). The process involves interaction with users whose needs and desires form constraints on the design process. The design process appears from the beginning to the end to be mediated by the shared artifacts being designed.

2. Research Aims

The purpose of the present exploratory study was to report the efforts of an elementary-school teacher and researchers to promote genuine knowledge building inquiry at the 4th and 5th grade of a Finnish elementary school. 'The Project of Artifacts – the Past, the Present and the Future' engaged students in collaborative inquiry and design across 13 months (almost three semesters). The project contributed to developing an understanding of Finnish culture, and the role and diversity of artifacts as a part of it. The technical infrastructure of the project was provided by Knowledge Forum, a networked learning environment providing sophisticated tools especially for building and visually organizing knowledge. The project integrated many school subjects, i.e. history, mother tongue, science, design and technology education, and thus, the students worked with a wide variety of knowledge objects, including hybrid artifacts, and experienced various phenomena related to artifacts. The general objective of the study was to investigate how elementary school students engage in their practical, knowledge construction processes in computer-supported collaborative learning. The study was focused on examining the general nature of the students' inquiry across history, science, and design related activities. It was, further, addressed to the nature of questions and explanations that the students provided on their notes in Knowledge Forum. We were interested in the nature of their knowledge-seeking questions. Another important aspect of inquiry is the generation of ones' own explanations, and the search for scientific information. Thus, we wanted to look into what kind of explanations the students generated for the phenomena under investigation. Moreover, we were interested in how different kinds of knowledge (historical, scientific and design knowledge) proceeded and accumulated during the Artifact project, and how students used expert resources.

Expert-like knowledge practices were facilitated in the present project in terms of creating a rich learning environment consisting in a technology-enhanced learning environment, a wide variety of classroom activities, as well as networking connections with expert communities outside of the educational institution in question. In order to examine how elements of the actor-network created supported one another, the present investigators analyzed how students referred to offline activities, material artifacts, and expert resources during their knowledge-creation processes. In the present study, we addressed the following specific questions:

(1) What kind of problems and questions did the students present during the project? What was the epistemic nature of students' questions?

(2) What kind of explanations did the students generate during the project? What were the epistemic levels of their explanations?

(3) What kind of material and conceptual artifacts did the students create and use during the project?

(4) What kinds of inquiry activities were pursued during the process? How did the students incorporate empirical data into knowledge building, and how did they use expert knowledge resources in their online discourses?

3. Method

3.1. *Participants and the setting of the study*

The present study is a part of a larger research project concerning computer-supported collaborative learning at the elementary level of education. 'The Artifact project' was designed together with the class teacher Marianne Bollström-Huttunen, and it took place in her classroom in Laajasalo Elementary School, Helsinki, Finland, in years 2003-2004. The school is located in a middle-class suburb of Helsinki. 32 students (13 boys and 19 girls) participated in the project; out of these, 7 students had linguistic or other educational problems. The project started at the beginning of their second term of fourth grade and continued over 13 months until the end of their fifth grade. Marianne has been very committed to developing the pedagogy of progressive inquiry (PI), and she has extensive experience as an elementary school teacher. Thus the students were familiar with the PI-model before starting the project.

The teacher and the researchers planned the general theme of the project - Past, Present and Future of the Artifacts. We also agreed to put the emphasis on PI and integration of various school subjects. Furthermore, our aim was to break boundaries of traditional schoolwork by supporting student-expert partnership by way of involving experts, such as museum staff, craftsmen, and designers in the students' collaborative inquiry. The actual project plan emerged through interaction between the organizers and students own' efforts, without strict pre-determined plans. We wanted the students to come up with their own ideas on how to study artifacts, and to design various learning activities and field trips with the teacher.

Ten computers were available for students working in the classroom; the teacher had her own computer and a data projector. The technical infrastructure of the project was provided by Knowledge Forum (KF), the networked learning environment developed by Scardamalia and Bereiter (Scardamalia, 1999; Scardamalia & Bereiter, 2003). The core of KF is a multimedia database consisting of knowledge created and organized by the participants. By authoring *notes*, the students contribute ideas, theories, working models, reference material and so on, 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 thus-far-completed inquiry.

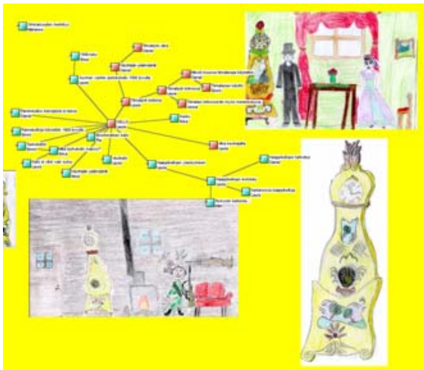
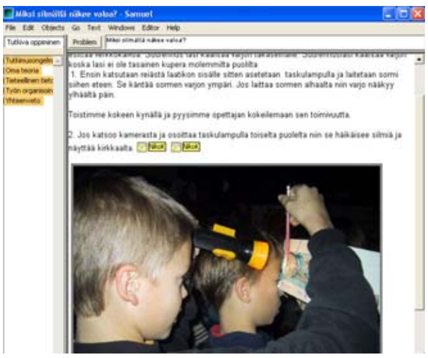
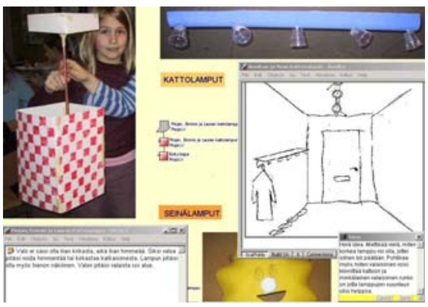
3.2. *Implementation of the Project*

