OULU 2010
E 108

ACTA UNIVERSITATIS OULUENSIS

E
SCIENTIAE RERUM
SOCIALIUM

Tarja-Riitta Hurme

METACOGNITION IN GROUP PROBLEM SOLVING— A QUEST FOR SOCIALLY SHARED METACOGNITION

FACULTY OF EDUCATION,
DEPARTMENT OF EDUCATIONAL SCIENCES AND TEACHER EDUCATION,
UNIVERSITY OF OULU

ACTA UNIVERSITATIS OULUENSIS
E Scientiae Rerum Socialium 108

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METACOGNITION IN GROUP PROBLEM SOLVING— A QUEST FOR SOCIALLY SHARED METACOGNITION

Academic dissertation to be presented with the assent of the Faculty of Education of the University of Oulu for public defence in Kaljusensali (Auditorium KTK 112), Linnanmaa, on 24 September 2010, at 12 noon

UNIVERSITY OF OULU, OULU 2010

Acta Univ. Oul. E 108, 2010

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ISBN 978-951-42-6269-2 (Paperback)
ISBN 978-951-42-6270-8 (PDF)
http://herkules.oulu.fi/isbn9789514262708/
ISSN 0355-323X (Printed)
ISSN 1796-2242 (Online)
http://herkules.oulu.fi/issn0355323X/

Cover design
Raimo Ahonen

JUVENES PRINT
TAMPERE 2010

Hurme, Tarja-Riitta, Metacognition in group problem solving—a quest for socially shared metacognition

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Acta Univ. Oul. E 108, 2010
Oulu, Finland

Abstract

The aim of this study was to explore metacognition, specifically *socially shared metacognition* within computer-supported collaborative problem solving. Another aim of this study was to find methodological solutions for uncovering how metacognition becomes visible and shared in group problem solving in a text-based and asynchronous learning environment.

During this dissertation study, two empirical experiments were performed. Participants in the first experiment were secondary school students (N=16) who worked with the Knowledge Forum (KF) learning environment. In the second experiment, triads of pre-service teachers' (N=18) problem solving was supported by the Workmates (WM) learning environment. The data of this study consist of discussion forum data, self-report questionnaires, and individual's feeling of difficulty graphs. In the data analysis, quantitative and qualitative research methods, along with individual and group level analyses, were combined to provide a deeper understanding of the phenomena being studied. A qualitative content analysis of the computer notes at the cognitive, metacognitive and social level were first analysed at the individual level, which made visible individual thinking and characterized the nature of the online discussions. In the interpretation phase, the categorizations were interpreted as group level processes in order to examine the contextual development of collaborative problem solving. To accomplish this, a process-oriented graph of group problem solving was developed. Further, to understand how socially shared metacognition in group problem solving can be related to individual metacognition, especially metacognitive experiences, group members' individual feelings of difficulty were combined with the results of the discussion forum data.

The results of this study show that the process of *socially shared metacognition* is a differentiator in the success of a group's mathematical problem solving. Socially shared metacognition requires that group members participate in joint problem solving intentionally and reciprocally, acknowledge each other's thinking and develop their ideas further. In other words, the process of socially shared metacognition has intention to steering the discussion rather than exchanging ideas about possible ways to solve the tasks. Further, the results of this study suggest that if the process of socially shared metacognition emerges, then the most of students will be able to reduce their feelings of difficulty. The results of this study suggest that socially shared metacognition is a complex and extra-ordinary group-level phenomenon. Socially shared metacognition could become more visible if participants focus on analysing the task and verifying the process as well as the outcome of the problem solving instead of exploring and implementing various unelaborated solution efforts. While socially shared metacognition fosters success in group problem solving, it also helps individual's thinking grow as a part of the group.

Keywords: computer supported collaborative learning, mathematical problem solving, metacognition, socially shared metacognition

Hurme, Tarja-Riitta, Sosiaalisesti jaettu metakognitio ryhmän ongelmanratkaisussa
Kasvatustieteiden tiedekunta, Kasvatustieteiden ja opettajankoulutuksen yksikkö, Oulun yliopisto, PL 2000, 90014 Oulun yliopisto
Acta Univ. Oul. E 108, 2010
Oulu

Tiivistelmä

Tässä tutkimuksessa selvitetään metakognition, erityisesti sosiaalisesti jaetun metakognition, ilmenemistä tietokoneavusteisessa yhteisöllisessä matematiikan ongelmanratkaisussa. Tutkimuksen tavoitteena on myös kehittää aineiston analysointimenetelmiä metakognition ja erityisesti sosiaalisesti jaetun metakognition tutkimiseksi.

Tutkimus koostuu kahdesta empiirisestä osatutkimuksesta. Ensimmäisessä tutkimuksessa koehenkilöinä olivat erään perusasteen yläkoulun seitsemännen luokan suomalaiset oppilaat. Toisessa tutkimuksessa koehenkilöinä toimivat ensimmäisen vuosikurssin suomalaiset luokanopettajaopiskelijat. Molemmissa tutkimuksissa yhteisöllisen ongelmanratkaisuprosessin tukena käytettiin tekstipohjaiseen, eriaikaiseen vuorovaikutukseen perustuvia oppimisympäristöjä: Knowledge Forumia ja Työporukkaa (engl. WorkMates, WM). Tutkimusaineisto koostuu verkkokeskustelukommenteista, kyselylomakkeista sekä ongelmanratkaisutehtävän jälkeen piirretyistä graafeista, jotka ilmentävät tehtävän aikana koettua vaikeuden tunnetta.

Ongelmanratkaisuprosessia kuvaavassa analyysissa yhdistetään sekä kvalitatiivisia että kvantitatiivisia menetelmiä sosiaalisesti jaetun metakognition tutkimiseksi. Verkkokeskusteluaineistoa analysoidaan yksilötasolla kvalitatiivisen sisällönanalyysin periaatteiden mukaisesti. Osallistujien tallentamat verkkokeskustelukommentit on luokiteltu kognitiivisiksi, metakognitiivisiksi tai sosiaalisiksi viesteiksi. Viestien sisällön tulkinta perustuu ainoastaan kirjoitettuun tekstiin eikä osallistujien ajatteluun viestien taustalla. Verkkokeskusteluaineistoa tulkitaan ryhmätasolla erilaisten visualisointimenetelmien, kuten sosiaalisen verkostoanalyysin ja ryhmän ongelmanratkaisua kuvaavan graafin, avulla. Sosiaalisesti jaetun metakognition yhteyttä yksilön metakognitioon, erityisesti tehtävään liittyvään vaikeuden tunteeseen, tutkitaan ryhmän ongelmanratkaisua kuvaavien graafien, verkkokeskustelukommenttien ja ongelmanratkaisutehtävän jälkeen piirrettyjen tehtävän aikana koettua vaikeutta kuvaavien graafien avulla.

Sosiaalisesti jaettua metakognitiota ei ilmene yleisesti ryhmän ongelmanratkaisussa. Tähän vaikuttaa muun muassa se, ettei ryhmissä kiinnitetä huomiota tehtävänantoon ja saadun ratkaisun oikeellisuuteen, vaan pääpaino ongelmanratkaisussa on ratkaisumenetelmien etsimisessä ja esitettyjen ehdotusten toteuttamisessa. Tämän tutkimuksen tulokset kuitenkin osoittavat, että sosiaalisesti jaettu metakognitio on ilmiönä monitahoinen. Tulosten perusteella sosiaalisesti jaettu metakognitio on myös tärkeä tekijä ryhmän ongelmanratkaisussa. Onnistuneessa ongelmanratkaisussa ryhmän jäsenet sitoutuvat yhteiseen prosessiin ja toimivat vastavuoroisesti perustellen esittämänsä ajatukset sekä huomioiden ratkaisun kannalta tärkeät kysymykset ja ratkaisuehdotukset. Tällöin on mahdollista, että sosiaalisesti jaettu metakognitio vähentää useimpien ryhmän jäsenten kokemaa vaikeuden tunnetta.

Sosiaalisesti jaetulla metakognitiolla näyttää olevan tärkeä tehtävä paitsi ryhmän myös yksilön ajattelussa.

Asiasanat: matematiikka, metakognitio, ongelmanratkaisu, sosiaalisesti jaettu metakognitio, tietokoneavusteinen yhteisöllinen oppiminen

Acknowledgements

A way forward in a PhD study is challenging in reaching the phenomenon under study. In my way, the steps taken were enriched by the knowledge and expertise of friends and collaborators.

I want to express my gratitude to Professor Sanna Järvelä who has been the supervisor of my PhD study. It has been inspiring to follow her working not only to find new challenges and to contribute to the field but also dedicating her time and effort for the Learning and Educational Technology Research Unit (LET). I wish to thank her for the constant support and encouragement she has given me during these years.

I am grateful to the reviewers of the thesis, Associate Professor Allyson Hadwin and Professor Jari Lavonen. I truly think that their constructive comments have helped me to learn more about the themes addressed in this study. I highly appreciate Associate Professor Hadwin's work on metacognition and self-regulated learning research and therefore I feel privileged to have received her comments on my thesis.

I also want to express my gratitude to Professor Kaarina Merenluoto. In addition to offering me opportunities to work in different projects, getting involved in different academic efforts and daily hard work with her has made me to see that my work is relevant and meaningful. I also wish to thank Professor Erno Lehtinen and Professor Marja Vauras who have supported my work and provided "a second university home" for this study at the Centre of Learning Research, the University of Turku.

It is my pleasure to thank two experts as well, Senior Researchers Tuire Palonen and Pekka Salonen, who are the co-authors in the original publications. Discussions with them have contributed to my dissertation and have been invaluable to me. Further, Professor Leena Syrjälä receives my respectful thanks for her advice and encouragement in my academic efforts.

During my PhD studies, I had an opportunity to work first at LET and currently at the Centre for Learning Research. Thus, all of the colleagues and friends who work or have been working at LET during the recent years get my sincere thanks for support. Further, my thanks belong to my current co-workers and colleagues who have been working at the Centre for Learning Research, especially in Educational Technology Unit. In particular, I want to express my appreciation for Hanna Järvenoja, Niina Junttila and Marjaana Veermans for the shared academic experiences and support in various issues. I would also like to thank Kari Nurmela and Jani Pöyhönen not only for their technical support but also the discussions we have had, for all the sense and nonsense. Jake McMullen I wish to thank for his corrections of the English language of this thesis.

My sincere thanks belong also to several colleagues and PhD-students. Discussions and meetings in conferences with Johanna Bluemink, Piritta Leinonen, Hanna Salovaara, and Kati Mäkitalo-Siegl have promoted my thinking.

There are also many national and international collaborators who have shared their expertise with me and supported my work. I want to express my thanks to Doctor Egbert G. Harskamp and Professor Celia Hoyles who devoted some of their time for commenting on my papers. Professor Erkki Pehkonen receives my respectful thanks for his encouragement and support in my PhD study.

This study was financially supported from many sources. I greatly appreciate all the funding from Doctoral Programme for Multidisciplinary Research on Learning Environments, The Finnish Graduate School of Mathematics, Physics, and Chemistry Education, Finnish Cultural Foundation, and the University of Oulu, Faculty of Education. Further, I would like to express my gratitude to the participants whose involvement in the studies made the thesis possible.

I want to express my warm thanks to my family, including my parents, grandmother, brother and his family, for their support and encouragement.

Finally, my warmest gratitude belongs to my dearest ones; my husband Martti and my two beloved children Petra and Niklas. Thank you three for making my life so meaningful.

Turku, June 2010 Tarja-Riitta Hurme

List of original articles

This thesis is based on the following articles which are referred to in the text by their Roman numerals:

I Hurme, T-R.(*) & Järvelä, S. (2005). Students' activity in computer supported collaborative problem solving in mathematics. *International Journal of Computers for Mathematical Learning, 10,* 49–73.

