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How Pictorial Knowledge Representations Mediate Collaborative Knowledge Construction In Groups

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Abstract

This study investigates the process of collaborative knowledge construction when technology and pictorial knowledge representations are used for visualizing individual and groups' shared ideas. The focus of the study is on how teacher-students contribute to the group's collaborative knowledge construction and use each other's ideas and tools as an affordance for their jointly evolving cognitive systems. The context of the study is a teacher-student (N=13) educational technology course. The data involved students' videotaped face-to-face group activities (mind-mapping with paper and pen and mind-mapping with a Mobile Mind Map Tool and pictorial knowledge representations) as well as stimulated recall interviews. The data-driven qualitative content analysis revealed that students were engaged in knowledge level and transactivity level activities and they processed their own ideas as well as others' ideas in their group interactions. (Keywords: Collaborative knowledge construction, cognitive tool, distributed cognition, knowledge representation, mobile technology.)

INTRODUCTION

Theories of distributed cognition have informed how efficient groups use and develop their expertise further by recognizing how a system of minds and artifacts can work efficiently together (Hutchins, 1995). Likewise, educational contexts can benefit a system of minds, tools, and artifacts where learners learn with, from and about each other. Learning for understanding is a dynamic, reciprocal and contextual activity, where cognition is propagated from mind to mind, from mind to tool and from tool to mind in such a way that it creates representations within and between the learners (Hutchins & Clausen, 1998).

Due to fast-developing technology, possibilities for group learning are continuously expanding; ideas on mobile and ubiquitous technologies offer new possibilities for constructing and sharing ideas in multiple contexts and thus creating adaptive learning environments (Pea & Maldonando, 2006; Roschelle & Pea, 2002; Sharples, Taylor, & Vavoula, 2007; Rochelle, 2003). Instruction and communication technology (ICT), including mobile technology, can be characterized as cognitive tools for searching, organizing, presenting and creating information – individually and as a shared process between several individuals (Jonassen & Carr, 1999). However, the importance of mobile technology in education has not yet been well argued even though there are new technological and pedagogical possibilities for enhancing shared learning processes in collaborative learning.

Teachers are in a critical position for promoting the meaningful use of technology, but even more critical is to bring the ideas of technology enhanced learning to teacher-students and give opportunities for them to have first-hand experiences while they are studying to be a teacher. This study focuses on teacher-student group learning and use of technology as a cognitive tool for visualizing thinking processes with pictorial knowledge representations. A study of negotiation of knowledge representations is grounded in the theoretical framework of distributed cognition—a framework that situates the study of knowledge representations in the social context where students are engaged in shared cognitive activities mediated by technological tools, artifacts and each other (Hutchins, 1995; Salomon, 1993). This is to say that the focus of the study is on how teacher-students contribute to the group's collaborative knowledge construction and use each other's ideas and tools as an affordance for their jointly evolving cognitive systems.

Ideas of Distributed Cognition In Collaborative Knowledge Construction

Ideas of distributed cognition have opened up new avenues for designing learning environments. The implications of distributed cognition for learning and teaching provide new ideas for rethinking the role of social interaction and the use of artifacts for learning. To be specific, Salomon and Perkins (1998) note that understanding the social contribution to learning is to recognize where information processes lie: within the individual mind or within the social interaction. Perception of information being situated in the individual mind relies on terms such as internalization and the externalization of information where as terms like participation and adaptation are used when emphasizing social interaction.

This study puts an emphasis on individuals in a specific framework of social interaction, referring to conceptualizations of Salomon (1993) and Perkins (1993). The focus is on the processes that take place in an extended cognitive system, which provides a basis for the coordination of individual actions as well as for the future communication and activity of the group (Clark & Brennan, 1991; Hutchins, 1995). Knowledge is something that individuals can posses and distribute around a variety of artifacts, and other individuals and group processes are seen as a way to facilitate individual learning. Thus, individual and distributed cognitions are viewed as distinct phenomena that exist in an interdependent dynamic interaction (Salomon, 1993). Furthermore, extended cognitive systems, namely, those in which there are multiple people interacting with each other and a range of artifacts to perform an activity, have properties that differ from the individuals that participate in them (Hutchins, 1995). For example, individuals working together on a collaborative task possess different kinds of knowledge and so will engage in interactions that will allow them to pool their various resources to accomplish their tasks.

The efficient extended cognitive system, as it is the case in group learning, requires the negotiation and coordination of group members' diverse views; in other words, it presumes at least some amount of shared understanding. However, reaching shared understanding is a challenging process because individuals need to make their own thinking visible for others and successfully interpret others' thinking processes. The process of building a shared understanding can contribute to rich argumentation and creative problem solutions, but in order to succeed it needs to be scaffolded both pedagogically and technically. Moschkovich (1996) and Roschelle (1992) found that shared metaphors can form a basis for shared understanding. Metaphors and negotiated meanings for metaphors support the creation of a shared understanding, and furthermore, negotiated meanings can be used as shared reference points when constructing a shared understanding (Roschelle & Teasley, 1995).

Technology and External Knowledge Representations as Cognitive Tools for Visualizing Knowledge

Cognitive tools are both mental and computational devices that support, guide, and extend the thinking processes of their users (Jonassen & Reeves, 1996; Lajoie, 1993; Teasley & Rochelle, 1993). They require students to think carefully in order to use the application to represent what they know. When cognitive tools function as partners in learning, the performance of the individual is enhanced, leaving some cognitive residue which will likely transfer to situations where the learners encounter the tool again (Salomon, 1993). Pictorial knowledge representations can be defined as a cognitive tool to visualize individual and group shared ideas in distributed cognitive systems (Pea, 1993). In other words, external knowledge representations can be defined as shared reference points for supporting shared understanding. Generally, knowledge can be represented visually in different forms; e.g. as a text, picture, figure, diagram and matrix (van Someren, Reimann, Boshuizen, & de Jong, 1998). With these cognitive tools, students can construct, further elaborate, monitor and manipulate their own visualized representation of knowledge, and thus, construct their shared understanding in between the group members.

Pea (1994) suggested the term "inscription" as an alternative to "representation," to refer specifically to external representations, rather than internal representations such as images and mental models. Inscriptions are created, for example, by students to externalize understanding and to serve as points of reference during discussion (Barab, Hay, Squire, Barnett, Schmidt, Karrigan, Yamagara-Lynch, & Johnson, 2000; Edelson, Gordin, & Pea, 1999). Students can create inscriptions by using paper and pencil or complex animated 3D authoring tools. The CoVIS project (Edelson et al., 1999), for example, is one of the best-known projects that use inscription to express and discuss students' own ideas on a learning task. Tools that let students create their own visualizations require them to master the content before committing their own ideas and then help them to use these visualizations as a point of reference in discussions with the other students. Barab et al. (2000) explored the creation of inscriptions by students as part of the learning process. This research shows that the students' actions of designing and building their own materials, and the discussion involved in those actions, contribute to students' learning to master the topics of the learning task with depth and clarity.

Purpose of Present Study

Despite of increasing information of a use of cognitive tools for learning, there seems to be a lack of information how individuals in a group self-generate their external knowledge representations in a form of pictures and use those pictorial knowledge representations as a support for their collaboration. The aim of this study is to understand a process of collaborative knowledge construction when technology and pictorial knowledge representations are used for visualizing the shared ideas of both individuals and groups. To be analyzed in particular will be the individuals' knowledge contribution to the group's collaborative knowledge construction and individuals' use of each other's ideas and shared tools as a reference in their group learning.

There are three key research questions:

1. How do individuals contribute to their group's collaborative knowledge construction?
2. How do individuals use each other's ideas in their collaborative knowledge construction?
3. How do students explain the use of pictorial knowledge representations for collaborative knowledge construction?