The Artifact project contributed to developing an understanding of Finnish culture and the role and diversity of artifacts, and it was divided into three phases – "The Past, the Present and the Future of Artifacts". In the first phase each student team was asked to choose one item for deeper investigation, from a classification created during the project introduction. The item had to 1) be used daily, 2) have a long history, 3) be originally made by hand, and 4) be used by hand. Students chose items which most of them had used and which they found interesting: a clock, a spoon, money, a lock and a key, a piece of jewelry, a ball, and a lamp. According to students' ideas the historical aspects of the artifacts were researched by visiting the Finnish National Museum, gathering offline and online reading materials, and interviewing grandparents. At the end of the first phase, the teacher and the students organized an exhibition of the 'Past of the Artifacts' during the school's culture week.

During the second phase, the students explored the present of the artifacts by investigating the physical phenomena related to the chosen artifacts, such as movement of a ball, functioning of the lamp, phenomena of light, and characteristics of metals. In some cases, for example while studying electricity and magnetism, expert-designed science experiments with pre-given tool kits were conducted in the classroom. The students also planned, conducted, and reported their own experiments, for instance during their inquiries into the phenomena of light. In addition, the teacher arranged visits to a blacksmith's shop and the Clock Museum in the beginning of spring, 2004.

In the last phase of the project, the students researched and designed present-day lamps and artifacts of the future. Leadership for this phase of the study was provided by a professional designer together with the teacher. Visiting the classroom frequently, the designer described his own design process and drew students' attention to the essential points of lamp designing. The interaction between the expert and the students varied from face-to-face whole-class discussions, to small team discussions, and to discourse within Knowledge Forum's database. In total, the project took 139 lessons (in Finland one lesson lasts 45 minutes) during three terms. Table 1 presents the duration and an abstract description of the structure of the three phases of the project.

Table 1. Duration, and the main phases and activities of the Artifact project

Week	Main Phases of the Project	Main activities
Spring 2003 1-12	**Past of the Artifacts** 53 lessons 	**A. Classifying artifacts** **B. Design and usability of artifacts** **C. Historical development of artifacts** - Building time line of the evolution of artifact investigated **D. Exhibition** - Organizing and guiding
Spring 2003 14-17 **Fall 2003** 1-13	**Present of the Artifacts** 44 lessons 	**A. Movement of ball** - Movement and interaction **B. The physical phenomena of light** - Designing and conducting experiments **C. The physical phenomena of force** **D. The physical phenomena of metals** - Making experiments with magnetism and metals
Spring 2004 1-10	**Future of the Artifacts** 42 lessons 	**A. Designing lamps** - Professional designer describing his own design process - Analyzing and examining existing lamps - Designing through drawing, sketching, and making prototypes **B. Conceptual designing of future artifacts** - Analyzing future user needs concerning the selected artifact - Considering functional principles in the background of the designed artifact

During the Artifact project students generated problems and research questions, provided diverse theories, ideas and explanations through face-to-face knowledge building discussions, conducted self-generated science experiments, made observations related to phenomena, shared new information extracted from reading material, Internet, and various expert resources. Along with these offline activities, students shared their problems, theories, ideas, explanations, and knowledge resources in the KF database. The teacher supported the students' efforts to integrate their offline and online discourses in several ways: On one hand, she encouraged the students to record their questions, explanations and findings from face-to-face situations to the database; on the other hand, she used the data projector to refer to students' notes during offline activities. Moreover, she sometimes wrote down students' ideas, or conducted summarizing notes of classroom discussions in the database, at the same time they had knowledge building discourse going on.

In the first phase of the project, the students worked in their "home teams" (about 4 students per group), which investigated the chosen artifacts and produced knowledge to the team views of KF. The teams were heterogeneous, consisting of boys and girls, as well as less and more advanced students. The composition of the teams changed when the investigations concerning the present of artifacts began. During the second phase of the project, all students worked with the same phenomena and created collective KF views shared by the whole class. The students returned to their original home teams when they started to design the artifact they originally selected for the future purpose. During the last phase of the project, all students worked in the same views. In this phase, notes were mainly written in teams rather than individually; i.e., all team members participated in creating the content of their note.

3.3. *Method of data analysis*

Our research relies on an extensive ethnographic data collected during the longitudinal study project. We videorecorded approximately 70 hours of classroom practices; the teacher wrote a project diary weekly; and knowledge produced in Knowledge Forum database accumulated across the project. For the present study, we analyzed the nature of the students' questions, theories, ideas and explanations, in their online discourse through Knowledge Forum database. The analysis was conducted in two stages. Firstly, the participants' quantitative contributions to KF database were analyzed by using the Analytic ToolKit which underlies Knowledge Forum. Analytic ToolKit provides a rich overview of activity regarding the participants' contributions to the database. It reveals the frequency of computer posting (i.e., notes, annotations, views, rise aboves), as well as note reading activity.