II Hurme, T-R.(*), Palonen, T., & Järvelä, S. (2006). Metacognition in joint discussion: an analysis of the patterns of interaction and the metacognitive content of the networked discussions in mathematics. *Metacognition and Learning, 2*, 181–200.

III Hurme, T-R.(*), Merenluoto, K., Salonen, P., & Järvelä, S. (2009). Regulation of group's problem solving – a case for socially shared metacognition? Manuscript.

IV Hurme, T-R.(*), Merenluoto, K., & Järvelä, S. (2009). Socially shared metacognition of pre-service primary teachers in a computer-supported mathematics course and their feelings of task difficulty: a case study. *Educational Research and Evaluation, 15,* 503–524.

The position in the byline order indicates each author's responsibility and contribution for a study design, data collection, data analysis and interpretations, and reporting. Corresponding author (*), supervised by Professor Sanna Järvelä, has the main responsibility in the different phases of the study.

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1 Introduction

The current development of network technologies, like social media and web 2.0, has provided people with new ways to interact with each other. These mediums are entering the educational field as a means of support for the collaboration among learners. However, research has shown that the tool in itself does not guarantee that interaction will lead to higher-level discussion and learning (Häkkinen, 2004; Häkkinen & Järvelä, 2006). Metacognition, since the pioneering work of Flavell (1979) and Brown (1987), has been recognized as essential for learning (e.g. Brown & Campione, 1994), and as being one of the most powerful predictors of learning (Wang, Haertel, & Walberg, 1990). In the 21st century, metacognition research is still topical as learners of all ages need metacognitive support when working with computer-based learning environments (Azevedo, 2002; Azevedo, 2005; Azevedo, Moos, Greene, Winters, & Cromley, 2008; Bannert, Hildebrand, & Mengelkamp, 2009). Furthermore, there is not much knowledge of how groups metacognitively regulate their joint problem solving in a computer-supported collaborative learning context (e.g. Winters, Greene, & Costich, 2008). In order to advance the understanding of metacognition in a computer-supported collaborative learning context, a case of socially shared metacognition in mathematical problem solving is examined in this dissertation.

In the 1980's, learner-centered methods of instruction and collaborative learning approaches, together with potential learning technologies, were combined to improve learning and instruction in various areas of education. These constitute the pedagogical framework of computer-supported collaborative learning, CSCL (Dillenbourg & Fischer, 2007; Koschmann, 1996; Koschmann, Hall, & Miyake, 2002). One of the core concepts of CSCL is that learners *make* their *thinking visible* by explaining, questioning, and providing arguments and counterarguments (Collins, Brown, & Holum, 1991; Lehtinen, 2003). These processes require individual metacognition, but they also trigger subsequent judgments and monitoring within the group's learning (cf. Brown, 1997; Flavell, 1979; Suthers, 2006; Karabenick, 1996). Further, using network technologies can provide new arenas for mathematics learning (De Corte, 2000). Integrating mathematical problem solving into CSCL environments provides potentially significant opportunities for promoting peer questioning and explanations about mathematics in order to make metacognition visible.

In summary, the aim of this thesis is to contribute to the understanding of socially shared metacognition in computer-supported collaborative mathematical problem solving. The other aim is to develop methods to examine metacognition in social learning situations.

The thesis consists of two parts. The first part describes the theoretical framework of the study, the methodological background, and finally the main findings and a general discussion. The second part consists of four articles published by (or submitted to) international peer-reviewed journals. The articles cover the body of empirical results from this dissertation study.

2 Theoretical framework

Research of learning has been intensive during the last decades. Since the 1990’s, there has been an ongoing debate between the cognitive and sociocultural perspectives of learning. These two perspectives have one main epistemological difference. In the cognitive perspective knowledge resides either in mental models within an individual’s mind, while in the sociocultural perspective knowledge is seen as socially derived (Alexander, 2007; Greeno, Collins, & Resnick, 1996). Further, the ontological status of knowledge is different among these two perspectives (Vosniadau, 2007, 56). This difference is described by Sfard (1998), who suggests two metaphors for learning; acquisition and participation metaphors. The acquisition metaphor, related to the cognitive perspective of learning, refers to knowledge as something in an individual’s mind that can be constructed, acquired, and developed. The participation metaphor, related to the sociocultural perspective of learning, emphasizes learning as a participation in social and cultural activities (cf. Lipponen, 2002; Vosniadau, 2007). However, to understand learning, both metaphors are needed (Sfard, 1998; cf. Billet, 1996). Recently, Paavola and colleagues (2004) suggested a third metaphor for learning, the knowledge creation metaphor. Here, learning is understood as a collaborative effort directed towards developing mediated artifacts. These artifacts are broadly defined to include knowledge, ideas, practices, and material or conceptual artifacts (cf. Hakkarainen, Palonen, Paavola, & Lehtinen, 2004). The situated perspective of learning (Anderson, Reder, & Simon, 1996; Brown, Collins, & Duguid, 1989; Greeno & MSMTAPG, 1998) is considered a bridge between the sociocultural and cognitive theories (Billett, 1996). It has been also suggested that social constructivism (Palinscar, 1998), situated cognition (Greeno & MSMTAPG, 1998) and socioculturalism (Lave & Wenger, 1991; Rogoff, 1993) have some differences in their epistemological viewpoints, although social interaction and participation in social activities are emphasized in all of these perspectives (e.g. Alexander, 2007).

In this dissertation study, situated and socioconstructivist perspectives of learning are used as a frame of reference. These perspectives highlight the interdependence of social and cognitive processes in the co-construction of knowledge, where the social context can be seen as an integral part of cognitive activity (Anderson, Reder, & Simon, 1996; Brown, Collins, & Duguid, 1989; Palinscar, 1998; Vygotsky, 1978). Epistemologically, knowledge is distributed and jointly constructed among participants in collaborative efforts, to reach a solution through the negotiations of meanings. According to Roschelle and Teasley (1995), this occurs through conscious and continued efforts to coordinate problem solving so that *socially shared cognition* is possible (Resnick, Levine, & Teasley, 1993). For the negotiations of meanings and coordination of efforts, it is essential that group members contribute to each other's ideas and develop them further in a knowledge-building process (Scardamalia, Bereiter, & Lamon, 1994; cf. Levine, Resnick, & Higgins, 1993). Further, mathematical problem solving, which is the context of this doctoral dissertation, is knowledge dependent (Resnick, 1989, 42). Mathematics has been constructed through decades among the community of mathematicians (Boyer, 1959; Hadamar, 1996). Students in schools have only been introduced to the pieces of mathematical content knowledge with little insight into mathematics culture (e.g. Merenluoto & Palonen, 2007). Thus we could say, that the knowledge students need in order to participate in collaborative problem solving is in itself a type of internalized discourse (Bruer, 1994).

2.1 Learning through social interaction

Learning through social interaction has been a subject for study from many different perspectives of learning. In the literature, the mechanisms by which students learn while working in a social learning situation are explained by using Piaget's idea of sociocognitive conflict (Piaget, 1978), and Vygotsky's (1978) construct, the zone of proximal development (ZPD). Sociocognitive conflict refers to a situation in which individuals have different responses to the same problem and try to achieve a joint solution, which leads to disequilibrium in an individual (Piaget, 1978). The zone of proximal development refers to the level of learning at which an individual is able to learn through mediation in interaction with a more knowledgeable peer or adult (Vygostky, 1978).

In educational research and practice, cooperative and collaborative learning methods have been used as techniques to organize group work. In models of cooperative learning (for a short description of four well-know techniques, see Slavin, 1980), the work is divided among group members, and individually solved subtasks are merged into a final product. Whereas, in collaborative learning, the group members work together (Dillenbourg, 1999; Webb, 1982). The distinction between cooperative and collaborative learning was made in the early years of computer-supported collaborative learning research to distinguish it from research on group learning (Stahl, Koschmann, & Suthers, 2006).

Roschelle and Teasley's (1995, 70) define collaboration as "a coordinated, synchronous activity that results of a continued attempt to construct and maintain a shared conception of a problem". In addition to peer interaction, essential processes for collaboration described in the literature are, the negotiation of a common ground (e.g. Beers, Boshuizen, Kirschner, & Gijselaers, 2005), grounding (in psycholinguistics Clark & Brennan, 1991; applied in CSCL context e.g. Baker, Hansen, Joiner, & Traum, 1999; Dillenbourg & Traum, 2006), and making thinking visible by explaining one's thinking to others (Collins, Brown, & Holum 1991; Hatano & Inagaki, 1993; Lehtinen, 2003; Lehtinen & Rui, 1996; Scardamalia & Bereiter, 1996).

2.2 Metacognition as a model of cognition

One important aspect of learning and problem solving is the understanding of what one is doing, while gaining an understanding of a problem or concept. Students who know different strategies for learning, thinking and problem solving are more likely to use them in different learning situations than those who do not have that knowledge (Pintrich, 2002). Effective learning also requires that learners take active control of their learning when faced with a task of intermediate difficulty (Baker & Brown, 1984). These processes refer to the concept of metacognition, which is one of the central issues in the cognitive perspective of learning (Greeno, Collins, & Resnick, 1996). Metacognition refers to two distinct areas of research, knowledge about and the regulation of cognition (Brown, 1987; Flavell, 1979; Schraw & Moshman, 1995; Schraw & Dennison, 1994). Knowledge about cognition is the metacognitive knowledge a person has of his/her own thinking and problem solving, whereas regulation of cognition refers to the ability to reflect, understand and control one's learning (e.g. Veenman, Van Hout-Wolters, & Afflerbach, 2006; Hacker, 1998). Metacognition is also considered to be a model of cognition in which cognitive and metacognitive processes interact through monitoring and controlling functions (Efklides, 2006; Nelson, 1996; Nelson & Narens, 1994; see Figure 1).

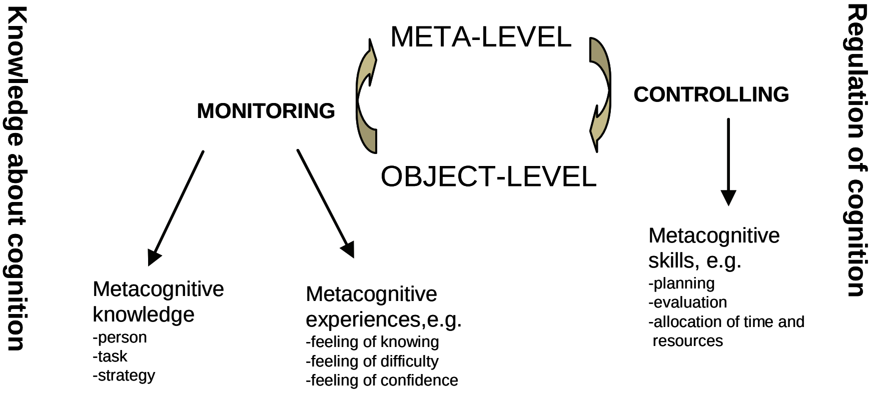

Fig. 1. Metacognition as a model of cognition (modified and combined from Brown, 1987; Efklides, 2006; Flavell, 1979; Nelson, 1996, Nelson & Narens 1994).

In this model of metacognition, cognitive activities, such as problem solving, are considered object-level processes (Figure 1). According to the model, the monitoring function transmits information about cognitive processes from the object level to meta-level. Through the controlling function the meta-level informs the object level about what to do next (Nelson, 1996). Furthermore, the meta-level cannot have information needed for controlling without the monitoring component (Nelson & Narens, 1994.). Monitoring of cognition refers to the ability to judge successfully one's cognitive processes by using metacognitive knowledge and metacognitive experiences (Flavell, 1987; Son & Schwartz 2002; Pintrich, Wolters, & Baxter, 2000). As coined by Flavell (1979), metacognitive knowledge is knowledge about the cognitive process and metacognitive experiences are any conscious cognitive or affective experiences that accompany and pertain before, after or during a cognitive enterprise. Metacognitive control refers to the online regulatory processes deliberately used to direct the course of cognitive activities like problem solving by, for example, planning and strategy selection (Schraw & Dennison, 1994; Son & Schwartz, 2002; Pintrich, Wolters, & Baxter, 2000).