METHOD

Process-oriented methods are required for exploring individual knowledge contribution to collaborative knowledge construction and depicting how individuals in a group refer to the contributions of their group members (Arvaja, Salovaara, Häkkinen, & Järvelä, 2007). Understanding collaborative learning, as a particular form of distributed cognition, requires making sense of the conversation that students engage in and the tools that mediate their learning (Hmelo-Silver, 2003). Therefore, to study collaborative knowledge we need to examine group activity in its specific context. The context is not predefined as an objective environment; it is a joint creation of the participants in the activity (Goodwin, 2000). The contextual approach of collaborative knowledge construction brings the process of tool-mediated negotiation of meanings into the focus of analysis (Linell, 1998). In this study, the process-oriented data were collected in order to explore how students construct knowledge together and use pictures as knowledge representations in groups.

Participants and Procedure

The participants of this study were teacher education students (N = 13, where 5 were males and 8 were females). The data were collected as a part of introductory studies in educational technology. The participants were randomly assigned to work in groups of 2–4 students—two groups of four students, one group of three students and one group of two students. The students worked with a collaborative learning task facilitated with the Mobile Mind Map Tool (© Scheible, 2005, see Figure 1), and a problem-oriented pedagogical structure (see Table 1). The idea of the Mobile Mind Map Tool was to use pictures as knowledge representations and a surrounding environment as a reference point for students to visualize their individual and shared thinking processes. The tool allowed students to take pictures with a mobile phone and to add text annotations to the pictures. The annotated pictures were sent to the server and they were used to construct a mind map with the computer. The tool allowed the participants to

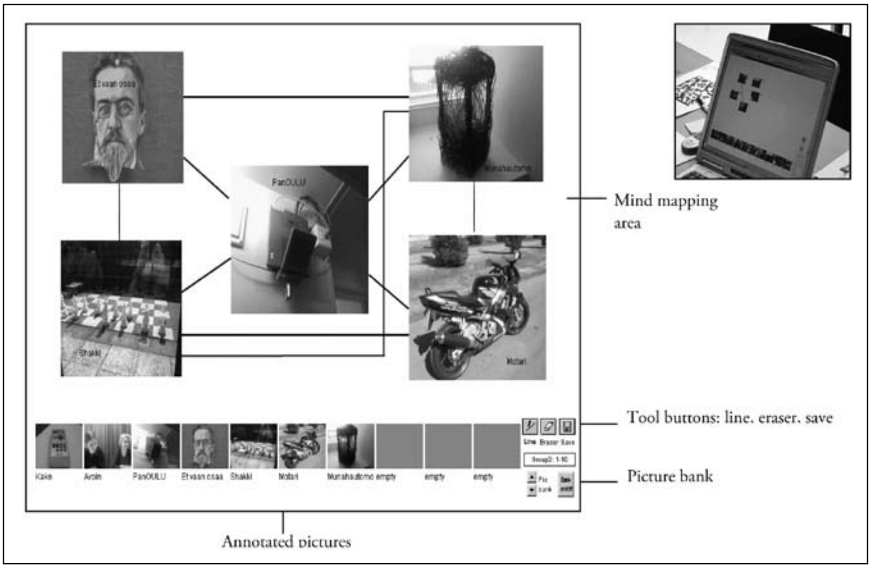

Figure 1: The Mind Map Tool.

move the pictures in a computer screen, change the size of the pictures and also connect the pictures with a line.

This experiment was planned and conducted in a close collaboration with the teacher of the studies of educational technology. Neither of the researchers were working as a teacher in this course. Participation for this experiment was optional for students and grades were not assigned for their work.

Student activities were structured around different phases in which they brainstormed, explored real-life examples to visualize their thinking and used pictures as knowledge representations to construct a group's shared understanding. In the first phase (see Table 1) the participants were asked to discuss the given topic: *What kind of qualifications the studies of Educational Technology will give to one's future working life* and they were asked to draw a shared mind map with paper and pen. The pedagogical aim of this phase was to support grounding; the students introduced their ideas to each other and negotiated the

Table 1: Pedagogical Structure

Description of group activities	Pedagogical idea	Outcome
1. Mind mapping with paper and pen	Grounding	Mind map with paper & pen
2. Campus area exploration for evidence with mobile phones	Inquiring	Annotated pictures
3. Mind mapping with Mind Map Tool and pictures by the computer	Constructing	Mind map with pictures
4. Reflection on the experience	Reflecting	Shared experiences

different ideas. In the second phase the abstract ideas were revised into more authentic form by asking participants to go around the campus and find real-life examples to support their previous discussion and then further construct new ideas. They were also asked to document their findings by taking concrete, symbolic or framed pictures with mobile phones and by adding text annotations to the pictures. The aim of this phase was to put abstract ideas to concrete form, and thus engage students in an inquiry process. After taking pictures the students sent them to the server. In the third phase ideas were developed further in a face-to-face group session by constructing a mind map of the collected pictures and the text annotations with the Mobile Mind Map Tool. Each phase lasted from half an hour to one hour. The time schedule was flexible and groups were given as much time as they needed to finish their mind maps.

Data Collection

The data collection included a video observation of students' face-to-face collaborative interaction when mind mapping with paper and pen and mind mapping with pictures on the computer. During the session, where the mind map tool and pictures were used, two video cameras captured students' facial expressions and the activities on a computer screen. Altogether six hours of video data were collected (about 90 minutes per group). Another part of the data was generated by stimulated recall group interviews (Ericsson & Simon, 1980). The interviews were conducted right after finishing the given task in order for students to reflect on their learning experience, including how they viewed group work and the use of cognitive tools. Furthermore, the students' mind maps were used for illustrating the outcome of their collaborative learning and stimulating the recall of their learning process during the interview.

Data Analysis

The analysis of the data involved two levels. The first level analysis focused on video data and collaborative knowledge construction activities in the face-to-face discussions. The second level analysis focused on the interview data and student accounts of the use of pictorial knowledge representations for collaborative knowledge construction.

Analysis of knowledge construction activity in the face-to-face discussion

The analysis of the student knowledge construction activity was divided into two main steps. First, a qualitative content analysis was conducted to explore *knowledge level* activities (Cannon-Bowers & Salas, 2001) for revealing how students contribute to collaborative knowledge construction. Second, a qualitative content analysis was conducted to explore *transactivity level* activities (Teasley, 1997) for revealing how students use each other and tools as contextual resources for building on each other's ideas. This analysis targeted primarily the student groups' knowledge construction, examining it through the discourse and the resources that mediated group activities.

In the first phase of the qualitative content analysis, the six hours of videotaped conversation data was transcribed and coded into segments. Segmentation was based on the principle that at least one meaningful statement should occupy a single segment. Hence, the meaningful statement is defined as the unit of the analysis. In this study the meaningful statement represents "an idea, argument chain or discussion topic" (Chi, 1997, p. 46). An inductive approach (Miles & Huberman, 1994) was used for identifying the meaningful statements. Therefore, analysis was based on the data-driven content analysis (Chi, 1997) and the nVivo (Bazeley & Richards, 2000) qualitative data analysis program was used as a support for the analysis. In order to find out the most critical parts of the data the transcriptions were read several times. The first author of this paper worked on the coding with a trained research assistant, who was first closely introduced to the theoretical ideas and collected data. The first author coded the data and then the research assistant coded the data; intercoder reliability was quantified. The parts of the data which were in disagreement were discussed in order to find an agreement in coding. After several repeated data-driven coding sessions, categories were formulated.

At first, the analysis focused on the *knowledge level* for exploring how individuals contribute their knowledge to collaborative knowledge construction. The conversation data was coded to the categories of *content discussions* and *action discussions* (see Table 2). The category *content discussions* includes statements wherein students use content-related concepts and construct knowledge by 1) *contributing ideas*, 2) *processing ideas* further or 3) *connecting different ideas* and used concepts. The category *action discussions* includes statements referring to concrete actions during the group work, such as 1) *suggestions on how to proceed* in the group work and 2) *keeping up the conversation*. While coding, differences were noticed between the different group activities (mind mapping with paper and pen and mind mapping with pictures). Therefore, an additional category: 1) *meaning making with pictures* was developed for analyzing content discussions in the session where mind maps were constructed with pictures.