Secondly, in order to examine how the use of KF mediated students' knowledge building activities, we selected two views from each phase of the project for qualitative content analysis. The six selected views involved various learning activities and were directly linked to the phases of the project. They also formed continua of students' inquiries, for example investigations of clocks from the historical point of view, to the mechanics of clocks, and to designing clocks of the future. Five of these views also contained external expert information gathered during museum visits and from the designer. The qualitative content analysis was conducted on the following views: 1) lamp history, 2) clock history, 3) phenomena of light, 4) clock museum (mechanics of clocks), 5) lamp designing, and 6) designing future objects.

Since the project involved different kinds of inquiry, i.e., historical, science and design inquiry, we developed coding schemata for qualitative analysis following the procedure of content analysis (see Chi, 1997). The unit of analysis was a note or an annotation produced by the students in KF database. The teacher's and experts' notes and annotations were left out of the qualitative content analysis. Each note was then coded according to the scheme presented in Appendix A. Notes were coded according to (a) what kind of questions the students proposed, (b) what type of explanations they provided, and (c) what were the knowledge resources to which they referred.

According to Hakkarainen (2003; see also Lipponen, Rahikainen & Hakkarainen, 2002) successful knowledge building is characterized by the generation of explanatory questions. In order to analyze the nature of students' knowledge-seeking questions, we rated the questions as 1) factual, 2) explanatory, or 3) design challenge. The factual questions were 'who', 'what', and 'when'-types of questions, whereas the explanatory questions were characterized as 'why', 'how', and 'what-if' -types of questions. Questions proposing design challenges were defining purposes, goals, or constraints for designing artifacts. We also analyzed who initiated the question, whether it was the student's own problem, or a task or problem given by the teacher or expert.

For rating the epistemic level of students' explanation, we adapted Hakkarainen's (1998; 2003; Hakkarainen, Lipponen & Järvelä, 2001) scale for rating explanations as follows: 1) isolated facts, 2) organized facts, and 3) own intuitive or scientific explanation. Isolated facts represent one simple fact or list of facts without any connection to each other, whereas organized facts represent facts that were introduced in a rather well-organized way, but do not provide deeper explanation or causal relations. Rating number three was assigned to notes in which the students constructed and elaborated their own intuitive explanations, or introduced a scientific explanation to the phenomena in question. This rating did not presuppose correctness or coherence of explanation. The usages of knowledge resources were coded according to 1) student's own knowledge, 2) reading material or Internet, 3) experiments 4), museum visits, or 5) teacher/designer. The resource was classified only if it was explicitly mentioned in the note (for example, "*Information is from the Clock museum guide.*" #1679), otherwise it was assumed to be the student's own knowledge.

4. Results

The students' production in the Knowledge Forum database was used to record the students' inquiry in the domains of knowledge; historical, science, and design. The present study is entirely based on conceptual as well as a qualitative and quantitative analysis of students' written production in the KF database, and therefore, it did not give direct information about psychological processes involved. The study focuses on examining how practices of knowledge production differed between the three different domains. By analyzing the questions, explanations, and external resources of students' inquiry processes, we evaluated how computer-supported collaborative learning facilitated higher-level inquiry practices insofar as they are recorded in postings to the database.

4.1. *Activity in the database*

In total, the students produced 1333 notes in 30 views on the KF database during the Artifact project. In the first phase of the project, 14 views were created, and 7 of them were related to the teams' historical inquiries. During this phase, the students worked mainly inside their own teams' views. The teams' work was integrated when the whole class built collaboratively the 'Timeline' view and the 'Exhibition of the Project' view. In addition, 5 views that functioned as additional photo galleries were created during the first phase. In the second phase, the students worked within 6 collective views, conducting and reporting experiments of the physical phenomena related to the artifacts. Also 1 photo gallery was created. During the third phase, 3 collective views were created and actively used. On top of these, 6 collective views were constructed for orientation and evaluation of the whole project.

In the first phase, students produced 660 notes (M=20.6, SD=10.79); in the second phase, 498 notes (M=15.56, SD=8.35); and in the third phase, 175 notes (M=6.28, SD=2.73). Moreover, the project's database consists of rich visualization and documentation (drawings and photos from the field trips, presentations of design ideas, and photos from the conducted experiments) produced by the students in KF's views or inside the notes. Table 2 depicts Knowledge Forum views selected for qualitative content analysis of the present study, and the number of notes, drawings, and photographs in each view. Since the Analytic ToolKit ignores the pictorial data on Knowledge Forum, the drawings and the photographs were counted manually.

Table 2. Number of notes, drawings, and photographs in the views selected for qualitative content analysis

Project phase	View name	Notes		Drawings	Photos
		student	expert/teacher		
Historical Inquiry	Lamp History	88	6	2	5
	Clock History	90	5	5	-
Science Inquiry	Clock Museum	84	16	14	1
	Phenomena of Light	262	23	1	20
Design Inquiry	Lamp Designing	99	6	55	17
	Future Artifacts	50	7	38	-
	Total	673	63	115	43

As stated earlier, during the historical inquiry, each student team studied the history of their selected artifact, and the teacher created a view for each team to collect and process all the information on the artifact. According to the students' ideas concerning how to investigate historical aspects of the artifacts, the teacher arranged a guided visit to the Finnish National museum. Before the trip, the students prepared questions for the guide; at the museum, the responses and other information obtained were written down by hand. The students were also asked to visualize objects being investigated and pay close attention to details. Afterwards, their notes and drawings from the museum were posted to KF, and the students used multiple sources of information to deepen their historical inquiries. ‘Lamp History’ and ‘Clock History’ views represented the team views of historical inquiry in the qualitative content analysis of the present study.