Metacognitive knowledge can be considered to be declarative knowledge about tasks, strategies, and a person as a problem solver (Flavell, 1979, 1987). Knowledge of cognition is stable, statable, often fallible and late-developing information that individuals have about their own cognitions and those of others that is stored in their long-term memory (Brown, Bransford, Ferrara, & Campione, 1983). In his well-known article, Flavell (1979) claimed that metacognitive knowledge can be activated unintentionally and automatically by retrieval cues, but also through a deliberate and conscious memory search to retrieve the knowledge from long-term memory. He also proposed that metacognitive knowledge about problem solving can be correct or incorrect and it is possible to use or fail to use it meaningfully in the assignment. The development of metacognitive knowledge requires that the individual steps back and considers his/her thinking as an object of thought, which is a time consuming process (Brown, 1987). The *person* category of metacognitive knowledge consists of beliefs about intraindividual differences and others (interindividual differences) as cognitive processors (Flavell, 1979). A belief of *intraindividual differences* could be for example, “I learn the task better by explaining it to myself than just repeating the procedure”. An example of *interindividual beliefs* could be “My friend Anna is more skillful in mathematics than all the others in my class”. The third subcomponent is beliefs about universals of cognition like, “To be successful in the task, I need to attend to it closely” (cf. Flavell, 1987; Brown et al., 1983). The *task* variable in Flavell’s (1979) model refers to the understanding of how a task formulated in two different ways but including the same information should be best managed and how successful an individual is likely to be in solving the task. For example, it could be easier to solve the equation $(x + 3/5):5= y+½$ by calculus than as a complex word problem that includes the same information about the relation between x and y. The *strategy* variable refers to knowledge about which strategies and procedures are effective for the different kinds of tasks (Flavell, 1979; Pintrich, Wolters, & Baxter, 2000).

Metacognitive experiences are products of the online monitoring of cognition (Flavell, 1979; Efklides, 2006), and they are likely to occur in situations where making correct decisions and judgements are required (Flavell, 1987). This means that metacognitive experiences are an online awareness of feelings and judgments (for the other aspects of metacognitive experiences, see, for example, Efklides, 2006) that the person experiences while monitoring ongoing cognitive processes (Efklides, 2001). Metacognitive experiences provide information about cognition (Koriat & Levy-Sardot, 2000), and can also have an affective function (Efklides, 2006). One metacognitive experience, the *feeling of difficulty* (Efklides, Papadaki, Papantoniou, & Kiosseoglou, 1997; Efklides, 2001), has been associated with a negative affect (Efklides & Petkaki, 2005).

Metacognitive skills refer to a person’s procedural knowledge about how different strategies and heuristics can be applied for regulating one’s learning and problem solving (Brown & DeLoache, 1978; Schraw, 1998). The basic metacognitive skills, like planning, monitoring, task analysis, checking, evaluation and variety of other behaviors for coordinating and controlling (e.g. time and effort allocation), are deliberately used to control cognition (Brown & DeLoache, 1978; Brown et al., 1993; Efklides, 2006; Pintrich, Baxter, & Wolters, 2000). Research on metacognitive skills has shown that these basic skills appear to be highly interdependent (Veenman, Wilhelm, & Beishuizen, 2004). Research has also shown that metacognitive skillfulness is a general and person-related characteristic, as well as a strong predictor of task performance and study success (Veenman & Verhej, 2003). Furthermore, metacognitive skills are domain-general, rather than domain-specific, processes (e.g. Schraw, Dunkle, Bendixen, & DeBacker Roedel, 1995). Unlike the knowledge of cognition, the regulation of cognition is unstable and age independent, as well, individuals are not always able to report their method of regulating their performance (Brown et al., 1983).

2.3 Metacognition in social learning situations

Research on individual metacognition has shown that there are differences in metacognitive abilities between capable and less capable learners. Learners with effective metacognitive skills are able to monitor and evaluate their ongoing learning, as well as plan and select appropriate strategies (Everson & Tobias, 1998). Instructional methods like Reciprocal Teaching (Palinscar & Brown, 1984), Communities of Learners (Brown & Campione, 1994), Ask and Tell Why (King, 1990) and Improve (Mevarech & Kramarski, 1997) were developed to facilitate and prompt students' metacognition in collaboration with a teacher or peers. These methods were designed to structure interaction in order to encourage learners to follow sequences of activities or particular patterns of dialogue. Methods for structuring interaction are presently called scripted collaboration both in face-to-face and computer-supported collaborative learning (King, 2007).

Shared metacognition. Since the 1980's, metacognition researchers have acknowledged the role of peers and more knowledgeable others in mediating (Brown, et al., 1983) and sharing metacognitive knowledge (Paris & Winograd, 1990). In social learning situations metacognitive knowledge is needed to understand individual, as well as other's, cognition in order to interpret the situational data and make effective control decisions (Nelson, Kruglanski, & Jost, 1998; Jost, Nelson & Kruglanski, 1998).

Shared metacognition as a phenomenon is manifested in diverse disciplines. Mead (1934) described how argumentation with a generalized other affects thinking, although he largely ignored the role of cognition, whereas Vygotsky's (1978) similar ideas were influenced by theories of cognitive development (e.g. Levine, Resnick, & Higgins, 1993). Similar ideas are presented in transactive memory research, which is a distinct area from metacognition. Transactive memory research examines how knowledge is distributed among team members and how effectively the shared knowledge is used (e.g. Wegner, 1986). Further, within the field of social psychology, the information processing framework promotes the idea that socially shared metacognition refers to members' knowledge of what other group members know and it has been suggested that the degree of sharedness is related to group performance (Tindale & Kameda, 2000).

The issues surrounding the definition of socially shared metacognition are still open for debate. In the field of educational psychology and learning sciences, early reports have emphasized that metacognition should be seen as an essential part of a group's work when cognitive processes are regulated advantageously (Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen 2003; Salonen, Vauras, & Efklides 2005). It has been also suggested that metacognitive activity is mediated among participants (Goos, Gailbraith, & Renshaw, 2002). There are also findings that suggest that metacognition is a socially shared phenomenon in pairs' problem solving (Iiskala, Vauras, & Lehtinen 2004). In addition, it has been mentioned that there emerges a shared metacognitive experience during social discourse (Lin, 2001), where peers or other participants in a group act as external regulators (Azevedo, 2005). Moreover, Jermann's (2004) study shows that while students regulate their own activity in collaborative learning, they are also able to monitor and control how their peers are working in the group.

2.3.1 Metacognition and mathematical problem solving in a social learning situation

The first studies about metacognition in mathematical problem solving were focused on individual processes (e.g. Garofalo & Lester, 1985) or the teacher's role in supporting, facilitating and modeling mathematical problem solving (Lester, 1989). Schoenfeld's (1985) studies, along with Campione and colleagues' (1989) extensions of Palinscar and Brown's (1984) reciprocal teaching program in mathematics increased interest in organizing problem solving within small groups. The development of instructional programs aimed at improving metacognitive skills in mathematical problem solving (e.g. Kramarski, Mevarach, & Arami,

2000) showed that metacognitive knowledge and skills influence mathematical problem solving (e.g. Borkowski, Chan, & Muthukrisna, 2000).

Mathematical problem solving. Problem solving, in general, refers to cognitive processing directed towards transforming a given situation into a goal situation when the obvious method of solution is not available (Mayer & Wittrock, 2006). Problem solving, including various types of tasks, has always had a central role in mathematics curricula (Schoenfeld, 1992). The role of problem solving in mathematics teaching has been characterized by three general themes, problem solving as a context, a skill or an art, the last of which is seen as central in Polya's heuristic model of problem solving processes (Stanic & Kilpatrick, 1989).

From the cognitive perspective of learning, one of the most influential concepts of individual problem solving has been Polya's (1973) model of a four-phase heuristic process consisting of *understanding, planning, implementing* and *evaluation.* According to Polya's model, a problem solver should *understand* what is asked in the problem in order to *plan* what to do. Then, the solver should *implement* the plan and, while doing so, check each step taken, and finally, *evaluate* the received result. Schoenfeld (1985) extended Polya's model and integrated it with an information-processing framework where executive or control processes played an important role in successful problem solving (cf. regulation of cognition, Brown, 1987). In Schoenfeld's (1985; 1987) model, the problem solving process consists of the following stages; *reading, analysis, exploration, planning, implementation and verifying*. Using this heuristic process requires the efficient usage of metacognitive skills, a typical feature of expertise problem solving, but not for most students. According to Schoenfeld's studies (1985; 1992), experts used most of their time thinking about the problem and analysing the task. They continuously monitored their ongoing problem solving process at the metacognitive level. In contrast to experts' problem solving processes, most students tend read the problem and decided quickly which approach they could use in order to find a solution. Students tend to keep the solution effort that first came into their mind without considering alternatives (Schoenfeld, 1985; 1992).

Based on Schoenfeld's and Polya's work, Garofalo and Lester (1985) presented a broader model for metacognition and the mathematical problem solving process, which consists of metacognitive behaviors associated with *orientation, organization, execution,* and *verification*. For example, the verification phase includes both evaluations of decisions made at the beginning of problem solving (e.g., what is asked in the problem, assessing the level of task difficulty) and evaluations of execution during and after problem solving. Artzt and Armour-Thomas (1992) proposed a synthesis of Garofalo and Lester's, Schoenfeld's and Polya's problem solving steps within cognitive psychology and Flavell's (1979) ideas of metacognition. They proposed a cognitive-metacognitive framework for examining mathematical problem solving consisting of *reading* (cognitive process), *understanding* and *analysing* (metacognitive processes), *exploration* (cognitive and metacognitive processes), *planning* (metacognitive process), and *implementation* and *verifying* (cognitive and metacognitive processes). A common denominator in these models is that cognitive and metacognitive processes are considered to be distinct but overlapping processes (Veenman, Van Hout-Wolters, & Afflerbach, 2006), where cognition is related to performing the task and metacognition is related to monitoring and controlling the process (Brown, 1987; Flavell, 1979).

Collaborative mathematical problem solving. The use of group work in mathematics has been encouraged by some recent curriculum documents (e.g. NTCM 2000; 2007). A basic goal of using small groups in mathematical problem solving is to make the students work with their existing mathematical knowledge efficiently. Working in groups requires the reciprocal engagement of multiple participants in order to make sense of mathematical ideas and make connections between the concepts and procedures (Saxe, 2002; Schoenfeld, 1992). There is some evidence that group work is effective (Slavin, 1990), but there are also findings suggesting that in mathematics, outcomes and types of collaboration vary between groups (Forman, 1989; Kieran, 2001). In successful collaboration, reciprocal discussions among the group members make individual's thinking visible, thus enabling the group to make productive metacognitive decisions (Artzt & Armour-Thomas, 1992; Forman, 1989; Kieran, 2001) In unsuccessful groups, group members tend to lead a 'wild goose chase' (Schoenfeld, 1987) due to the lack of verification and analysis procedures (Stacey, 1992; Artzt & Armour-Thomas, 1992). Alternately, in unsuccessful groups, members have difficulties making their emergent thinking visible to their peers in a mathematically productive way (Kieran, 2001). It can be argued that it is essential for successful problem solving that group members engage themselves in reciprocal interaction where they experiment with presented ideas and ask their peers to clarify and justify their thinking. Further, Watson and Chick's study (2001) showed that triads' (in Grades 3, 6 and 9) collaborations could lead to better, worse or unchanged performance, which were influenced by various *cognitive* (e.g. cognitive ability, misunderstanding, picking the easiest idea), *socia*l (e.g.

leadership, disagreement) and *external* factors (e.g. type of task, classroom noise). That is to say, the process of co-constructing a solution is a more complex phenomenon than reaching consensus on a proposed solution (Kruger, 1993).