Since the knowledge level approach does not capture how learners construct shared knowledge, the transactivity approach was implemented (Teasley, 1997). The transactivity approach aimed at exploring how students refer to the contributions of their group members. Therefore, further categories (see Table 3, p. 366) were developed to explore how individuals use each other's ideas as contextual resources and if they *process their own or others ideas further.*

Next, a more detailed qualitative analysis was conducted and conversation was coded to the above described categories based on the specific rules constructed

Table 2: The Categories for the Knowledge Level Analysis

KNOWLEDGE LEVEL ANALYSIS	1st Session mind mapping with paper & pen	2nd Session mind mapping with mind map tool & pictures
A. Content discussions	New idea Processing ideas Connecting ideas Placing ideas	Meaning making Processing ideas Connecting ideas Placing ideas
B. Action discussions	Suggestion Keeping up conversation	Suggestion Keeping up conversation

Table 3: The Categories for the Transactivity Level Analysis

TRANSACTIVITY LEVEL ANALYSIS	1st Session mind mapping with paper & pen	2nd Session mind mapping with mind map tool & pictures
A. Content Discussions	Processing own idea Processing others' ideas	Processing own idea Processing others' ideas

for this analysis (See Appendix A). To increase the reliability of coding the principal researcher coded the data several times and the whole video data were coded by another trained researcher, thus intercoder reliability (De Wever, Schellens, Valcke, & Van Kerr, 2006) was quantified. Agreement between researchers was 86%. The parts of the data which were in disagreement were discussed in order to find an agreement in coding. After consensus was reached, the whole data was coded again by the principal researcher. Careful coding definitions and several examples are provided in order to increase the validity of the analysis.

Analysis on students' interpretations of the collaborative activity

The second level of analysis focused on the students' interpretations of the collaborative activity. First, the four hours of audio-taped group interviews were transcribed. The transcribed data was then categorized based on the ideas of content analysis. The focus of the analysis was to find out meaningful statements regarding the students' reflection of their learning experience, including how they viewed their group work and the used cognitive tools. Particular interest was given to students' evaluation of the use of pictures as knowledge representations.

RESULTS

The aim of this study was to understand a process of collaborative knowledge construction when technology and pictorial knowledge representations were used for visualizing individual and groups' shared ideas. Particularly, the individuals' knowledge contribution to the groups' collaborative knowledge construction and the individuals' use of each other's ideas and shared tools as a reference in their group learning was analyzed. Next, the results of the study will be presented. First, the results of the content analysis will show how members of a group contribute to their collaborative knowledge construction and use and process each other's ideas further. Second, the results of the stimulated recall interview will demonstrate how students reflected upon the learning situation.

How Do Individuals Contribute to Their Group's Collaborative Knowledge Construction?

Results of the knowledge level analysis show how the students contributed to the group's collaborative knowledge construction. *Processing ideas further* was the most often used activity (f = 384) in all of the groups (See Table 4). *Suggesting actions of how to proceed during the group work* was the second most used activity (f = 297) and the third most used activity was *keeping up the conversa-*

Table 4: Knowledge Level—Collaborative Knowledge Construction Activities

		New idea *f*	Processing *f*	Connecting *f*	Placing *f*	Suggesting actions *f*	Keeping up conversation *f*
1st session mind mapping with paper and pen	G1	14	98	1	18	30	51
	G2	7	32	-	-	12	7
	G3	17	26	13	-	48	59
	G4	6	68	1	11	43	24
		44	**224**	**15**	**29**	**133**	**141**
2nd session mind mapping with pictures	G1	32	91	35	66	79	16
	G2	2	18	19	3	30	6
	G3	17	25	13	1	18	29
	G4	28	26	5	12	37	10
		79	**161**	**72**	**82**	**164**	**61**
		123	**376**	**87**	**111**	**297**	**202**

tion (*f* = 202). *New idea contribution,* including *meaning making for the idea,* was the fourth most used activity (*f* = 123), while the fifth was *placing the ideas in the mind map* (*f* = 111). *Connecting different ideas* was the least used activity (*f* = 87).

The results show that the groups (designated as G1–G4) used different activities to construct knowledge together during the two different collaborative learning sessions (mind mapping with paper and pen, and mind mapping with a mind map tool & pictures) (see Table 4). The most used activity during the *first mind mapping session* with paper and pen was *processing ideas further* (*f* = 224). The second most used activity was *keeping up the conversation* (*f* = 141) and the third was *suggesting actions for how to proceed* (*f* = 133). The frequencies for the other activities were as follows: *contributing new ideas* (*f* = 44), *placing ideas in the mind map* (*f* = 29) and *connecting different ideas* (*f* = 15).

During the *second mind mapping session*, when pictures and technological tools were used, the most used activity was *suggesting actions for how to proceed* in the group work (*f* = 164). The second used activity was the *processing ideas further* (*f* = 161) (see Table 4). *Placing ideas* (and in this session, particularly pictures) in the mind map was the third most used activity (*f* = 82). The frequencies for the other activities were as follows: *meaning making* (*f* = 79), *connecting different ideas* (*f* = 72) and *keeping up the conversation* (*f* = 61).

Groups showed differences with regards to the amount of their utterances and also the type of activities they used (see Table 5, p. 368). Overall, Group 1 had the greatest number of coded utterances (*f* = 523). Group 4 was the second in

Table 5: Knowledge Level—Groups' Differences

	1. Group		2. Group		3. Group		4. Group		
	Paper *f*	Picture *f*	Paper *f*	Picture *f*	Paper *f*	Picture *f*	Paper *f*	Picture *f*	
New idea/ meaning	14	32	7	2	17	17	6	28	**123**
Processing	98	91	32	18	26	25	68	26	**384**
Connecting	1	35	-	19	13	13	1	5	**87**
Placing	18	66	-	3	-	1	11	12	**111**
Suggesting actions	30	79	12	30	48	18	43	37	**297**
Keeping up conversation	51	16	7	6	59	29	24	10	**202**
	212	**319**	**58**	**78**	**163**	**103**	**153**	**118**	**1204**

the amount of utterances (f = 271) while the third was Group 3 (f = 265) and the least amount of utterances was in Group 2 (f = 136). In Group 1 processing ideas further were the most used activity type in the first mind-mapping session (f = 98) and in the second mind mapping session (f = 91). In Group 2 processing ideas further were the most used activity type in the first mind mapping session (f = 32) and suggesting actions how to proceed in the second mind mapping session (f = 30). In Group 3 the most used activity type in the first and in the second mind mapping session was keeping up the conversation (f = 59 and f = 29). In Group 4 the most used activity type in the first mind mapping session was processing ideas further (f = 68) and suggesting actions for how to proceed (f = 37) in the second mind mapping session.

How Do Individuals Use Each Other's Ideas in Their Collaborative Knowledge Construction?

Results of the transactivity level analysis show how the students process presented ideas further—ideas, which are presented either by themselves or other group members. Overall, students *processed others' ideas* (f = 235) more than their *own ideas* (f = 135). Furthermore, students processed ideas more during the *first mind mapping session* (f = 210) than in the *second mind mapping session* (f = 160). However, during the second mind mapping session students' processed others' ideas (f = 112) more than their own (f = 48).

Groups showed differences regarding the amount of processing activities during the different mind mapping sessions (see Table 6). Overall, *Group 1* had the biggest amount of processing activities (the first mind mapping session: f = 91 and the second mind mapping session: f = 92). *Group 4* was the second in the amount of processing activities (the first mind mapping session: f = 68 and the second mind mapping session: f = 26). The frequencies for the other groups' processing activities were as follows: *Group 2* in the first mind mapping session

Table 6: Transactivity Level—Processing Own and Others' Ideas Further

		Processing own ideas *f*	Processing others' ideas *f*	
Paper	G1	35	56	**91**
	G2	11	21	**32**
	G3	10	16	**26**
	G4	38	30	**68**
		87	**123**	**210**
Picture	G1	24	68	**92**
	G2	4	14	**18**
	G3	7	17	**24**
	G4	13	13	**26**
		48	**112**	**160**
		135	**235**	**370**

(f = 32) and in the second mind mapping session (f = 18) and *Group 3* in the first mind mapping session (f = 26) and in the second mind mapping session (f = 24).