In science and design inquiry phases, the KF views were collective and thematic in nature -- i.e., the views based on the thematic topic they were studying -- and all students worked inside the same view. When the students examined light as a physical phenomenon, they first made notes concerning things that they wondered about and generated initial working theories. Relying on these preparatory activities, they planned, conducted, and reported their own experiments concerning light. These experimental situations were also documented by taking photos and inserting them into KF database. The field trip to the Clock Museum brought new information about present-day clocks and their mechanisms. The main purpose of the visit was to gain an understanding of how various clocks work and what kind of mechanisms they consist of. Thus, the students were asked to make notes and draw the details of the clocks’ mechanisms.

During lamp designing, the students analyzed the function and properties of existing lamps, formed design teams based on the lamp type they selected, and designed new lamps within collective views. Beyond conceptual design that relied on writing, the students supported their design through drawing by hand or with the computer and by making prototypes. The investigations on lamp designing led the students towards the end of the project, to focus on projecting how their chosen artifacts would look -- be designed -- in the year 2020. This conceptual design process was otherwise similar to lamp designing, only prototypes were not produced. The emphasis was on explicating how the future artifact will function and how it will be used.

4.2. *The nature of students’ questions*

We were interested in what kind of questions and problems the students’ presented in the database during the project, and in the epistemic nature of their questions. In the selected 6 views, students addressed 273 questions in total. Out of these 40.5% (f=96) were rated as factual, 38.8% (f=92) as explanatory, and 20% (f=49) as design challenges in nature. Generating explanatory questions is characteristic of successful knowledge building, however, young children often ask more factual than explanatory questions (Hakkarainen, 2003). Many kinds of research questions may be useful; in many cases fact-seeking questions are more easily available to young students working with history topics that other type of skills.

As presented in Table 3, 44.7% (*f*=106) of students' questions were contributed during historical inquiry, 30% (*f*=70) during science inquiry, and 25% (*f*=59) during design inquiry. The cross-tabulation on the field of inquiry and the nature of the questions on Table 3 also reveals what kind of questions were dominant in the three phases of the project (see Appendix A). At the beginning of the project, the questions were mainly factual (91.7% *f*=88) in nature, because historical knowledge was considered factual by the students. They asked, for example, questions like "*Who first invented a lamp?*" (#309), "*When was the first sun clock invented?*", or "*Where is the oldest clock?*" (#463). In this study, students also addressed and proposed many explanatory problems (19.6 %, *f*=18) during their historical inquiries.

Table 3. The cross-tabulation on the field of inquiry and the nature of the problems

Nature of Questions	The Field of Inquiry						Total	
	History Inquiry		Science Inquiry		Design Inquiry			
	f	%	*f*	%	*f*	%	*f*	%
Factual	88	91.7%	8	8.3%	0	0%	96	100.0%
Explanatory	18	19.6%	64	69.6%	10	10.9%	92	100.0%
Design challenge	0	0%	0	0%	49	100.0%	49	100.0%
Total	106	44.7%	72	30.4%	59	24.9%	237	100.0%

While studying the physical phenomena, the questions more clearly changed towards explanation seeking questions (69.6%, *f*=64) (Table 3). As anticipated by the interrogative model of inquiry (Hakkarainen & Sintonen, 2002, see also Zhang et al., 2007), advances in understanding lead to further questions or redefinition of existing questions at more abstract levels. For example, at the Clock Museum, the students were able to formulate more complex questions, concerning both the history and the mechanisms of clocks, such as "*How did the water clock function?*" (#1614). While studying the phenomena of light, students asked, for instance, "*Why can we see a rainbow only after rain*" (#1149) and "*How do rainbows come into being?*" (#1249), leading them to understanding of rain droplets refracting the sunlight. Based on this understanding, students generated further problems, such as: "*Why is the red color in a rainbow always first?*" (#1153) and "*What causes the order of colors in a rainbow?*" (#1250). Evidently, the design inquiry phase contained almost entirely questions related to design challenges (100%, *f*=49), for example "*What kind of lamp would function well as a pendant?*" (#1910), and "*Goals for future ball designing*" (#2078).

4.3. *The nature of students' explanations*

In order to analyze what kinds of explanations the students generated in their online discourse during the project, we rated the epistemic complexity of their explanations on a three-point-scale (see Appendix A). In total, the students wrote 363 notes including explanations. 26.4% (*f*=96) of these represented isolated facts, 37% (*f*=134) organized facts, and 36.6% (*f*=133) explanations.

Table 4 reveals that 31.7% (*f*=115) of explanations were produced during historical inquiries, 29.5% (*f*=107) during science inquiry, and 38.8% (*f*=141) during design inquiry. The number of isolated facts was large (79%, *f*=76) in the historical phase, but decreased clearly in the next phases, and only 5.2% (*f*=5) of the explanations represented isolated facts during the design inquiry phase. By contrast, the number of organized facts and explanations increased towards the end of the project. Approximately 18% (*f*=24) of notes included organized facts during history inquiry phase; in science inquiry the number increased up to 38% (*f*=51), ending up to 44% (*f*=59) in design inquiry. The amount of scientific explanations increased even more; only 11% (*f*=15) of the students' notes were classified as scientific explanations in the history phase, but 31% (*f*=41) in science inquiry, and 58% (*f*=77) in design inquiry.