Computer-supported collaborative learning facilitating mathematical problem solving. There are many innovative ways to use technology-enhanced learning environments in mathematics learning, beginning with the drill-and-practice programs and computer-assisted instruction (Kaput, 1992; Kaput & Thompson, 1994) to learning environments such as Logo (Papert, 1980), The Jasper Series (Cognition and Technology Group at Vanderbilt, 1994, 1996) and computer simulations (Enyedy, 2003). These programmes provide opportunities not only for individual knowledge construction but also for sharing mathematical experiences, different representations and mathematical understanding (De Corte, Greer, & Verschaffel, 1996; Shaffer & Kaput, 1999). Further, the development of network technologies make it possible for collaboration facilitated by computer based learning environments to provide new arenas for mathematics learning (De Corte, 2000).

Recently, asynchronous and text-based learning environments and pedagogical models of computer-supported collaborative learning (Koschmann, Hall, & Miyake, 2002) have been used to facilitate and support mathematical problem solving (e.g. Moss & Beatty, 2006). Usage of asynchronous learning environments make it possible for participants to make their ideas visible and to provide explanations to others by writing computer notes (Cohen & Scardamalia, 1998; Scardamalia & Bereiter, 1996; Lehtinen, 2003). The messages are continuously available to the students, providing support for reflection before responding, as well as providing on-task recombination of ideas (Tolmie & Boyle, 2000). Discussion threads saved in a database enable students to step back and consider their own and their peers' cognitive processes as objects of thought and reflection. This is an important feature of metacognitive knowledge (Flavell, 1979; Nelson, Jost, & Kruglanski, 2006). Participants need to use their metacognitive skills to engage in conscious and reciprocal interaction with each other.

In this dissertation study, the general aim is to examine metacognition in groups' joint problem solving facilitated by an asynchronous and text-based learning environment. The main aim is to recognize metacognition as a socially shared process embedded within group problem solving.

3 Methods for investigating metacognition at individual and group levels in collaborative learning situations

In the field of learning sciences, cognitive learning theorists have done pioneering work in developing methods for the analysis of an individual's learning processes (Sawyer, 2006). In the 1980's, protocol analysis of thinking-aloud data (Ericsson & Simon, 1980, 1984) was used to examine individual's problem solving paths within the information-processing framework. These individual's problem solving paths were compared with a model of ideal problem solving sequences generated through detailed cognitive task analysis. The analysis was focused on how the individual's problem solving path matched with the model, and it did not provide any information on, for example, how an individual used prior knowledge in problem solving. Another influential approach to examining processes of learning was the design experiment, in which the main aim was to design teaching interventions to inform practice and thus contribute to theories of learning (Brown, 1992).

Early investigations of metacognition described developmental patterns of children's knowledge about memory processes (Hacker, 1998). In the field of educational psychology, metacognition research is focused on empirical studies (e.g. Schraw & Impara, 2000), in which on-line and off-line assessment measures are used. Off-line methods are used either before or after tasks, whereas on-line methods are used to examine processes occurring during tasks (Van Hout-Wolters, 2000). Methods used before and during a task are considered to be prospective and predictive, whereas methods used after a task are considered retrospective (Veenman, 2005). Interviews (e.g. Zimmerman & Martinez-Pons, 1990) and self-report questionnaires like the Knowledge Monitoring Assessment (KMA; Tobias & Everson, 2000), the Metacognitive Assessment Inventory (MAI; Schraw & Dennison, 2004) assess metacognitive knowledge, and Learning and Study Strategy Inventory (LASSI; Weinstein, Schulte, & Palmer, 1987) and Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1993) assess metacognitive regulation. In the measurement of metacognitive experiences, especially feelings of task difficulty, both prospective and retrospective research methods, like questionnaires (e.g. Efklides, Samara, & Petropolou, 1999), have been used. In addition questionnaires, other measures, like rating scales, have been used in assessing the subjective perception of task processing, especially in the field of cognitive load research (e.g., Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Paas & van Merriënboer, 1994). Many other methods, in addition to those gathering trace data of study events using log-files (e.g. Hadwin, Nesbit, Jamison-Noel, Code, & Winne, 2007; Veenman, Prins, & Elshout, 2002), are currently used in metacognition research (Veenman, Van Hout-Wolters, & Afflerbach, 2006). In order to advance methodological solutions, more multi-method designs are needed to increase understanding of diverse assessment methods (Veenman, 2005).

Since the early phase of research on metacognition in collaborative mathematical problem solving, multiple and multidimensional methods have been used to capture the complexity of the phenomena being studied. Schoenfeld (1985; 1987) used protocol analysis of video data and developed a time-line graph that presented a dynamic picture of how an individual's or a small group's cognitive and metacognitive processes emerged in the problem solving process. Based on Schoenfeld's work, Artz and Armour-Thomas (1992) developed a cognitive-metacognitive framework to analyse seventh-grade students' group discussions using video data. Individuals' cognitive and metacognitive behavior was coded and displayed as a function of time used for problem solving. In the graph, the characters of cognitive activity were listed on vertical axis, and metacognitive utterances were identified. Further, individual students' perceptions and attitudes of the collaborative learning situation were examined by using stimulated-recall interviews (Artz & Armour-Thomas, 1992). Another multidimensional method was developed by Sfard and Kieran (2001; Sfard, 2001), who used an interactivity flowchart to identify how the participants move between individual and inter-individual communications dealing with on-task and off-task discussion. For the flowchart, video data transcripts of individual and inter-individual communications were synthesized to show the ways in which a student interacted with his/her peer(s). In the graphical display, personal and interpersonal channels were combined in order to display the process of a collaborative learning situation.

During the 1980's and 1990's, the situative perspective of learning shifted the focus from individual's cognitive processes to the social practices of reasoning and understanding that go beyond knowledge acquisition (Greeno & MSMTAPG, 1998). The focus of the analysis changed from an individual's processes to groups' learning as an activity system, in which individuals participate in the co-construction of knowledge (Greeno, 2006). Interactional analysis methods and analysis of cognitive activities embedded in social learning situations were combined in order to reach a better understanding of how learning occurs in collaborative learning environments (Sawyer, 2006).

3.1 Integrating individual and group level analysis

In the first decades of computer-supported collaborative learning research the aim was to clarify the quality of discussions by subjects by using discourse or content analysis (Dillenbourg, Järvelä, & Fischer, 2009). One reason for that could be the unique and computationally formal recordings of participants' interaction that technology-based learning environments provided for tracing the social exchange and co-construction of knowledge (Clark, Stegmann, Weinberger, Menekse, & Erkens, 2007; Kumar, Gress, Hadwin, & Winne, 2007). Further, the co-construction of knowledge requires a deliberate exchange of information in the written form because the non-verbal aspects of the process are often missing in these environments (cf. Markham, 2005). In the analysis of discussion forum data, the written computer notes were considered to represent an individual's thinking. Recently, researchers have emphasized that the meaning of a computer note lies not only in the utterance itself, but it should be interpreted with relation to the group's discussion, in other words at the group level (cf. Greeno & MSMTAPG, 1998; Stahl, Koschmann, & Suthers, 2006).

An ongoing methodological challenge has been finding ways to capture the situational dynamics of online discourse (Hmelo-Silver & Bromme, 2007). To reach this goal, a broad spectrum of methods has been utilized to study the processes and outcomes of collaboration (Strijbos & Fischer, 2007). In many studies, qualitative research methods like content analysis revealed the nature of the online discussion (Strijbos & Stahl, 2007). Quantitative methods like social network analysis (Bruggeman, 2008; Scott, 1991; Wasserman & Faust, 1994) were used to examine the participatory aspects of computer-supported collaborative learning (Martinez, Dimitriadis, Gómez-Sánchez, Rubia-Avi, Abellán, & Marcos, 2006; Nurmela, Lehtinen, & Palonen, 1999; Nurmela, Palonen, Lehtinen, & Hakkarainen, 2003): social network and centrality measures were used as a tool to examine both the individual level and group level simultaneously (Kameda, Ohtsubo, & Takezawa, 1997). In the late 1990's, mixed methods (Tashakkori & Teddlie, 2003) became popular as a result of them being considered to be the natural complement to traditional qualitative and quantitative research (Johnson & Onwuegbuzie, 2004), as one possibility of using mixed methods is the combination of qualitative and quantitative methods. The results of the qualitative content analysis are quantified in order to summarize the findings in either tabular or graphical form (cf. Chi, 1997).

Currently, researchers have been developing methods to examine individual and group level processes in collaborative learning situations. One promising way for performing these analyses has been a process-oriented approach (Arvaja, Salovaara, Häkkinen, & Järvelä, 2007), where individual and group level analyses are separated and their results are triangulated during the interpretation phase. In Arvaja and her colleagues' (2007) study, the group level was examined by using a qualitative content analysis of participants' knowledge construction activities in an asynchronous learning environment. For the self-report questionnaire data of individuals' interpretations of collective activity, quantitative data analysis methods were used. The quantitative data were used to validate the results of the qualitative analysis. Further, in Järvelä and her colleagues' (2008) study, quantitative data of self-report questionnaires and the qualitative analysis of the three videotaped collaborative learning sessions were used as equal weights in order to explore the role of motivation in the interactive context of collaborative learning. Another option for analysing collaboration processes is the combining of multiple qualitative data sources such as video-observations, interviews, content analysis of computer notes, experience-sampling-analysis and motivational profile questionnaires. This would allow for the exploration of the relation between the context and individual perceptions of the phenomenon under study (Järvelä, Veermans, & Leinonen, 2008).

In the field of computer-supported collaborative learning research, the issues of validity and reliability are pertinent, particularly in those studies using transcripts and content analysis techniques (cf. Beers, Boshuizen, Kirschner, & Gijselaers, 2007; De Wever, Schellens, Valcke, & Keer, 2006; Hmelo-Silver & Bromme, 2007). In a broader sense, validity pertains to whether a method investigates what it is intended to investigate (Kvale, 1995). According to Yin (2003), construct validity and external validity are important forms of validity for an exploratory study. Construct validity means not only confirming the chosen construct with that given in relevant literature, but also looking for counter-examples that might falsify the researcher's defined content (Cohen, Manion, & Morrison, 2007). External validity, in general, refers to the degree to which the results can be generalized to the wider population, cases or situations (Cohen, Manion, & Morrison, 2007). Triangulation provides many possibilities to strengthen validity. One type of triangulation, data triangulation, is the use of different methods of data collection (Yin, 2003). Another type of triangulation is the combined levels of triangulation, where more than one level of analysis, for example, individual and group level analysis, is used (Cohen, Manion, & Morrison, 2007). It is also possible to use investigator triangulation where more than one evaluator is used in the data analysis (Yin, 2003). Different methods are used with the same objects of the study with methodological triangulation (Cohen, Manion, & Morrison, 2007). Further, statistical methods can be applied to draw conclusions about patterns of activity; although the results of such analysis are not generalizable in a traditional quantitative sense; they justify drawing statistically based conclusions about observations in a qualitative context (Shaffer & Serlin, 2004).