When comparing groups' amounts of *processing own ideas* further in the first mind mapping session to the groups' second mind mapping session, all the groups processing activities decreased (see Table 6). Furthermore, the amount of *processing others' ideas* was also compared in the first mind mapping session to the second mind mapping session (see Table 6). Group 1 processed ideas presented by others further during the second mind mapping session (f = 56) more than in the first mind mapping session (f = 68). Whereas the other groups processed ideas presented by others further during the first mind mapping session more than in the second mind mapping session. The following examples (see Appendices B–E, examples 1 to 8) illustrate how groups' activities during the first and the second mind mapping sessions were coded to the above described and used categories. Each coding is illustrated in brackets and coding explanation is offered.

How Students Discuss the Use of Pictorial Knowledge Representations for Collaborative Knowledge Construction?

In the stimulated recall group interview the students were asked to describe what was the most meaningful situation in their group work. The content analysis of the interview data revealed that there were differences in what situations the groups regarded as the most meaningful (see Examples 9–12). Group 1 defined the situation where they started to collect pictures as the most meaningful for their group work (see Example 9, p. 370). However, this group also regarded a discussion before collecting pictures as very important to them, since it formed a common ground and showed a direction of what kind of pictorial knowledge representations they would need.

Example 9: Group's Reflection of the Learning Experience
Group 1

Interviewer: What was the most meaningful situation in your group work?
Gary: I think the most meaningful moment was when we went out of the room… Then there were no limitations. When we worked in the room there was certain limitations, those bits of papers and pens, but when we went out, you needed only to turn your head around and you could notice different things.
Kirsten: Yes, but maybe the mind map was a help; it was some kind of common ground. I think it could have been different without it.
Ann: Yes, probably those themes would have not come to our minds, and maybe we could have not been able to find and connect the things of which we took photographs to our discussions.
Gary: Yes, we would have taken photographs of whatever, if we would have not discussed before, so the discussion was very important
Ann: With that kind of discussion as a starting point, I think it is up to your creativity and imagination. You can find things for every task, but of course you need some kind of direction.

Group 2 stated that the most meaningful situation for them was the creation of the first mind map with paper and pen (see Example 10). This group of students viewed that the mind mapping with paper and pen as a tool was more meaningful for them than using pictures to represent their ideas. Still, they said that in the second mind mapping session their ideas were clearer, they evaluated that the collection of pictures and the use of computer mind map tool distracted their group work. This group felt that their ideas were difficult to represent with pictures.

Example 10. Group's Reflection of the Learning Experience
Group 2

Interviewer: What was the most meaningful situation in your group work?
Emma: I think the two different sessions was a good idea. When you had the first mind map on a paper and when you did the second one, it was much simpler. I mean that those different brainstormed ides were clearer when you did it a second time.
Jake: I think we lost a lot of good information.

Interviewer: Why do you think so?
Jake: I think the space was too small. And I think the pictures were difficult… I have used to express my ideas in a written form, not with pictures.
Kirsty: Yes I think we lost something, since it was hard to find things to take pictures.
Emma: Those things which we tried to represent with pictures were not so concrete, like collaboration and other things. Those are not so easy to put into the pictures.

Group 3 evaluated the situation where they collected pictures as the most meaningful for them, but they regarded also the second mind mapping as important for putting all the ideas together (see Example 11). Furthermore, this group pointed out that mind mapping and group work were challenging for them, but since in this task the orientation was practical, they felt that it was also a rewarding experience for them.

Example 11. Group's Reflection of the Learning Experience
Group 3

Interviewer: What was the most meaningful situation in your group work?
Jane: I think it was when we went outside! And especially taking picture of the motorbike… and of course constructing a mind map, because, especially in a last phase when we needed to put all the ideas together.
Jonathan: That was it, for me… or I mean that I needed to remind myself of what actually mind mapping is and how it works. Because I haven't done those in a long time.
Matt: Well, it is not a really natural way to work for me either. So, maybe it was like Tom said that I didn't know what we were doing and you had to turn or twist your ideas a little bit.

Interviewer: Can you describe a little bit more why you felt that this kind of work was unnatural for you?
Matt: Well, I think it was maybe because I like to think of things as a whole and straightforward.
Jonathan: Ye-es, somehow I feel that lately all the studying has been mostly done alone, so maybe one reason is that I am not used to working in group. But in this I think that since there were more practical actions, we got something else besides theory. I think that is what is the most important".

Group 4 reflected the situation of choosing pictures to be the most meaningful for their work (see Example 12). They also pointed out that the overall design of the task was interesting as an example of the research design and as an example of the pedagogical model.

Example 12. Group's Reflection of the Learning Experience
Group 4

Interviewer: What was the most meaningful situation in your group work?
Zak: Hmmm… maybe the choosing of the things for taking pictures.
Tina: Yes, we went to museum…and that was great fun.
Zaki: Also, this was a good experience of participating in the research. I mean overall, you hardly ever see how research is done.
Tina: This was an interesting experience of the pedagogical model. I could do this kind of experiment with my own students also.

In sum, there were some variations in how groups reflected the learning situation. Most of the groups viewed that visualizing thinking with pictures supported their group activities, but some felt the task too challenging. All of the groups pointed out that negotiation is necessary as a form of grounding, so that the pictures can be grounded on the content discussions.

DISCUSSION

Theoretical framework of distributed cognition provides a possibility to explore learning as a contextually bounded and situated activity, and thus, focus on how individual contributions affect how a group is building up its jointly evolving cognitive system. Extended cognitive systems, including multiple participants interacting with each other and a range of artifacts as a support for their interaction, can provide a basis for the coordination of individual actions (Clark & Brennan, 1991; Hutchins, 1995). Within this extended cognitive system, knowledge can be distributed around a variety of artifacts and other individuals (Salomon, 1993). This study explored the distribution of knowledge in a face-to-face collaborative learning situation, where students were engaged in *knowledge level activities* (Cannon-Bowers & Salas, 2001) and *transactivity level activities* (Teasley, 1997). Knowledge level activities mean individual contributions to the evolving collaborative knowledge construction, while transactivity level is focused on how students refer to the contributions of the group members. The findings of this study indicate that both knowledge level and transactivity level activities need to be explored to see how individuals in a group construct knowledge together.

This study sought to discover how individuals contribute to their group's collaborative knowledge construction (research question 1). The knowledge level analysis showed that the students were active in *processing ideas further* in their group interaction processes. The relatively high amount of *processing* -activities indicate that, in this study, knowledge was distributed between individuals. Processing one's own and others' ideas further is one of the most important activities in collaboration; in addition to contributing various ideas, it is especially needed to elaborate and specify ideas (Andriessen, Baker, & Suthers, 2003; Barron, 2003). Studies of collaborative learning (e.g. Dillenbourg & Traum, 2006; Fisher & Mandl, 2005; Roschelle, 1992) have highlighted that individuals should take part in discussions to converge their knowledge representations, which might lead to new knowledge. The results of this study also showed that the students in groups *suggested specific actions for how to proceed* in their group work. For example, they negotiated how to start group work, how to collect different ideas and how to finish their shared mind map. Fruitful collaboration requires negotiation on how group members co-ordinate their collaboration actions as a group (Barron, 2000; Webb & Palincsar, 1996). Moreover, the results of this study indicate that a level of cognitively challenging activities grows during the group process. It was seen that as student groups proceed in their group learning situations, the amount of *meaning making, placing and connecting ideas* increased and simultaneously activities for *keeping up the conversation* decreased. The amount of *placing* activities show that knowledge was also distributed via tools, either paper and pen or the Mind Map tool, which students used in their collaborative interaction.