Table 4. The cross-tabulation on the field of inquiry and the epistemic level of students' explanations

Level of Explanation	The Field of Inquiry						Total	
	History Inquiry		Science Inquiry		Design Inquiry			
	f	%	*f*	%	*f*	%	*f*	%
Isolated facts	76	79.2%	15	15.6%	5	5.2%	96	100.0%
Organized facts	24	17.9%	51	38.1%	59	44.0%	134	100.0%
Explanation	15	11.3%	41	30.8%	77	57.9%	133	100.0%
Total	115	31.7%	107	29.5%	141	38.8%	363	100.0%

During the field trip to the Finnish National Museum the students gathered the information obtained in the form of mind maps. The students used KF's build-on tool spontaneously to create mind-maps (build-on notes are connected to the parent note with a line) to the database. The lines may be stretched and notes arranged in many flexible ways. The online social interaction during the whole project based on neutral, topic-related build-ons and annotations, i.e. the students continued and challenged each others theories and ideas, and made very few off-topic remarks. However, the knowledge produced in the historical inquiry phase was relatively factual in nature; they provided explanations, such as "*Sandglasses were used to measure time*." (#415) In order to solve this problem, the students were asked to go, together, through notes produced by each student at the museum; a comparison of notes revealed a substantially enriched body of knowledge. Further, the student teams were asked to comment on other teams' notes, which helped to recover even more information, because the teams had visited different units of the museum. Finally, the students were asked to synthesize their findings by creating a summary in the middle of the mind map. They were expected to elaborate the synthesis collaboratively, rather than just simply combine their individual contributions. Such facilitating activities guided the students to repeatedly revise their contributions and helped to refine the knowledge generated during the project. For example, after visiting the Clock Museum in spring 2004 (over six months after the historical inquiry phase), the students went back to their team views, and completed some of their contributions there.

The idea of progressive inquiry is to guide students to engage in an expert-like process of working with knowledge (Hakkarainen, Lonka & Lipponen, 1999; 2004). When investigating the phenomena of light, the students were guided to use Epistemological V (EV, Novak, 1998) to structure their contributions to the database. Figure 1 reveals a part of a build-on inquiry thread conducted by a student team. The students' first proposed a question concerned rainbows, and they produced their own theory to explain the phenomena. Then they provided ideas on how to experimentally investigate their theory, and also generated further questions. During the science inquiry, 20 notes were related to designing experiment, i.e. the students described how they conducted the experiments. The students also provided conclusions of their investigations.