In qualitative research, reliability could be considered to be the ability of replication, which can be addressed, for example, through the stability of observations and inter-rater reliability (Denzin & Lincoln, 1994). In the qualitative content analysis of discussion forum data, the computer note was selected as a unit because it is objectively recognizable (Rourke, Anderson, Garrison, & Archer, 2001). For reliability, two of the most often used inter-rater coefficients, Cohen's kappa (Cohen, 1960) and proportion agreement (Miles & Huberman, 1994) were used. Proportion agreement, is considered to be insufficient to serve as an indicator for reliability because it does not correct for agreements by chance (Strijbos & Stahl, 2007). Cohen's kappa does correct for agreement by chance but it fails to recognize two coders' unequal use of categorizations (Fleiss, 1978; Krippendorf, 2004). De Wever and colleagues (2006) suggest the usage of multiple reliability indices together with an adequate description of the coding procedure in order to increase the quality of research in the field of content analysis. Another possibility for increasing reliability is to report two kappa statistics, one for the subcategory level and one for the level of the main categories (Strijbos, Martens, Prins, & Jochems, 2006). In conclusion, in analysis where multidimensional coding is used, the issues of reliability, validity and generalization should be taken into account.

4 Aims and methods of the study

4.1 Aims

The general objective of this study is to examine metacognition in groups' joint problem solving facilitated by an asynchronous and text-based learning environment. The main aim is to recognize metacognition as a socially shared process embedded in group problem solving. To enable this, two empirical experiments were conducted to represent the phenomena being studied using the current theoretical understanding of metacognition and the situative perspective of learning.

The detailed aims of the current thesis are presented below (numerals I-IV refer to the original articles of the thesis):

1. *The first aim* is to examine what kinds of metacognitive processes become visible during computer-supported collaborative problem solving in mathematics (I, III).
2. *The second aim* is to contribute to the understanding of socially shared metacognition and propose a definition of socially shared metacognition (III, IV).
3. *The third aim* is to examine the interplay between individual metacognition and socially shared metacognition (IV).
4. *The fourth aim* is to develop methods to analyse metacognition becoming visible and shared in computer-supported collaborative problem solving (II, III).

4.2 Participants and research settings

This study consists of two empirical experiments carried out in a computer-supported collaborative learning context. In both experiments, an asynchronous and text-based learning environment was used to facilitate joint mathematical problem solving (cf. Moss & Beatty, 2006). Usage of asynchronous learning environments made it possible for participants to make their thinking visible and to provide explanations to others by writing computer notes (Cohen & Scardamalia, 1998; Scardamalia & Bereiter, 1996; Lehtinen, 2003). Participants' real-time presence in classrooms influenced the usage of the learning environments; asynchronous interaction turned out to be more synchronized.

The focus of the first experiment was to explore metacognition in group problem solving in an authentic classroom condition. In this study, the participants were 13-year-old Finnish upper elementary school students who worked in pairs with their mathematics teacher. They participated in a one year project where the asynchronous and text-based Knowledge Forum (KF, Scardamalia & Bereiter, 1996) learning environment was used during the two courses concerning geometry (autumn 1999) and probability (spring 2000). The KF database consisted of two discussion areas, each of which contained participants' written computer notes including text and graphics. As authors of the computer notes, they were able to edit or delete their own notes. The students had some previous experience in working with the KF learning environment in a literacy course. In this respect, the students were familiar with the idea of collaborative learning and the technological environment but they were inexperienced in implementing these ideas with mathematical problem solving. The students were homogenous in terms of race and family background.

The second experiment was conducted in a more experimental condition aimed at examining metacognition as socially shared phenomena. The participants were 45 pre-service primary school teachers, half of whom worked with an asynchronous and text based learning environment. The other half of the participants worked without computers. Two questionnaire data examining metacognition in mathematical problem solving and group working skills were quantitatively analysed in order to create the triads. The created groups working with computers were randomly assigned to one of the two different conditions: *working with WorkMates (WM) learning environment* and *working with WM including a stimulated recall group interview.* All triads solved open and closed mathematical problems requiring proportional or algebraic thinking. For the asynchronous and text-based WM learning environment, each participant had an individual user account and password with which to log-in to his/her group's folder that contained a particular discussion area for each problem. In the discussion area, the participants were not able to edit and remove their comments or include graphics or mathematical symbols in the computer notes. The participants had previously used WM for course materials but not for collaborative problem solving.

4.3 Data collection and data analysis

In metacognition research, traditional research methods like questionnaires and interviews are mostly focused on an individual's thinking and problem solving (e.g. Schraw & Impara, 2000). These methods, however, are not adequate to assess metacognition as a central part of a social learning situation. In this dissertation study, qualitative and quantitative research methods were used to capture the complexity of the phenomenon being studied. Further, a multi-method approach made it possible to reveal the interdependence of social, cognitive and metacognitive processes in collaborative learning situations and to interpret computer notes in relation to a group's discussion (cf. Greeno & MSMTAPG, 1998; Stahl, Koschmann, & Suthers, 2006).

In this study, the main data consist of discussion forum data collected in the two experiments. These data are used to trace the social exchange and co-construction of knowledge by utilizing the asynchronous learning environments' computationally formal recordings of participants' interactions (Clark, Stegmann, Weinberger, Menekse, & Erkens, 2007). In the first experiment, other qualitative data such as students' notebooks and observations are used to augment the researcher's interpretations of the joint problem solving (Article I).

In both two experiments, the discussion forum data are analysed by following the framework of qualitative content analysis (Chi, 1997). In the analyses, multi-dimensional coding schemes are used to examine the *process* of joint problem solving in the computer-supported collaborative learning context. In the first experiment, the qualitative content analysis was designed to move from a general level to a detailed level in order to examine what kind of mathematical problem solving (Polya, 1979; Schoenfeld, 1985) and metacognitive (Pintrich, Wolters, & Baxter, 2000) activity emerges in joint problem solving. The detailed categorization revealed that students mediate mathematical and metacognitive knowledge and monitor the ongoing problem solving process (Article I). The categorization was, however, too detailed, because there were not many items in one category. This was taken into account in Article II, where metacognition was characterized as metacognitive knowledge and metacognitive skills (Brown, 1987; Flavell, 1979), and a distinction was made between computer notes that were at the cognitive and metacognitive level. Further, in the analysis of the discussion forum data, interpretations of the thinking behind the written computer notes were not made. The detailed analysis, however, revealed a large amount of computer notes that were not directly related to the ongoing problem solving. These computer notes were considered to be important for social interaction (Articles I and II).

On the basis of the remarks presented above, in the second experiment, the multidimensional coding scheme included metacognitive levels (Brown, 1989; Efklides, 2006; Flavell, 1979; Nelson, 1996), cognitive levels (Dewey, 1910; Schoenfeld, 1985) and social levels (Kreijns, Kirschner, & Jochems, 2003). At the metacognitive level, only the metacognitive regulation messages were identified. These computer notes were considered to be a starting point for the emergence of socially shared metacognition (Article III). Inspired by Artz and Armour-Thomas's (1992) and Schoenfeld's (1985;1987) work, a graphical representation of a group's collaborative problem solving process, *a process-oriented graph of joint problem solving,* was designed to visualize the collaborative problem solving process (Articles III and IV). On the basis of the multiple data analysis methods, the results of the qualitative content analysis were triangulated (Arvaja, Salovaara, Häkkinen, & Järvelä, 2007). An additional value of a graphical presentation is the ability to interpret joint problem solving at the group and individual level simultaneously. In addition to examining the quality of the joint problem solving discussions, in the first experiment, quantitative and qualitative research methods were combined to examine social aspects of metacognition in networked learning. In order to find a relation between participants' metacognitive activity and the features of interaction in the asynchronous learning environment, quantitative research methods, *social network analysis method*s (Bruggeman, 2008; Scott, 1991; Wasserman & Faust, 1994) and *correspondence analysis* (Greenacre, 1984; Greenacre & Blasius, 1994) were used for discussion forum data. These methods were used to visualize the patterns of interaction and to describe how the metacognitive activities were distributed among participants. In the interpretation phase, the results of the three analysis methods were triangulated (Article II). In the second experiment, quantitative methods were again used to group students into triads. Two self-report questionnaire data concerning metacognition in mathematical problem solving (modified, Howard, McGee, Shia, & Hong, 2000) and group working skills, *Students Appraisals of Group Assessment, SAGA* (Volet, 1998), were analysed using principal component analysis. The equality of the groups was confirmed by using the analysis of variance (Article III).

In the measurement of the feelings of difficulty, learners are asked to assess how easy of difficult they found the task, for example, by using questionnaires (e.g., Efklides, Samara, & Petropolou, 1999) either before or after solving the task. Questionnaires and other subjective measures like rating scales have been found to be reliable in assessing the subjective perception of task processing (e.g., Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Paas & van Merriënboer, 1994). Further, the use of prospective and retrospective research methods relies on the accuracy of an individual’s knowledge of his or her behaviour (Veenman, 2005). Thus, in this dissertation study, feelings of difficulty graphs were used as retrospective assessment of task difficulty. The graphs were drawn immediately after the group had reached a joint solution of each task. Interpretation of the perceived task difficulty at the end of the problem solving was combined with qualitative data analysis in order to find how socially shared metacognition can be related to individual metacognition (Article IV). The challenge for using the graphs as data is that there is variance within the group or even within one participant’s graphs of how precisely they are able to visualize their metacognitive feelings of difficulty on different types of tasks.

The summary of data collection and data analysis in relation to the articles of this thesis is presented in Table 1. The detailed descriptions and assessments of the methods used in the data analyses are provided in the articles.

Table 1. Summary of data collection and data analysis in relation to the articles of this dissertation

Article Research Experiment	Subjects	Research aim	Data	Analysis
Article I Empirical experiment I	Secondary school students	Metacognition in joint problem solving and how technology-based learning environments can be utilized in mathematics learning	Computer notes	Qualitative content analysis
Article II Empirical experiment I	Secondary school students	Social aspects of metacognition and the patterns of interaction	Computer notes	Qualitative content analysis, Social Network Analysis (SNA), Correspondence analysis, Statistical analysis
Article III Empirical experiment II	Pre-service primary school teachers	Operational definition of socially shared metacognition	Computer notes, Self-report questionnaires	Qualitative content analysis, Statistical analysis
Article IV Empirical experiment II	Pre-service primary school teachers	How socially shared metacognition can be related to individual metacognition	Computer notes, Feelings of difficulty graphs Self-report questionnaires	Qualitative content analysis, Statistical analysis

5 An overview of the empirical studies

In the following overview, the two empirical studies reported in the four articles are briefly described with respect to the research questions posed in this doctoral thesis. Article I clarifies what types of metacognitive processes become visible during computer-supported collaborative learning in mathematics, as well, the applicability of networked learning in mathematics is also discussed. In article II, social aspects of metacognition and the patterns of interaction are examined through the use of qualitative and quantitative data analysis methods. In article III, an operational definition for socially shared metacognition is provided in order to explore in what types of problem solving situations socially shared metacognition does or does not become visible. Article IV is focused on investigating the interplay of individual metacognition and metacognition as socially shared phenomena in a group's joint mathematical problem solving process. The results of the dissertation study are presented in chapter 6.

5.1 Hurme, T-R. & Järvelä, S. (2005). Students' activity in computer supported collaborative problem solving in mathematics. *International Journal of Computers for Mathematical Learning, 10*, 49-73.

In this article, the first experiences of utilizing computer-supported collaborative problem solving in mathematics are reported. The aim of the study was to explore what kinds of metacognitive processes emerge during computer-supported collaborative problem solving. Another aim of this study was to discuss the applicability of a network-based learning environment for mathematical problem solving.

The participants of this study were 13-year-old secondary school students (N=16) and their mathematics teacher, working with the Knowledge Forum (KF) learning environment during geometry and probability projects. The discussion forum data consisted of the eight student pairs' posted computer notes (n=188), which were analysed through qualitative content analysis (Chi, 1997) from a mathematical problem solving (Polya, 1973; Schoenfeld, 1985) and a metacognition (Pintrich, Wolters, & Baxter, 2000) point of view. The students' portfolio materials such as notebooks, and observations were used to augment the researchers' interpretations of the discussion forum data.