The study sought to find out how individuals use each others' ideas in their collaborative knowledge construction (research question 2). In a transactivity level analysis it was seen that students *processed others' ideas further more than their own*. When compared between the different sessions, the results point out that students processed ideas further during the mind mapping session with paper and pen more than in the mind mapping session with pictures. However, when pictures were used as a tool for mind mapping, students processed others ideas further more than their own. This may suggest that pictures were used as affordances for their knowledge construction (Suthers, 2005) and pictures also stimulated the students' shared metacognition (Hurme, Palonen & Järvelä, 2006). However, it can be pointed out that efficiently processing ideas further is cognitively challenging, and particularly when various types of representations are used, cognitive challenges can grow. Sometimes knowledge representations, such as pictures, can be worth of thousand words, but as Schnotz & Bannert (2003) point out, presenting representations is not always beneficial for the acquisition of knowledge and in order to understand a picture rather than only to perceive it, semantic processing is required (Schnotz & Bannert, 2003). Cox (1999) argues that effective reasoning with representations involves a three-way interaction between the cognitive and semantic properties of the representation, the match between the demands of the task and the type of information afforded by the representation and the effects of subject factors, such as prior knowledge and cognitive style. Even though pictorial knowledge representations did not increase the amount of *processing* activities, it increased the amount of *meaning making* activities. It can be pointed out that the quality of the groups' conversation showed that the use of pictorial knowledge representations supported students' collaborative knowledge construction. The students, for example, used multiple metaphors in their conversation, which can contribute to deeper level knowledge construction. Studies of Moschkovich (1996) and Roschelle (1992) have shown that shared metaphors can form a basis for shared understanding in a collaborative learning situation. Meaning making with metaphors is an indicator of deeper level cognitive understanding, and shared metaphors indicate deeper level shared understanding. Notably, this study did not focus on shared understanding, but in future studies it would be important to explore pictorial knowledge representations' role as a mediator for shared understanding.

In order to find out more information about the students' subjective experiences, their accounts for the use of pictorial knowledge representations for collaborative knowledge construction were investigated (research question 3). These results showed that there were some variations in how groups reflected the learning situation. Most of the groups viewed that visualizing thinking with pictures supported their group activities, but some groups felt the task too challenging. All of the groups pointed out that negotiation is needed as a form of grounding, so that the pictures can be grounded on the content discussions.

The results of this study imply that students should be encouraged, when appropriate, to create, modify or co-design the learning environments they work in. Inscription (Pea, 1994), or construction of external representations, can be a successful learning strategy that not only helps students by externalizing and sharing their thoughts, but provides a source of information to teachers about students' current task understanding (Butler & Cartier, 2004). The results of this study encourage teachers and students to use cognitive tools for distributing visual knowledge representations for collaborative learning. There are at least three useful perspectives to be pointed out: Visual representations as cognitive tools can help researchers to better understand student's learning process, they can help teachers evaluate students' learning, and visual representations can help students' self-regulated learning by externalizing what they are themselves thinking and to see what others are thinking and when possible, to then continue their own and others' flow of thinking.

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References

Andriessen, J., Baker, M., & Suthers, D. (2003). Argumentation, computer support, and the educational context of confronting cognitions. In J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 1–25). Dordrecht, Holland: Kluwer.

Arvaja, M., Salovaara, H., Häkkinen, P., & Järvelä, S. (2007). Combining individual and group-level perspectives for studying collaborative knowledge construction in context. *Learning and Instruction, 17,* 448–459.

Barab, S. A., Hay, K. E., Squire, K., Barnett, M., Schmidt, R., Karrigan, K., Yamagara-Lynch, L., & Johnson, C. (2000). The virtual solar system: Learning through a technology-rich, inquiry-based, participatory learning environment. *Journal of Science Education and Technology, 9*(1), 7–24.

Barron, B. (2000). Achieving coordination in collaborative problem-solving groups. *The Journal of the Learning Sciences*, *9*(4), 403–436.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences*, *12*(3), 307–359.

Bazeley, P., & Richards, L. (2000). *The nVivo qualitative project book*. London: Sage.

Butler, D. L., & Cartier, S. C (2004). Promoting effective task interpretation as an important work habit: A key to successful teaching and learning. *Teachers College Record, 106*, 1729–1758.

Cannon-Bowers, J. A., & Salas, E. (2001). Reflections on shared cognition. *Journal of Organizational Behavior, 22*, 195–202.

Chi, M. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, *6*(3), 271–315.

Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 127–149). Washington, DC: American Psychological Association.

Cox, R. (1999). Representation construction, externalised cognition and individual differences. *Learning and Instruction*, *9*(4), 343–363.

De Wever, B., Schellens, M., Valcke, H., & Van Keer, H. (2006). Content analysis schemes to analyze transcripts of online asynchronous discussion groups: a review. *Computers & Education, 46*, 6–28.

Dillenbourg, P. & Traum, D. (2006). Sharing solutions: persistence and grounding in multimodal collaborative problem solving. *The Journal of the Learning Sciences*, *15*(1), 121–151.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *The Journal of the Learning Sciences, 8,* 391–450.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, *87*(3), 215–251.

Fischer, F. & Mandl, H. (2005). Knowledge convergence in computer-supported collaborative learning: the role of external representation tools. *The Journal of the Learning Sciences*, *14*(3), 405–441.

Goodwin, C. (2000). Actions and embodiment within situated human interaction. *Journal of Pragmatics, 32*, 1489–1522.

Hmelo-Silver, C. E. (2003). Analyzing collaborative knowledge construction: Multiple methods for integrated understanding. *Computers and Education, 41*, 397–420.

Hurme, T-R., Palonen, T., & Järvelä, S. (2006). Metacognition in joint discussions: An analysis of the patterns of interaction and the metacognitive content of the net worked discussions in mathematics. *Metacognition and Learning*, *1*(1), 181–200.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA: MIT Press.

Hutchins, E., & Clausen, T. (1998). Distributed cognition in an airline cockpit. In Y. Engeström, & D. Middleton (Eds.), *Cognition and communication at work* (pp. 15–34). New York: Cambridge University Press.

Jonassen, D. H., & Carr, S. (1999). Mindtools: Affording multiple knowledge representations for learning. In S. P. Lajoie (Ed.), *Computers as cognitive tools II: No more walls: Theory change, paradigm shifts and their influence on the use of computers for instructional purposes* (pp. 165–196). Mahwah, NJ: Lawrence Erlbaum Associates.

Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology: Using computers as cognitive tools. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 693–719). New York: Macmillan.

Lajoie, S .P. (1993). Cognitive tools for enhancing learning. In S.P. Lajoie & S.J. Derry (Eds.), *Computers as cognitive tools* (pp. 261–289). Hillsdale, NJ: Erlbaum.

Linell, P. (1998). *Approaching dialogue: Talk, interaction and contexts in dialogical perspectives*. Amsterdam: John Benjamins.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis*. London: SAGE Publications.

Moschkovich, J. N. (1996). Moving up and getting steeper: Negotiating shared descriptions of linear graphs. *The Journal of the Learning Sciences*, *5*(3), 239–277.

Pea, R. D. (1993). Practises of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). Cambridge, UK: Cambridge University Press.

Pea, R. D. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. *Journal of the Learning Sciences*, *3*(3), 285–299.

Pea, R. D., & Maldonando, H. (2006). WILD for learning: Integrating through new computing devices anytime, anywhere. In K. Sawyer (Ed.), *Cambridge University handbook of the learning sciences* (pp. 427-441). New York: Cambridge University Press.

Perkins, D. N. (1993). Person-plus: A distributed view of thinking and learning. In G. Salomon (Ed.). *Distributed cognitions: Psychological and educational considerations* (pp. 88–110). Cambridge, UK: Cambridge University Press.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *The Journal of the Learning Sciences*, *2*(3), 235–276.

Roschelle, J. (2003). Keynote paper: Unlocking the learning value of wireless mobile devices. *Journal of Computer Assisted Learning*, *19*(3), 260-272.

Roschelle, J., & Pea, R. (2002). A walk on the WILD side: How wireless handhelds may change computer supported collaborative learning. *International Journal of Cognition and Technology*, *1*(1), 145–168.

Roschelle, J. & Teasley, S. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer supported collaborative learning* (pp. 67–97). Heidelberg: Springer-Verlag.

Salomon G. (1993). No distribution without individual's cognition: A dynamic interaction view. In G. Salomon (Ed.), *Distributed cognition: Psychological and educational considerations*. (pp. 111–138). Cambridge: Cambridge University Press.

Salomon, G., & Perkins, D. N. (1998). Individual and social aspects of learning. In A. Iran-Nejad (Ed.), *Review of research in education* (Vol. 23, pp. 1–24). Washington, DC: American Educational Research Association.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction*, *13*(2), 141–156.