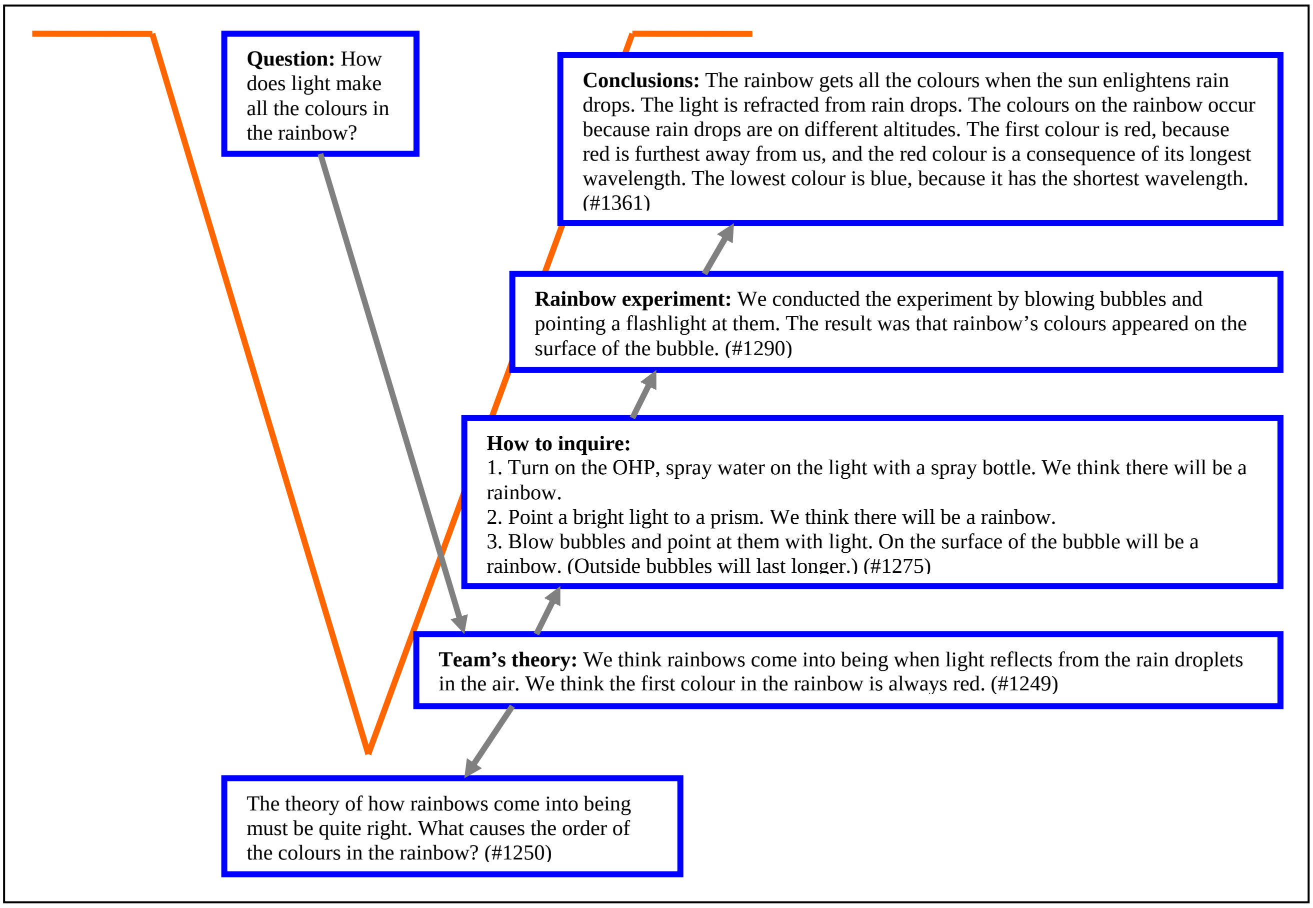


Figure 1. A part of a student team's build-on inquiry thread on rainbows.

During design inquiry, all the notes contributed (*f*=97) represented design ideas; they introduced ideas and challenges related to composition, construction and properties for the artifact. If the ideas were merely described without elaboration, the epistemic complexity of the note was rated as organized facts. When rated as intuitive explanation, the note also included explication, elaboration and justification of the design ideas. Figure 2 shows a part of the inquiry thread of lamp designing by one student-design team. All the teams started the process by gathering their presentations on the existing lamps inside rise-above notes, i.e., notes that summarize, distill, and advance discussions. From this note, the actual designing continued with build-ons, leading to a final presentation of the new lamp. During both design processes, the designer assigned many analytic tasks to the students, and also commented on the students' notes by writing annotations.

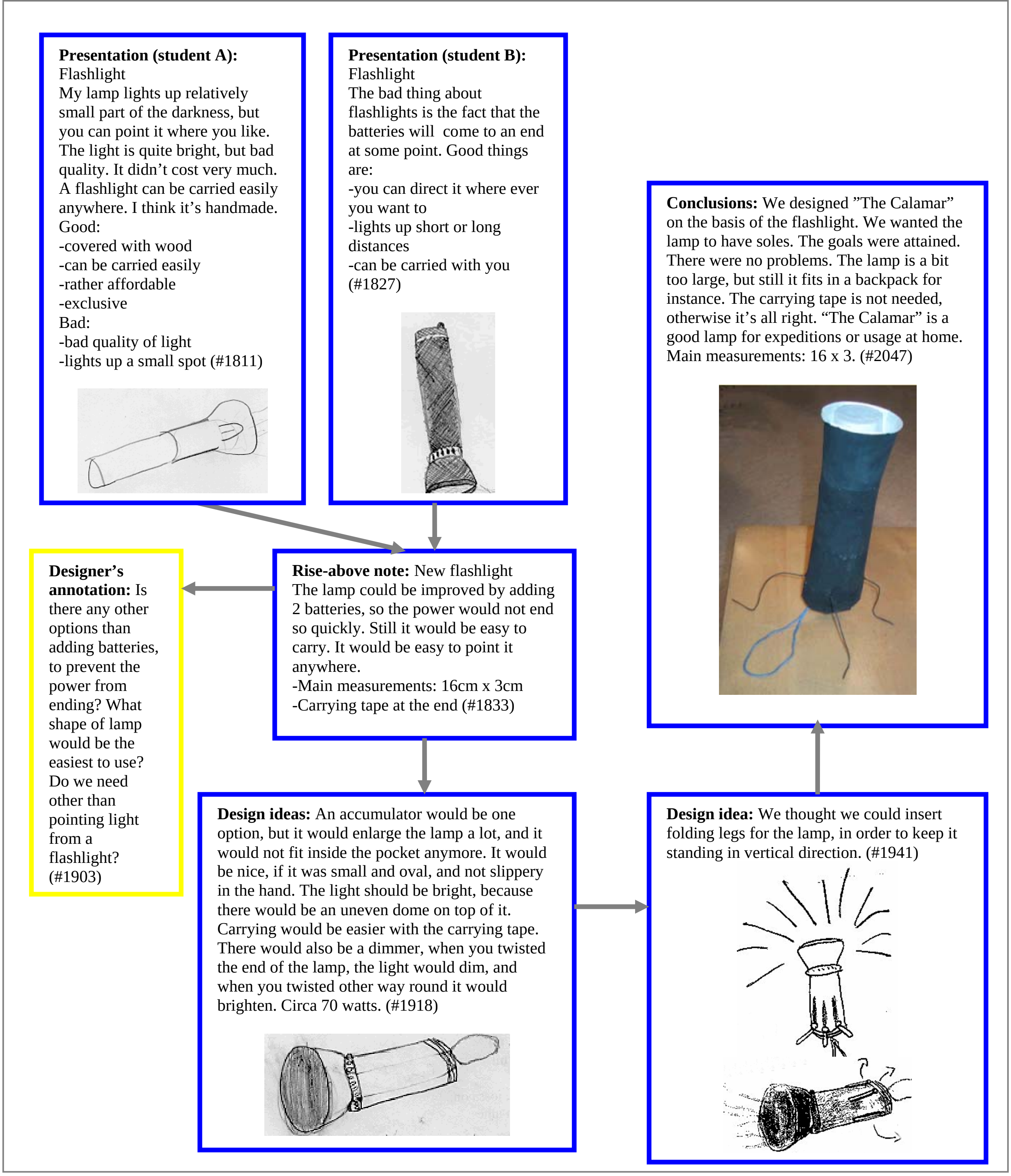


Figure 2. A part of a lamp designing inquiry thread by a student design team.