The results of this study showed that instructions given to students played an essential role in joint discussions. The detailed analysis revealed that students mediated mathematical knowledge and strategies to solve the problem. In other words, they asked questions and provided guidelines for the solution and they mediated task specific mathematical knowledge. The results also showed that metacognition can be seen as a component of joint problem solving; the students mediated some metacognitive knowledge and metacognitive monitoring and judgements in joint problem solving. There were, however, a large amount of messages that were not directly related to problem solving and were also not metacognitive, but these computer notes were considered to be important for social interaction. This may be due to interaction based only on written text, through which the students needed to use more narrative ways of clarifying their thinking for others.

The first study of this thesis provided some insights into the phenomenon of metacognition in computer-supported mathematical problem solving and produced questions for the future studies of this thesis. These questions address how to analyse the social aspects of metacognition and how the participants utilize each other’s thinking in problem solving during computer-supported collaborative learning situations.

5.2 Hurme, T-R., Palonen, T., & Järvelä, S. (2006). Metacognition in joint discussion: an analysis of the patterns of interaction and the metacognitive content of the networked discussions in mathematics. *Metacognition and Learning, 2*, 181-200.

The purpose of article II was to examine the social aspects of metacognition and to develop methodological solutions to trace the patterns of interaction and examine the quality of the online discussions. The participants of this study were 13-years-old secondary school students (N=16) and their mathematics teacher, working with the Knowledge Forum (KF) learning environment during a geometry project. As in Article I, the discussion forum data consisted of eight student pairs’ posted computer notes (n=188), of which 95 computer notes were chosen for detailed analysis, because these computer notes were part of longer discussion threads (cf. Suthers, Dwyer, Medina, & Vatrapu, 2007). For the discussion forum data analysis both qualitative and quantitative methods were used. The qualitative content analysis of the computer notes was performed from a metacognition point of view (Brown, 1989; Flavell, 1979). Social network analysis methods (Scott, 1991; Wasserman & Faust, 1993) were used to examine the patterns of interaction between the partners of the pairs and their peers. The data analysis of the discussion forum data was performed in four phases: multidimensional scaling, metacognitive content analysis of computer notes, correspondence analysis and social network analysis. The analyses were based on students' active participation and further, it was distinguished whether the posted computer notes indicated regulation of a student pairs' own or of another pair's cognitive processes. This made it possible to recognize metacognition at the individual level and as well as a social phenomenon where the more knowledgeable participants metacognitively co-regulated another pair's problem solving (Hadwin, Oshige, Gress, & Winne, 2007).

The results of this study show that students make their metacognitive thinking visible especially in *reciprocal interaction* with peers in a computer-supported collaborative learning situation. The results of the study showed that the participants who have a central and mediating role seem to monitor and evaluate their learning processes more than their peers. The students also mediated some metacognitive knowledge and co-regulated their peers' thinking, although the amount of metacognitive computer notes was not high. The results of this study provided a starting point for the further studies on metacognition as a shared process as these results were not adequate to explain how participants benefit from their peers' thinking in social learning situations (Salomon & Perkins, 1998).

5.3 Hurme, T-R., Merenluoto, K., Salonen, P., & Järvelä, S. (2008). Regulation of group's problem solving – a case for socially shared metacognition? Manuscript.

Article III aimed to contribute to the understanding of socially shared metacognition by proposing an operational definition of the phenomenon under study. The participants in this study were 45 pre-service teachers in a first year university course concerning teaching mathematics at the elementary level. Half of the participants worked with the WorkMates (WM) learning environment and the other half in a face-to-face situation. The participants worked in triads, which requires participation by everyone and allows for emergence of different views needed to be discussed reciprocally (cf. King, 2002). The triadic groups were formed on the basis of two self-report questionnaire data.

The proposed operational definition for socially shared metacognition was drawn from the recent literature of shared regulation (Hadwin, Oshige, Gress, & Winne, 2008). According to the operational definition, *the process of socially shared metacognition* is recognized if: (a) a *metacognitive regulation message* is contributed to the joint problem solving in order to *interrupt, change or promote* the group's problem solving; (b) this metacognitive regulation message is *acknowledged*; and (c) the presented idea is *developed further* by the other group members in order to make progress in joint problem solving. The operational definition was not, however, suitable for all situations where metacognition emerged in joint problem solving. In addition to defining how socially shared metacognition could be recognized, other kinds of metacognitive regulation emerging during group problem were considered to be either *metacognition becoming visible but not shared* or an *individual's attempt to metacognitively regulate the group's problem solving*. For analysing discussion forum data, a multidimensional coding scheme was used to capture the metacognitive (Brown, 1989; Efklides, 2006; Flavell, 1979; Nelson, 1996), cognitive (Dewey, 1910; Schoenfeld, 1985) and social (Kreijins, Kirschner, & Jochems, 2003) features of collaborative problem solving and the results of these analyses were triangulated during the interpretation phase (cf. Arvaja et al., 2007). Further, on the basis of the multidimensional qualitative content analysis, a *process-oriented graph of joint problem solving* (Artz & Armour-Thomas, 1992; Schoenfeld, 1985) was used to address the interdependencies of the individual and group level processes in computer-supported collaborative problem solving.

The results showed that socially shared metacognition is a differentiator in making *group* problem solving successful, although it is an extraordinary and complex phenomenon requiring intentionality and reciprocity. However, for shared metacognition, it is not essential that all group members regulate the ongoing problem solving simultaneously. The results also show that there were not very many metacognitive computer notes, though the amount of metacognitive messages increased when the complexity of the problems increased. Thus, an optimal level of task difficulty is also essential for shared metacognition. Each of the groups had a tendency to ignore the analysis and verification phases of problem solving, which may have decreased the amount of metacognitive messages. On the basis of the results it is suggested that in order to get deeper insights into socially shared metacognition, the interplay of individual processes and socially shared metacognition should be examined.

5.4 Hurme, T-R., Merenluoto, K., & Järvelä, S. (2009). Socially shared metacognition of pre-service primary teachers in a computer-supported mathematics course and their feelings of task difficulty: a case study. *Educational Research and Evaluation, 15*, 503-524.

In order to gain a more detailed understanding of phenomenon under study, the aim of article IV was to examine how socially shared metacognition can be related to group members' individual metacognition, especially feelings of difficulty. For this study, two triads of 45 pre-service teachers were chosen at random. Triad A consisted of pre-service teachers who we named Anna (female), Alina (female), and Tapio (male). In triad B, Liisa (female), Aino (female), and Antero (male), solved problems together.

In the analysis of the discussion forum data, the operational definition of socially shared metacognition (Hurme, Merenluoto, Salonen, & Järvelä, 2008) was followed. First, in the qualitative content analysis of the computer notes (Chi, 1997), a distinction between metacognitive regulation, cognitive, and social statements was made. Based on the qualitative content analysis, the triads' process oriented graphs of joint problem solving were drawn in order to establish whether a metacognitive regulation message takes effect on discussion. In the analysis, feelings of difficulty graphs were categorized according to whether an individual's feeling of difficulty decreased, increased or was the same at the beginning and end of the task.

The results of this study suggest that if the process of socially shared metacognition emerges in group interactions then the most of the students will be able to reduce their individual feelings of difficulty. However, if the interaction is based on simple forms of exchange where the students compare the results of their individual processing (cf. King, 1999; Webb & Farivar, 1999), collaboration induces feelings of difficulty. In these kinds of situations, group members interact actively but lack domain-specific and/or metacognitive knowledge to provide elaborated explanations. The results of this study also suggest that, if the more knowledgeable peer is responsible for the metacognitive regulation of group interactions, the other students experienced reduced feelings of difficulty. However, the other group members' co-present cues was not a sufficient condition to decrease the more knowledgeable peer's feelings of difficulty because he had to be aware of his own and the others' cognition and/or metacognitive experiences to control the collaborative learning situation (cf. Salonen, Vauras, & Efklides, 2005).

6 Main findings

The general purpose of this dissertation study is to examine how a group’s regulation of joint problem solving is facilitated by an asynchronous and text-based learning environment. These findings can help to further understanding of *socially shared metacognition.* In the first experiment, the aim was to examine how metacognition becomes visible in a social learning situation supported by a text-based and asynchronous learning environment. The other aim was to explore how metacognition becomes shared in computer-supported collaborative problem solving. The aim of the second experiment was based on the findings in the first experiment. The operational definition of socially shared metacognition was proposed and the phenomenon under study was explored during groups’ collaborative problem solving situations. The main findings are summarized below.

6.1 Intentionality and reciprocity are prerequisites for socially shared metacognition

In the dissertation studies, the process of socially shared metacognition was examined using an operational definition based on the theories of individual metacognition (Flavell, 1979; Brown, 1989; Nelson, 1996) and the current understanding of socially shared learning processes (Hadwin & Oshige, 2006; Hadwin & Järvelä, 2009; Järvenoja & Järvelä, 2009). In the analysis, these kinds of processes were found. The results of this study showed that for metacognition to become shared, it is essential that the other group members acknowledge a metacognitive regulation message. By acknowledging the other’s messages and replying to them, individuals show that they are engaged in the joint problem solving making it possible for the group to truly collaborate (Järvelä, Veermans, & Leinonen, 2008). Further, building on the other group member’s thinking, and developing the presented idea through reciprocal interaction enables the group to construct mutual understanding (cf. Roschelle, 1992). As a consequence, for shared metacognition, it is not essential that all group members regulate the ongoing problem solving simultaneously. The most important principle is that one of the group member’s has an intention to steer the group as a whole, and the other group members react to the initiative. For socially shared metacognition to take place, group members should make their thinking visible by using clear wording and acknowledging questions and ideas important for the solution. This is however, a challenge for the group members. In order to benefit the individual’s attempts to metacognitively regulate the problem solving, the other group members should be able to provide equal level feedback on metacognitive suggestions. This could make the process of socially shared metacognition a complex and extraordinary phenomenon. Through reciprocal interaction and intentional participation, the process of socially shared metacognition could be considered as a differentiator that makes problem solving successful at the group level.

6.2 Not all metacognitive processes are shared during group problem solving

The results of this dissertation show that it is possible that metacognition becomes visible but is not shared among participants in computer-supported collaborative problem solving. In these cases, it is typical that an individual’s attempt to regulate the group’s problem solving is not acknowledged and the presented idea is not developed further. In these cases, the group makes either poor metacognitive decisions (Goos, Gailbraith, & Renshaw, 2002), or they lack the content specific knowledge and/or metacognitive knowledge. This could emerge in situations where a group member contributes a metacognitive regulation message to the discussions and the other group members reply by sending messages like, “aha, that way”, or “Now I get it”. It is possible that interpreting these transactional responses leaves the group with false sense of understanding (cf. Webb, Nemer, & Ing, 2006) because it could be that students’ reactions do not accurately represent their thoughts about a message from a group member (Shavelson, Webb, Stasz, & McArthur, 1988). It is possible that a metacognitive regulation message enhances a group member’s comprehension, and thus a more knowledgeable peer could trigger the other group members’ comprehension monitoring (Flavell, 1979; Karabenick, 1996). Another possibility is that the group member responds so as not to reveal a lack of understanding.

Another reason why metacognition becomes visible but is not shared could be a result of interactions among the group members (Kreijns, Kirschner, & Jochems, 2006). It could also be that during the interaction the group members are not able to take the other’s perspective into account and provide equal feedback for a more knowledgeable peer who steers the discussions because they lack the individual metacognitive and/or content specific knowledge needed to acknowledge the importance of the proposed solution method.