Sharples, M., Taylor, J., & Vavoula, G. (2007). A theory of learning for the mobile age. In R. Andrews, & C. Haythornthwaite (Eds.), *The sage handbook of e-learning research* (pp. 221–247). London: Sage.

Suthers, D. (2005). Technology affordances for intersubjective learning, and how they may be exploited. In R. Bromme, F. W. Hesse, & H. Spada (Eds.), *Biases and barriers in computer-mediated knowledge communication: And how they may be overcome* (pp. 295–319). Boston: Kluwer Academic Publishers.

Teasley, S. (1997). Talking about reasoning: How important is the peer in peer collaboration? In L. B. Resnick, R. Säljö, C. Pontecorvo, & B. Burge (Eds.), *Discourse, tools and reasoning: Essays on situated cognition* (pp. 361–384). Berlin: Springer.

Teasley, S. D., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 229–258). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Van Someren, M. W., Reimann, P., Boshuizen, H. P. A., & de Jong, T. (1998). *Learning with multiple representations.* Amsterdam: Elsevier Science, Ltd.

Webb, N. M., & Palincsar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 841–873). New York: Simon & Schuster Macmillan.

APPENDIX A: Coding Structure

Name of the category		Description of the category
	New idea	Student contributes new idea to the discussion
	Meaning making	Student states what a picture represents
	Processing	Student further processes idea presented by him/herself or other group members
	Connecting	Student finds connections between different ideas
	Placing	Student finds a place for the idea in a mind map
	Suggesting actions	Student suggests how the group work could proceed
	Keeping up conversation	Student keeps up the conversation either by stating that he/she is listening to what others are saying or discusses off-task issues

APPENDIX B: Group 1. Example from the 1st and the 2nd mind mapping sessions and the group's constructed mind map

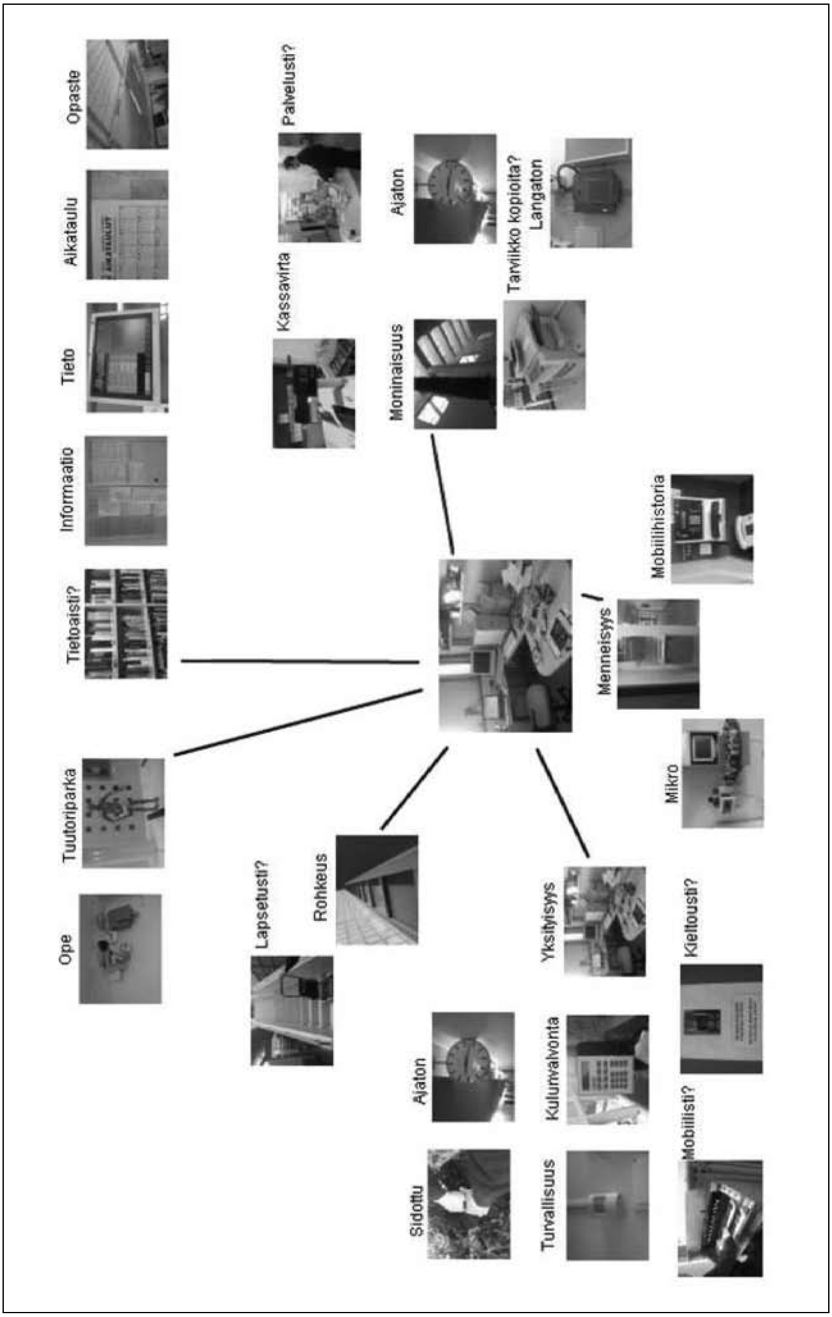
Example 1. Group 1. The first mind mapping session with paper and pen

Transcribed and coded conversation	Explanation
41. Kirsten: And those **technical skills** are never enough; we have been doing web pages today and I'm still quite lost. *[A. CONTENT/ Processing idea [row 33] further/ own idea]*	Kirsten is continuing the idea she presented earlier (row 33 in the transcriptions) by saying that she thinks that more technical skills would be needed.
42. Ann: Yes, I feel the same. I think my **skills have improved** a lot during these studies, but still more is needed. *[A. CONTENT/ Processing idea [row 33] further/ Kirsten's idea]*	Ann continues Kirsten's idea of technical skills and says that her skills have improved but not enough.
43. Kirsten: Mmmh, I think I **wouldn't still manage** it all by myself. *[A. CONTENT/ Processing idea [row 33] further/ own idea]*	Kirsten continues the discussion of technical skills and says that she still wouldn't manage technical tasks by herself.
44. Sandy: Exactly, and I think I now have a **broader view** of what different things this area of educational technology includes and what can be done. *[A. CONTENT/ Processing idea [row 33] further/ Kirsten's idea]*	Sandy enters the discussion and continues on with the ideas of technical skills by saying that she now has a broader view of different possibilities than she had before the study.

45. Ann: Ok, what next? *[B. ACTION/ suggesting actions]*	Ann suggests proceeding actions by asking what the group should do next.
46. Gary: Hmmmh, I wrote here ability to choose **correct information** *[A. CONTENT/ New idea]*	Gary enters to discussion and contributes new ideas of information to be discussed.
47. Ann: Where to put it, is it by itself or? *[A. CONTEN/Placing]*	Ann reacts to Gary's idea by asking where the idea could be placed in the mind map.

Example 2. Group 1. The second mind mapping session with pictures and Mind Map tool

Transcribed and coded conversation	Explanation
19. Kirsten: Should **information, timetable** and choosing the correct information *(reference to a picture)* be together? *[A. CONTENT/Connecting]*	Kirsten contributes an idea to connect information and the timetable together.
20. Gary: Yes, take all those [reference to the pictures] and those **other information things** *(reference to a picture)* also, and put those in here. *[A. CONTENT/ Placing]*	Gary shows agreement for Kirsten's suggestion and contributes the idea of where to place pictures.
21. Sandy: Yes, put it *(reference to a picture)* next to those *(reference to the pictures)* *[A. CONTENT/ Placing]*	Sandy enters to the discussion, shows agreement for Gary's suggestion of placing the pictures.
22. Gary: Yeah, it goes. *[B. ACTION/Keeping up the conversation]*	Gary keeps up the conversation by showing a positive mood on how the group is proceeding.
23. Kirsten: How I will put these *(reference to a picture*), should those be next to each other? *[A. CONTENT/Placing]*	Kirsten asks assistance on how to place pictures and makes a suggestion of where she would place the pictures.
24.Ann: we can move them later *[B. ACTION/Suggestion]*	Ann enters the discussion and suggests that they can also move the pictures later.