To understand how the students used different knowledge resources, we identified notes that referred to museum visits, reading material or Internet, experiments, or the designer. We were interested in how the students incorporated empirical data into knowledge building, and how they used expert knowledge resources in their online discourses. Out of the total number of notes in the selected views (f=373), only 138 notes were categorized as notes referring to the expert resource, for example "*Information obtained from the Clock Museum.*" (#1656). The students mainly referred to the source with their own words; they did not necessarily go beyond the resource material. 'Going beyond' means generating ideas based on the information from the source, leading to deeper understanding (see Zhang, 2007).

5. Discussion

The aim of the study was to explore the epistemological nature of the elementary students' inquiry processes in a longitudinal and multifaceted inquiry project involving a wide variety of virtual and classroom activities and networking with expert communities. Furthermore, the purpose of the present project was to pursue, in parallel, an examination of material and conceptual artifacts. Some of the artifacts in the present case were considered to be hybrids involving both physical and material characteristics as well as embedding meanings and objectified intentions. In all their explorations, the students worked with shared ideas and thoughts. There was, first of all, an exploration of historical artifacts, through looking into the evolution of artifacts as cultural entities (cf., Wheeler, Ziman, & Boden, 2002). The inquiry, secondly, involved present artifacts, and looked into natural science topics through experiments. While the students pursued natural-science experiments, they addressed physical principles involved in the design of artifacts and engaged in a deliberate process of working with conceptual artifacts (e.g., problems and theories). Thirdly, students considered future artifacts, in the form of conceptual design for such artifacts. In designing a lamp conceptually, and fashioning a prototype of it, the students, in this multifaceted process, ensured the ultimate integration of material and conceptual artifact. The project focused on material and concrete things, and the students were able to find a great deal of information concerning significations and historical meanings embedded in selected artifacts.

Practically all knowledge created during the project was generated by the students themselves, under the teacher's guidance. The students were delegated a great deal of responsibility for higher-level cognitive (questioning and explaining) and metacognitive (planning, monitoring, and evaluating) processes at individual, team- and collective levels (cf., Bereiter & Scardamalia, 2003). The students generated problems and research questions, provided diverse theories, ideas and explanations in the computer-supported learning environment. Moreover, the students conducted self-generated science experiments, made observations related to phenomena, shared new information extracted from reading material, Internet, and various expert resources (museums, a blacksmiths' shop, the designer). A special character of the project was parallel knowledge-creation through writing and visualization. The participants were systematically guided to draw pictures of the object of their inquiry (where it was material) as well as to take digital photographs to support the process. Scanning or storing these entities to the KF database allowed visual organization of knowledge, a special advantage of the KF environment.

The analysis of students' questions revealed clearly that they moved from fact-seeking questions towards explanatory questions and design challenges in accordance with the different fields of inquiry. The history inquiry mainly consists of short and fragmented fact-seeking questions. The science inquiry is based on mainly 'why', 'how', and 'what if' types of explanatory questions. The questions proposing design challenges were defining purposes, goals, or constraints for designing artifacts during the design inquiry. Furthermore, the analysis revealed that the epistemological nature of knowledge production differed among the inquiry phases. The students produced notes classified as isolated facts, organized facts, or explanation in all inquiry phases, but isolated facts were dominant only in the history inquiry. The structure of fact-seeking questions and short fragmented answers implied clear questions-answer pairs. In science and design inquiry, the students focused more on organized facts and explanations. In science inquiry, the structure of the notes more represented a knowledge chain or inquiry threads'; it was characterized by many build-on and annotation notes. The design ideas presented by the students were rated as descriptive design idea (i.e., organized fact) or explanatory design idea (i.e., explanation). The former represented only the descriptive information about the design whereas the later also included explication, elaboration and justification of the design ideas. 'Descriptive' indicated introducing a design idea without elaboration, whereas the assigned label, 'explanatory design ideas', was linked with introducing and elaborating ideas and challenges related to composition, construction, and properties of the artifact being designed. Students, in fact, produced almost a same amount on both kinds of explanations. In spite of the factual-oriented process in the beginning of the project, we are entitled to conclude that the students engaged with an explanation-oriented process of inquiry towards the end of the project. According to Bereiter and Scardamalia (2003), in the knowledge building approach knowledge is dealt with in design mode rather than belief mode. In belief mode ideas and theories are considered as extrinsic or given entities. In design mode students are concerned with the usefulness, adequacy, and improvability of ideas and theories, and continuous improvement of ideas is seen to be essential. It appears to us that the design mode (Bereiter & Scardamalia, 2003) and learning by collaborative designing was facilitated by examining everyday artifacts from a design perspective, to systematically assess function, material, usage, and production of the artifacts.