6.3 Metacognition is not evident in collaborative problem solving

The results of the study show that in computer-supported collaborative problem solving there were not many metacognitive messages made visible. This finding is consistent with previous research, which showed that,very often, groups do not reach a metacognitive level (Law, 2005; cf. Häkkinen, 2004). This may be a result of group members having difficulties in making their thinking available to their partners in such a way that interaction would be beneficial to all the group members (cf. Kieran, 2001). The results of this study also support findings suggesting that a technology-based learning environment itself does not guarantee a high-level of collaboration (cf. Garrison & Cleveland-Innes, 2005; Järvelä & Häkkinen, 2002).

Furthermore, the absense of metacognition seems be related to the amount of social level computer notes. This may be due to the instructions given, the quality of interaction, and a lack of conceptual knowledge (articles II, III). Participants who were not so knowledgeable tried to complete the participation requirement by sending social level comments or merely wanted to inform their group that they are online (cf. Jochems & Kreijns, 2006; Van den Boscche, Gijselaers, Seger, & Kirschner, 2006). Social level computer notes were also included that encouraged the group to engage in joint problem solving, provided agreement or disagreement, or revealed participants' perceptions about a task. However, it is possible that group members' social level computer notes that showed a lack of content knowledge could also provide an opportunity for the group to make thinking visible. This situation requires that there is a more knowledgeable peer in a group, because unhelpful social interactions sometimes impede progress (Goos & Gailbraith, 1996). For example, progress may be impeded in situations where group members only made their individual thinking visible and did not take into account the others' ideas. In these cases, the group members were too engaged in their individual problem solving, or there were inconveniences with engaging in group work (Van den Boscche, Gijselaers, Seger, & Kirschner, 2006).

One possible explanation for the absence of metacognition in collaborative problem solving may be that participants are not used to formulating their mathematical thinking by writing computer notes. That is to say, they were not used to solving mathematical problems in computer-supported collaborative learning situations, which may require them to change their own perceptions of mathematics learning and socio-mathematical norms (Yackel & Cobb, 1996). Enculturation in instructional practices affects students' understanding of how to interact and think in a mathematics classroom, and may even have an effect on adults. A study by Verschaffel and colleagues (1997) revealed that pre-service primary school teachers shared, in a less extreme form, students' tendencies to think that in word problems there is always a single solution. This single, precise answer should be obtained by performing arithmetical operations with numbers given in the text, while real world knowledge may be ignored. This kind of surface level perception of mathematics learning could lead to a learning situation where the participants' try to reach the solution quickly (Webb, 1989). Instead of analysing and verifying the task, and thus using their metacognitive knowledge, often students tried randomly exploring and implementing different solution methods. As a result of this, problem solving often leads to a "wild goose chase" (Schoenfeld, 1985).

6.4 If the process of socially shared metacognition emerges, then the most students are able to reduce their feelings of difficulty

The results of this study suggest that if the process of socially shared metacognition emerges in group interactions then the most of the students will be able to reduce their individual feelings of difficulty. For socially shared metacognition, it is important that interaction is based on argumentation and explanations of processes, not on reaching a solution as soon as possible. For socially shared metacognition, it is essential that, in addition to thinking, the group members make their feelings visible which can be done with social messages. Social messages could activate other individuals to adjust their thinking and feelings to the group processes. Feelings of difficulty will decrease, if students reassure each other and explain why they think they are on the right track to solve a problem.

It is possible that that collaboration induces feelings of difficulty, if the interaction is active but it is based on simple forms of exchange where the students compare the results of their individual processing (cf. King, 1999; Webb & Farivar, 1999) and act only at the cognitive and social levels. In these kinds of situations, group members lack domain-specific and/or metacognitive knowledge to provide elaborated explanations. However, if feelings of difficulty decrease, it could indicate after obtaining any result, students are relieved because they think they have fulfilled the task requirements. This could indicate a surface-level perception of mathematics learning according to which every problem has a single, precise answer obtainable by performing some basic operations (Verschaffel, DeCorte, & Borghart, 1997).

The results of this study also show if only one group member was responsible for the metacognitive regulation of group interactions, the other students experienced reduced feelings of difficulty. In these situations, the group members interact intentionally and a more knowledgeable peer scaffolds the group's problem solving by engaging the others in sequences of problem solving steps (King, 2007) and acting as external regulator (Azevedo, 2005). The more knowledgeable peer's feelings of difficulty will increase during collaboration if a person does not receive equal level feedback on his metacognitive suggestions. Further, it is possible that students' feeling of difficulty increase if they do not receive metacognitive messages to solve a problem or they lack to domain specific and/or metacognitive knowledge to respond the questions and ideas presented to reach a solution. These results show how socially shared metacognition and collaboration among group members affects an individual's metacognition. These results also point out that, interpersonal processes (e.g. Janssen, Erkens, Kirschner, & Kanselaar, 2009; Van den Bossche, Gijselaers, Segers, & Kirschner, 2006) are essential for understanding how learning can be monitored and controlled in a collaborative learning situation.

6.5 Methodological considerations

In this dissertation, a situative perspective of learning (e.g. Greeno, 2006) was used as a frame of reference for developing methods to examine socially shared metacognition in the computer-supported collaborative learning context. The methodological solution for examining socially shared metacognition consisted of combining qualitative and quantitative methods for the individual and group level analyses. Using multiple methods to gather and analyse data can be considered to be methodological triangulation, which helps to ensure validity in qualitative research (Cohen, et al., 2007; Lincoln & Guba, 1985). The participants of this study were not chosen based on statistical grounds, decreasing generalizability overall, but making the findings of this study transferable to the other studies in similar contexts (Lincoln & Guba, 1985).

In the first and the second experiments, the main data analysis method was the qualitative content analyses of computer notes (cf. Chi, 1997), in which a computer note as a unit of analysis is objectively recognizable (Rourke, Anderson, Garrison, & Archer, 2001). Further, the participants wrote the computer notes themselves, and in the analysis, interpretation into the thinking behind the messages was not made, which supports validity in both experiments. In the qualitative content analysis, a multidimensional coding scheme (cognitive, metacognitive, social level computer note) was used. In the second experiment, a computer note was allowed to be included in two different categories, especially at the cognitive level. For each dimension, inter-rater coefficients, Cohen's kappa (Cohen, 1960) and proportion agreement (Miles & Huberman, 1994) were calculated. In the assessment of the reliability of this study, whether the computer notes are valid units for different dimensions should be considered. The calculation of the reliability of the social, cognitive and metacognitive dimensions can be problematic because not all computer notes are a valid unit in one of these dimensions. In a reliability calculus, units were coded by two independent coders, there were no missing values, and non-coded units were excluded. That is to say, by only using valid units for analysis, the overestimation of reliability was avoided (cf. Strijbos & Stahl, 2007).

The computer notes created a network of messages dependent on each other and those that were contributed to the discussion earlier. The messages were considered as visible representations of thoughts emerging in interaction with other group members. This, in turn, enabled the exploration of socially shared metacognition as a group level phenomenon (cf. Barron, 2003; Greeno, 2006; Stahl, 2005). In the interpretation phase of the second experiment, a process-oriented graph of group problem solving was developed to represent the data without compromising information. This graphical representation made it possible to get a detailed description of how the participants interacted with each other, and allowed for the assessment of the quality of the joint problem solving. Further, through the use of the graphs, it was also possible to identify and visualize the specific moments where metacognition became visible and shared.

In the first experiment, social network analysis and correspondence analysis were used to visualize the data. In both methods no statistical hypothesis is tested, and there are no requirements for the normality of the distributions. These methods have indicators like Chi-square statistics (in correspondence analysis) and stress-value (in social network analysis, mds-map) which illustrate the goodness-of-fit of the model used. These quantitative techniques were not used as a way to generalize results to a larger population of students, but as additional warrants for claims identified through the qualitative analysis (Shaffer & Serlin, 2004). Thus, interpretations can be made to a reasonable extent although the number of participants was limited. In addition to these, in the second experiment, retrospective assessment of feelings of difficulty was used to find connections between socially shared and individual metacognition. The accuracy of retrospective methods relies on the participants' knowledge of his or her own behaviour (Veenman, 2005).

6.6 Practical implications

The two empirical experiments explored metacognition in computer-supported collaborative mathematical problem solving. The results of this study showed how socially shared metacognition emerges during group problem solving. One participant's thinking made visible in the regulation of the joint problem solving process can give impetus to the others to jointly negotiate different possibilities in solving the problem. By acknowledging and utilizing each others thinking it is possible for a group to reach a joint solution or reach a joint decision on how to proceed with the task. In general, in group thinking where socially shared metacognition emerges, the shared metacognitive knowledge helps individuals' thinking grow as a part of the group.

Socially shared metacognition was not easily reached in group problem solving. One practical issue relates to the organization of the collaborative learning situation. As shown in this study, students tended to work precisely as instructed, which could decrease their intentionality to participate in the co-construction of a solution. Working in triads requires participation by everyone and allows for the emergence of different views that need to be discussed reciprocally (cf. King, 2002). It is essential that the tasks are suitable for collaboration, for example open problems that have many possible solutions, provide opportunities for discussion, and allow participants to negotiate, justify and attempt to convince the other group members (Dillenbourg, 1999). Tasks with one correct solution (i.e. closed problems) can, however, reveal conceptual difficulties students have. Further, if the task difficulty level is too low, there is no need for true collaboration with peers. On the other hand, if the task is too difficult, collaborating with peers is not sufficient for successful problem solving, if no one in the group is more knowledgeable than the others. In these cases, the computer notes were more social in nature and it is likely that these messages were only contributed to the discussion in order to meet the course requirements. The type of task used for collaboration is related to the pedagogical goals a teacher wants students to reach. For example, for pre-service teachers, it was essential that they learn how to explain their mathematical thinking and be able to understand thoughts behind the explanations. This is what they need to be able to teach children to think mathematically in their future work. Different types of tasks make it possible for roles to change in a student group; the more knowledgeable student in one task can be less knowledgeable in another task. However, as shown in this study, formulating ideas and thinking about one's own or other's thinking are key factors in joint discussions and require some mathematical knowledge and skills. If the groups lack some domain-specific required knowledge, they may work side-by-side writing computer notes merely detailing their procedures. This is not what collaborative learning contexts are designed for and in these kinds of situations the group would need external assistance in order to continue working collaboratively.

Collaboration and making thinking visible are demanding processes. For participants, it is essential that they feel "social safety" in bringing up one's ideas (Kreijins, Kirschner, & Jochems, 2003; Van den Bossche, Gijselaers, Segers, & Kirschner, 2006). If there are social conflicts among group members, the participants may work side by side either by providing thinking guidelines or ignoring the more knowledgeable peer's explanations. The challenge for learning in collaborative learning situations is having a group reach and maintain a common ground. Consequently, a practical challenge is how to facilitate the group members' interaction (e.g. Littleton & Whitelock, 2005). For a teacher, it is important to pay attention to group dynamics in order to arrange the most suitable collaborative learning situations possible. Thus in collaborative problem solving, a teacher's or tutor's presence is needed to prompt the students' joint problem solving processes to help them reach a metacognitive level (cf. King, 1990). This can be done by asking them to clarify their thinking, through providing explanations, by asking them to acknowledge each other's ideas, and having them describe their understanding of how the other participants' suggestions of solving the problem would have an effect on the group's solution (Barron, 2000).

7 Discussion

In this dissertation study it was shown how socially shared metacognition can be reached through individual metacognition made visible for the joint regulation of group problem solving. This contributes to the current discussion of how learning no longer emerges only in an individual's mind, but in a collaborative learning situation in a particular learning context (e.g. Greeno, 2006). The core finding is that the process of socially shared metacognition requires that at least one of the group members regulates the ongoing problem solving at a metacognitive level. For metacognition to become visible and socially shared, metacognitive regulation messages should be acknowledged and further developed by peers. As a result of this, the group is able to reach a joint solution or a joint decision on how to proceed with their problem solving. The results show how individual metacognition and socially shared metacognition are interrelated and that both are needed for the conscious and continuous regulation of joint problem solving. These findings contribute to the situative and social constructivist perspectives of learning. Empirical experiments conducted in this dissertation address how social, cognitive and metacognitive processes are interdependent in a collaborative learning situation enhanced by a computer-supported learning environment.