Picture 2: Mind map, group 1.

APPENDIX C: Group 2. Example from the 1st and the 2nd mind mapping sessions and the group's constructed mind map

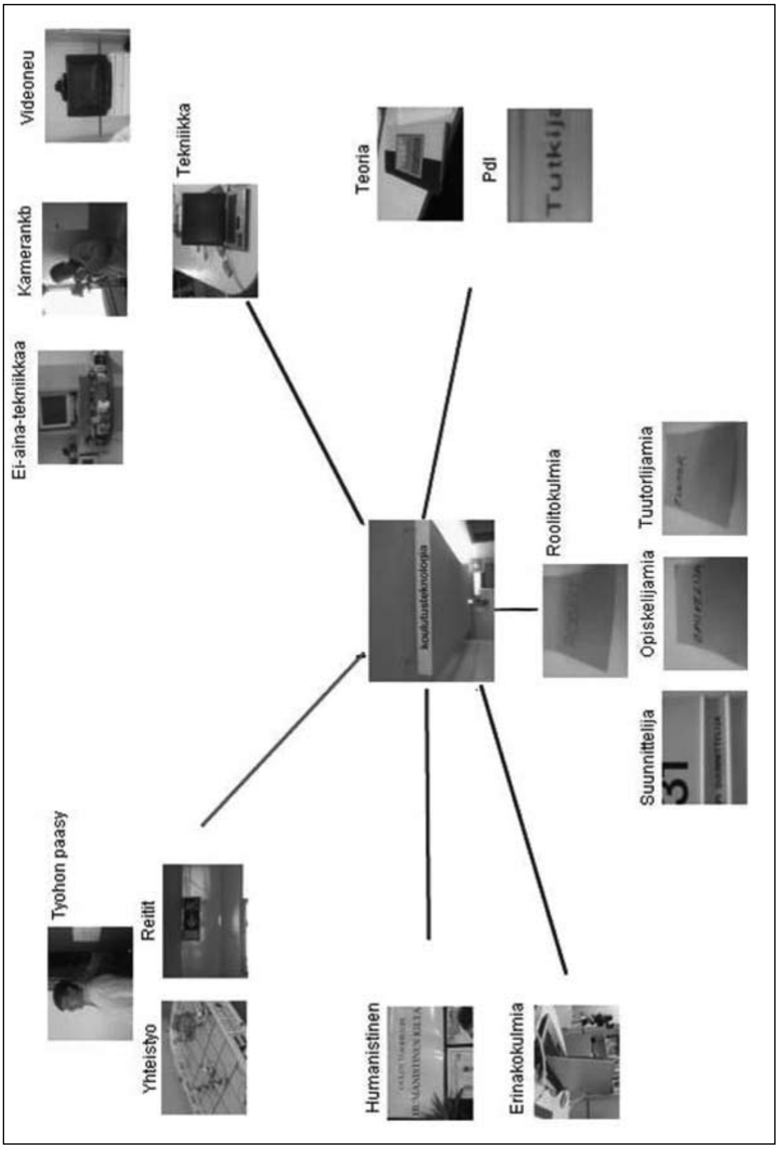
Example 3. Group 2. The first mind mapping session with paper and pen

Transcribed and coded conversation	Explanation
1. Jake: **Perspectives on technology**, at least for me, I mean like more ideas for that. *[A. CONTENT/New idea]*	Jake starts the discussion by contributing an idea on technology.
2. Kirsten: Yes, and also that the whole **attitude** towards technology has changed after these studies; I mean that in here the point of view is in what it can be used, not only how it can be used. *[A. CONTENT/ Processing idea (row 1.) further/ Jake's idea]*	Kirsten continues Jake's idea of technology by saying that her whole attitude towards technology has changed due to studies.
3.Emma: But also, I think I have learned **how to use** different technologies, and now I know more technological concepts than before. *[A. CONTENT/ Processing idea (row 1.) further/ Jake's idea]*	Emma enters the discussion and continues Jake's idea by saying that she has learned new skills and technological concepts.
4. Sarah: And then, well, hmm, like if you know how to use those, then maybe it is a **benefit in applying for a job.** *[A. CONTENT/ Processing idea (row 1.) further/ Jake's idea]*	Sandy enters the discussion and continues Jake's idea further by pointing out those technological skills can be valuable in applying for a job.

Example 4. Group 2. The second mind mapping session with pictures and Mind Map tool

Transcribed and coded conversation	Explanation
45. Kirsty: **Routes**, what does this mean, like.. *[A. CONTENT/Meaning]*	Kirsty points to picture and asks what it means.
46. Jake: It means different **studying routes** or trails *(reference to a picture)* *[A. CONTEN/Meaning]*	Jake gives an answer to Kirsty's question and says that the picture represents different studying routes.
47. Sarah: Does it go together with **employment** *(reference to a picture)*, even though we didn't plan it to go there? *[A. CONTENT/Connecting]*	Sarah enters the discussion and connects the idea of study routes to employment.
48. Jake: And then we have this idea of a **researcher** *(reference to a picture),* is it there in **roles** *(reference to a picture)* or… no it wasn't *[A. CONTENT/Connecting]*	Jake continues the discussion by connecting the idea and the picture of a researcher to the idea and the picture of roles.

49. Sarah: Is it connected to this **theory** *(reference to a picture)* ? *[A. CONTENT/Connecting]*	Sarah asks if the picture of the researcher is connected to the picture of theory.
50. Kirsty: Hmm, maybe yes, but it could also be here with **roles** *(reference to a picture)* *[A. CONTENT/Connecting]*	Kirsty continues by pointing out that the picture of a researcher could be connected to the various ideas, either with the picture of theory or with the picture of roles.



Picture 3: Mind map, Group 2.

APPENDIX D: Group 3. Example from the 1st and the 2nd mind mapping sessions and the group's constructed mind map

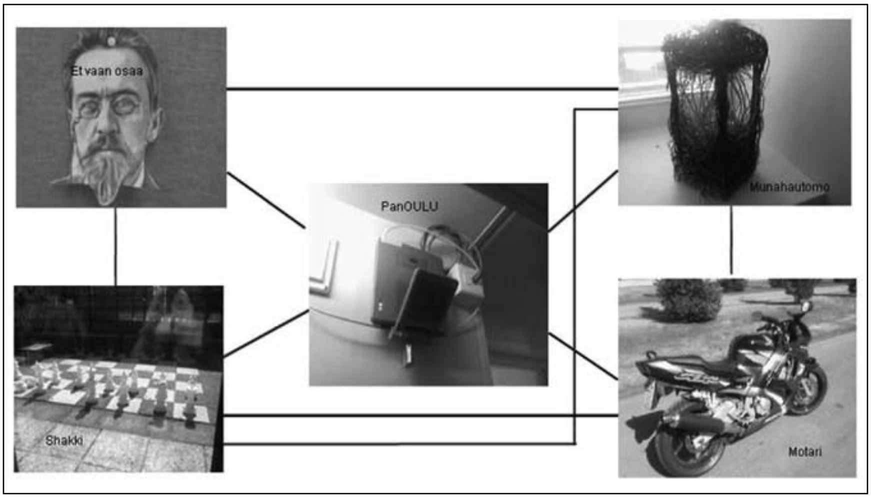
Example 5. Group 3. The first mind mapping session with paper and pen

Transcribed and coded conversation	Explanation
31. Matt: I think one important thing is to be **open minded** to new things. *[A. CONTENT/New idea]*	Matt contributes a new idea for discussion by pointing out the importance of keeping an open mind for new things.
32. Jane: hmm-m *[B. ACTION/Keeping up the conversation]*	Jane reacts to Matt's contribution but does not process it further.
33. Jonathan: What ever it is… I mean open mind **for new technologies or pedagogical ideas** or whatever. *[A. CONTENT/Processing idea [row 31] further/ Matt's idea]*	Jonathan continues Matt's idea by saying that an open mind should be towards new technologies and new pedagogical ideas.
34. Matt: This has something to do with what you said, I mean, like overall, keeping up in the **spirit of times**, like, following what's happening in the world. *[A. CONTENT/Processing idea [row 31] further/ own idea]*	Matt continues his own idea by saying that one should keep up in the spirit of times.
35. Jonathan: Yes and you **are not afraid** if there is for example… hmm.. new version of Skype 1.8 or something, and you are able to learn how to use it. *[A. CONTENT/Processing idea [row 31] further/ Matt's idea]*	Jonathan continues Matt's idea by saying that one should not be afraid of new things.