Results of the present study indicate, further, that there is a very close relationship between the epistemological nature of knowledge produced by the students and the learning activities carried out. Hakkarainen et al. (2001) have pointed out that elementary school students do not break constraints of concurrent pedagogical or epistemological practices by themselves without the teacher's guidance. Factual and somewhat fragmentary knowledge dominated in the beginning of the project; this was, however, closely monitored by the teachers and researchers. Certain compensating activities were performed: pushing students to synthesize their findings and asking students, collaboratively, to go through their notes, requiring them to provide constructive feedback to each other. At the very least, it appears that nothing in the design of the present project prevented students from working with conceptual artifacts, and, moreover, the rich material context of the project facilitated students' engagement and apparently helped everyone involved to feel that something worthwhile has been achieved. While there were certain challenges concerning facilitating students' in-depth inquiry and the development of their principled scientific understanding, the evidence indicates that involving material artifacts is a productive way to facilitate knowledge-building inquiry. Students can learn to shift between practical and epistemic manipulation of artifacts as they are engaged in "design mode".

According to Zhang et al. (2007) a knowledge building community needs expert resources to inform and produce further cycles of idea improvement. In the present study, we were interested in how students used expert knowledge resources in their online discourses. The analysis revealed that the students simply referred to the resource with their own words, and they did not necessarily go beyond the resource material in the same note. According to Zhang et al. (2007) 'going beyond' means generating ideas based on the information from the source, leading to deeper understanding. This implies that further analysis is needed; we need to analyze note chains or inquiry threads (Zhang et al., 2007) in order to understand the advancement of students' knowledge and influence of the expert resources on improvement of students' ideas. We can conclude that the teacher's and the designer's guidance have a central role. From time to time, the teacher arranged collective knowledge building sessions (face-to-face discourse with shared view of KF database), where she discussed with the students the present problems and ideas related to inquiry. Also, the designer gave feedback regarding the teams' design ideas in the face-to-face discussions and in KF annotations. From the students' notes we can infer that the designer's feedback was important and pushed students to go deeper in their designing. However, there were not many explicit references to the designer's feedback in the students' notes. Since we have many hours of video material from the face-to-face interaction, we can deepen our analysis to include the interactions between team and designer.

To conclude, the present project appears to diverge from, or move beyond a knowledge building approach in the conceptual realm insofar as it undertook to engage the students in parallel working with idea improvement and manipulating and prototyping material artifacts. The students were very much both "hands on" and "minds on" during the project. Physical manipulation of artifacts, designing and conducting concrete experiments, and creation of concrete prototypes helped students to pursue their inquiries. It appears that the conceptual and material aspects of the inquiry mutually supported and enriched one another. Regarding the project's success, we believe it was essential to have the designer working intensively with the students across several weeks. From a psychological perspective, it is crucial to provide students with the experience of interacting and working along with an adult expert who can be identified or to whom they can relate.

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Appendix

Appendix A. Coding framework for content analysis of discourse in each inquiry phase. (adapted from Hakkarainen, 1998 and Zhang et al., 2007)

Categories	**Sub-categories and defining features**	**Examples**
Problems (addressed or proposed)	*Factual:* Questions seeking for factual information (who, where, when, how many, etc.).	*When was the lamp invented?(#313)* *What colour was the lead glass?(#462)* *Who woke up before there were clocks?(#464)*
	Explanatory: Questions seeking for explanation (why, how, what-if, etc.).	*Why was the first clock invented?(#261)* *Why burning generates light? (#1098)*
	Design Challenge: Defining purposes, goals, or design constraints for designing artifacts.	*Challenges for future spoon designing. (#2080)* *What's inside the lamp and for what is it used?*(#1976)
Level of Explanation	*Isolated facts:* Simple statements of facts or lists of facts without elaboration.	*Long-case clocks became common during the 18th century.(#396)* Thomas Edison invented the electric lamp. (#700)
	Organized facts: Connected pieces of factual information, elaboration of phenomena, or experiences.	*Greeks invented the water clock. It was used in public meetings for measuring the time of speeches. There were two buckets, the other one had a hole in it. Water run to the other bucket and made the hand move. (#593)* *Digital clocks have a circuit broad inside for it to function. The circuit board shows the clock numbers. (#1647)*
	Intuitive or scientific explanation: Construction and elaboration of reasons, relationships, or mechanisms, or introduction of scientific explanation. Correctness or coherence of explanation not presupposed.	*Sun light cannot reach other side of the moon, that's why there is a shadow on the moon. Light reflects from the moon to earth, and then we can see different phases of the moon. Sun light moves and hits the moon. From the moon the light reflects to earth. There is no light on the moon itself, if sun light didn't hit the moon, it would be completely dark. (#1270)*
Knowledge resources	*Student's own knowledge:* Personal ideas and understandings, and previous knowledge.	*The sandglass can tell the time. If there is sand for an hour, and you'll want, for instance, to go some place, at two o'clock, you'll turn the sandglass, and then you'll know when it is two o'clock.(#1658)*
	Museum visit: Information (notes, mind maps, drawings, videotapes) gathered during the museum visits	*Information is from the Clock museum guide. (#1679)*
	Reading material or Internet: Information found from books, articles or online resources	*We found information from net. (#587)*
	Experiments: Physical experiments conducted by the students	*What we did: We placed a super ball in warm water. (#1276)*
	Designer: Continuous offline and online interaction, feedback, and thinking tasks provided by the professional designer	*We'll design by drawing the lamp on a scale of 1:10, and maybe after that we'll prepare a mock-up. (#1963)*