Example 6. Group 3. The second mind mapping session with pictures and the Mind Map tool

Transcribed and coded conversation	Explanation
31. Jonathan: **Chess** (*reference to a picture)* represents the mind, thinking, logic and meaning behind everything and **motorbike** (*reference to a picture)* represents movement, technology and simply that we are going somewhere. *[A. CONTENT/Meaning making]*	Jonathan is pointing out the picture of a chess board and the picture of a motorbike. He argues that chess represents cognitive abilities of individuals and the motorbike represents movement and development forward.

45. Matt: This **old man** *(reference to a picture)* is conservative, who is against everything new, especially against new **technology** *(reference to a picture),* who either is afraid of technology since he doesn't know how to use if or doesn't want to change and it is linked to this **bird's nest** *(reference to a picture*), which represents a research unit. *[A. CONTENT/Meaning making and connecting]*	Matt is pointing out the picture of a painting, picture of wlan and picture of a bird's nest. He argues that painting represents a conservative person who is against new technology (which is here represented with the picture of wlan) and a bird's nest represents research unit.
47. Jane: Or, I think this **bird's nest** *(reference to a picture)* is something that symbolizes where we are, and when we are ready, we will fly away from the nest. Is it something like that? *[A. CONTENT/Meaning making and connecting]*	Jane continues Matt's idea of the bird's nest and she argues that the nest is a place where it is possible to develop various skills.
59. Matt: But you need **knowledge and skills** *(reference to a picture)* and **right movement** *(reference to a picture)* in the **bird's nest** *(reference to a picture)*. **Thinking** (*reference to a* picture) and **movement** *(reference to a picture)* need to be together, since movement without thinking is a waste of time. *[A. CONTENT/Meaning making and connecting]*	Matt continues and with this utterance he connects the picture of a chess board, the picture of a motorbike and the picture of nest. He argues that thinking, movement and development need to be connected together.
63. Jane: So of course this **man** here (*reference to a picture)*, either he is academic or conservative or whatever; he **thinks** *(reference to a picture)* *[A. CONTENT/Meaning making and connecting]*	Jane continues and with this utterance she connects the picture of painting and the picture of chess. She argues that the person who resists development also thinks.
64. Matt: Yes, he thinks, but mainly about how to protect himself against new **things** *(reference to a picture)*. *[A. CONTENT/Meaning making and connecting]*	Matt continues Jane's idea of painting and the chess board and argues that the person thinks how to protect himself from changes.
65. Jane: So, he has **ideas** for this chess game *(reference to a picture)*, but this guy is not a favoring **speed and movement** *(reference to a picture).* *[A. CONTENT/Meaning making and connecting]*	Jane continues and concludes by using the pictures of painting, chess and the motorbike. She argues that the person thinks but is not favouring speed and movement.



Picture 4: Mind map, Group 3.

APPENDIX E: Group 4. Example from the 1st and the 2nd mind mapping sessions and the group's constructed mind map

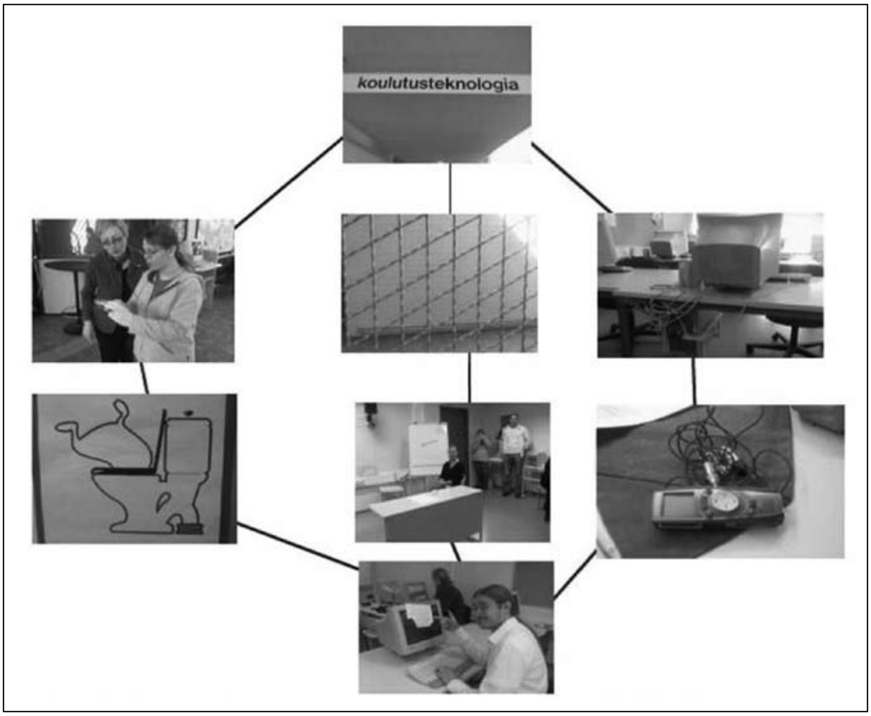
Example 7. Group 4. The first mind mapping session with paper and pen

Transcribed and coded conversation	Explanation
12. Zak: Well then, hmm, one important thing could be technology or like technical things for… like I mean the use of **technology as a tool.** A. CONTENT/ Processing idea [row 1] further/Own idea	Zak continues the idea he presented earlier during the discussion. He points out that technology is a tool.
13. Tina: yeas, technical skills and like **courage** to use technology for several purposes. A. CONTENT/ Processing idea [row 1] further/ Sakari's idea.	Tina continues Zak's idea and points out that technical skills can enhance one's courage to use technology for several purposes.
14. Zak: hmm, yeah, like when you know something about how to use it, you get encouraged **to try out different things**. A. CONTENT/ Processing idea [row 1] further/Own idea	Zak continues and shows an agreement to Tinas idea by saying that when one has some level of skills one can get more courage also to try out different things.

15. Tina: But in the end, it is up to you, like you might get some hints of how to use technology but **you need to practice** by yourself a lot. A. CONTENT/ Processing idea [row 1] further/Zak's idea	Tina continues the idea by saying that further practice of skills is needed.

Example 8. Group 4. The second mind mapping session with pictures and Mind Map tool

Transcribed and coded conversation	Explanation
57. Zak: Was this *(reference to a picture)* something like **new perspectives?** A. CONTENT/Meaning	Zak points to the picture and requests to know if the picture represents new perspectives.
58. Tina: yes, and this was **courage** *(reference to a picture)* and then we should put this one, this is **skills to use technology** *(reference to a picture)*, is it? A. CONTENT/Meaning	Tina agrees and points to the other picture and states that the picture represents courage and the other picture represents the use of technology.
59. Zak: Hmm, yes, technology, lets put it *(reference to a picture)* in here. A. CONTENT/Placing	Zak continues by suggesting a place for the picture of technology in a mind map.
60. Tina: But was the **new perspectives** *(reference to a picture)* in here, or where should we put it? A. CONTENT/Placing	Tina continues by suggesting a place for the picture of new perspectives in a mind map.
61. Zak: Hmm B. ACTION/Keeping up the conversation	Zak reacts to Tina's suggestion but does not process it further.
62. Tina: And then, what else do we have? B. ACTION/Suggestion	Tina suggests proceeding actions by asking what pictures the group has.
63. Zak: We don't have anything about teaching yet; should we put **pedagogical models**… this picture was about pedagogical models *(reference to a picture)*, was it? A. CONTENT/Meaning	Zak reacts to Tina's suggestion and states that they don't have a picture of a pedagogical model and he points out which picture represents a pedagogical model.



Picture 5: Mind map, group 4.