In this dissertation study, it was established that *socially shared metacognition* is a key differentiator in making mathematical problem solving successful in a computer-supported collaborative learning context. When metacognition becomes visible and shared at least one group member needs to use his/her individual metacognition to monitor the group's problem solving. He/She must then share the results of his/her individual metacognitive thinking as objects of thought with the others by contributing a computer note suggesting, for example, a new approach for problem solving. This shared thought acts as a control function (cf. Nelson, 1996) externalized for the group to make them redirect their ongoing thinking. Groups that interact reciprocally and recognize the value of other's thoughts engage in high-level discussions (Järvelä & Häkkinen, 2002) and make it possible for socially shared metacognition to emerge.

Therefore, it should be asked, what would learning or problem solving in a group be like if there were not any socially shared metacognition? The results of this study show that without socially shared metacognition, group members are not able to construct a *joint* solution. It is possible that in a group one individual is capable of metacognitively controlling the ongoing problem solving. However, in this case the others are not aware of their thinking or have a lack of domain specific knowledge, and therefore unable to change the current way of thinking. Alternatively, metacognitive control by one group-member could lead to a scaffolding situation where, for example, the more knowledgeable participant models his/her thinking step by step to the others (article IV). For fading his/her scaffold (Puntambekar, 2005), it is essential that the other group members contribute computer notes and share what they know and whether they need further assistance. If there is not a more knowledgeable peer in a group to control the process at the metacognitive level, then it is possible that the group members do not benefit from the social learning situation (cf. Forman, 1989; Watson & Chick, 2001). Further, if disrespectful interaction appears among group members and interpersonal conflicts are sustained, one group member may be excluded from the group and his/her metacognitive control attempts may then not be acknowledged at all (Kreijns, Kirschner, & Jochems, 2003; Van de Bossche, Gijselaers, Segers, & Kirschner, 2006). In these collaborative learning situations, the more knowledgeable is not the most powerful member within the group and the educational potential of collaborative learning is greatly diminished (Forman, 1989). In a group where no metacognition, neither individual nor socially shared, becomes visible, the group members work side-by-side without acknowledging each other's thinking. They use the computer-based learning environment to decrease the cognitive load of their individual processes or they fulfill the participation requirement by reporting what they are doing. That is to say that the groups with similar profiles in mathematics and group problem solving functioned rather differently. These finding reported in this dissertation study as well as those of others confirm that among different groups, there is variance in the quality of interaction (Artzt & Armour–Thomas, 1992; Barron, 2003; Forman, 1989; Järvelä & Häkkinen, 2002; Watson & Chick, 2001).

7.1 Metacognition and different forms of regulation of learning

The current discussion in the field of educational psychology has focused on the different forms of regulation of learning among individuals and within groups. These conceptualizations vary greatly. The results of this dissertation study are in line with the ongoing discussion about different forms of regulation, individual self-regulation, co-regulation and socially shared regulation (e.g. Hadwin, Oshige, Gress, & Winne, 2007; Järvelä & Järvenoja, 2007; Volet, Vauras, & Salonen, 2009). Pintrich (2000) defines *self-regulated learning* as "an active process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment”, (Pintrich, 2000, 453). That is to say, self-regulated learners are aware of what kind of cognitive learning strategies one has, and while engaging in academic tasks they are able to select, monitor, and regulate their use of those strategies (Wolters, 2003). To regulate one’s own learning, learners have to deal with their cognitive, motivational and contextual knowledge (Boekaerts, 1995; Zimmerman, 2008).

Current research (e.g. Hadwin, Oshige, Gress, & Winne, 2008; Järvenoja & Järvelä, 2009) proposes that the *socially shared regulation* of learning refers to the process by which multiple others regulate their collective activity in order to advance the group’s work or to reach a joint solution through reciprocal interaction where the regulatory processes and products are shared (Hadwin, Oshige, Gress, & Winne, 2008). *Co-regulation* of learning refers to a transactional process where a student and a more capable peer share the regulation of the student’s learning (Hadwin, Oshige, Gress, & Winne, 2008; Volet, Vauras, & Salonen, 2009; Salonen & Vauras, 2006). In other words, the more knowledgeable peer provides regulation for the student by using metacognitive monitoring and evaluating to ask questions like, “How do you know these methods should be used?” These questions, as well as some computer based learning environments (Azevedo, 2005; Zellermayer, Salomon, Globerson, & Givon, 1991; Hadwin & Winne, 2001; Perry & Winne, 2006), could act as external regulators for students learning to help another student focus on the task at hand. Thus it can be argued that, co-regulation relies on two processes, scaffolding and intersubjectivity. These refer to supporting regulation for another peer’s cognitive and metacognitive processes, while participating in a joint discussion and shared rationale in a common regulatory space (Hadwin, Oshige, Gress, & Winne, 2008). When these processes emerge, from the Vygotskian perspective, the participants have asymmetric roles, where the more knowledgeable peer scaffolds the other students appropriating the support (Forman & Cazden, 1985). Whereas, from the Piagetian viewpoint the role of sociocognitive conflict is emphasized (Buchs, Butera, Mugny, & Darnon, 2004). Neither of these viewpoints relies on processes of mutually constructed shared knowledge (Roschelle, 1992).

How, then, is socially shared metacognition related to socially shared regulation? Both of these phenomena require collaboration, negotiations of meanings, and engaging in the construction of mutual knowledge in reciprocal interaction. Socially shared regulation consists of motivational, emotional and cognitive aspects of regulation processes, the products of which are shared (e.g. Hadwin, Oshige, Gress, & Winne, 2008; Järvenoja & Järvelä, 2009). Whereas, in this dissertation study, socially shared metacognition refers to deliberate monitoring and controlling of the group's problem solving processes. A common feature in these two concepts is the interpretation of what the word *shared* means (for different interpretations of the word *shared*, see Stahl, 2005). When group members acknowledge a metacognitive regulation message and develop it further, the outcome of this shared metacognition is either a joint solution or a joint decision on how to proceed with problem solving. In these cases, it is not possible to reduce these to the attribute of an individual (cf. Hadwin & Oshige, 2006; Järvenoja & Järvelä, 2009; Volet, Vauras, & Salonen, 2009). Similar kinds of ideas can be found in the social network perspective, where cognitively central members can provide social validation for other member's knowledge, along with their own knowledge being confirmed by other members (Kameda, Ohtsubo, & Takezawa, 1997). Metacognition, as socially shared, could also pertain to shared metacognitive knowledge (Paris & Winograd, 1990). Thus, for future research one question is if socially shared metacognition, like individual metacognition, has two distinct but overlapping components, knowledge about and regulation of (joint) problem solving.

7.2 Conclusions and future research

The quest to uncover socially shared metacognition has been a challenging but a rewarding process. The central issue for the phenomenon being studied is how cognition and understanding arise from group member's interaction (e.g. Barron, 2003; Roschelle, 1992).

Different perspectives on learning and mathematical problem solving formed the frame of reference for this dissertation study. Metacognition and the mathematical problem solving process are strongly rooted in the cognitive perspective of learning (Greeno & Resnick, 1996), whereas understanding learning as the participation in collaborative discourse in a social and/or technological context is at the heart of the situative perspective of learning (cf. Brown, Collins, & Duguid, 1989). Furthermore, the general goal of mathematics is the explicit formulation of a mathematical phenomenon by using symbolic notations. The use of more subjective and less exact explanations increases the possibility for incoherence and leads to the emergence of contradictions (e.g.

Boyer, 1959). In contrast to this fundamental feature of mathematics, mathematical thinking was made visible and explained through the use of written computer notes in this dissertation study. In many schools, students are introduced to pieces of mathematical content knowledge and rarely to the thinking behind the theorems (e.g. Merenluoto & Palonen, 2007). For expert mathematicians, mathematics is not repeating successive steps of a proof of a theorem, but utilizing formed mental models where mathematical concepts are interrelated with each other (Hadamard, 1996; see also Merenluoto, 2001). To begin to understand the interrelationships between mathematical concepts, the processes behind these methods and interrelations between them need to be made visible and explained, which requires metacognition. By engaging in mathematical thinking, it is possible that students go beyond reaching a consensus on a proposed solution and get involved in the process of co-constructing a solution (cf. Kruger, 1993).

One of the main challenges in examining socially shared metacognition is to operationalize the word *shared* at the *meta*-level. In this study, interaction was based on written information and participants had some *shared* knowledge in mathematics based on the national curriculum, but what they have previously learned has some individual differences. Thus, for establishing the emergence of metacognitive monitoring and controlling, it was required that participants explicitly express their intention to interrupt, change or promote the ongoing problem solving strategy and provide an explicit explanation as to why they think this. Following Nelson’s (1996) model of an individual’s metacognition, the results of this dissertation suggest that one group member could use his/her own metacognitive knowledge and skills to monitor the ongoing joint problem solving. The others could then, acknowledge the idea and develop it further with the assistance of their individual metacognition (cf. controlling function). For this process, intentionality, reciprocity and engagement in negotiations through the externalization of one’s own thinking and the internalization of the other’ thinking are required (cf. Beers et al., 2005; Kirschner, Beers, Boshuizen, & Gijselaers, 2007) in order to continue the joint problem solving or a solution. The description of the process of how metacognition becomes visible and shared can be considered to be a theoretical contribution of this dissertation study. It is not, however, comprehensive, but gives impetus for future research in this field. Furthermore, in this dissertation study, novel data gathering methods, like feeling of difficulty graphs, were used. For analysis of the data, multiple research methods not generally used in metacognition research were applied to reveal the complexity of the phenomenon under study. However, in using multiple research methods, issues of reliability, validity and generalization should be taken into account.

Another issue that may be important for the understanding of socially shared metacognition is the role of the technology and pedagogical models applied. Asynchronous learning environments, wikis or social media can be used to facilitate collaboration (Stahl, Koschmann, & Suthers, 2006). Research on computer-supported collaborative problem solving have, however, addressed that simply placing students in such an environment does not guarantee that learners engage in effective collaboration and reach a shared understanding (e.g., Kreijns, Kirschner, & Jochems, 2003; Mäkitalo, 2006; Soller, 2001). Current pedagogical ideas highlight the role of scripts in facilitating collaboration and higher level discussions (e.g., Dillenbourg & Jermann, 2007; Fischer, Kollar, Mandl, & Haake, 2007; Morris, et al., in press; Weinberger, Kollar, Dimitriadis, Mäkitalo-Siegl, & Fischer, 2009). The effects of scripts on socially shared metacognition would be meaningful to examine.

To conclude, socially shared metacognition is a complex and extraordinary phenomenon. In order to gain a deeper understanding of socially shared metacognition, one challenge lies in establishing theoretical linkages between individual and shared metacognition, and concepts like scaffolding, shared regulation, socially shared motivation and emotion regulation, and shared cognition. Further, to avoid having the concept of socially shared metacognition become an epiphenomenon, it would be essential to examine how it develops in groups, whether it is general or context bound, and whether it consists of knowledge and regulation components similar to individual metacognition. Further, the issues of a group member’s awareness of socially shared metacognition and its effects on the group’s performance and learning outcomes should be addressed in future research. As well, the role of group dynamics in the process of socially shared metacognition should not be ignored. The first steps taken in this doctoral dissertation to examine socially shared metacognition establish that the work has just begun. Despite the development of new technologies and pedagogical approaches for organizing learning activities in individual or group contexts, the very fundamental processes of learning, like metacognition, are constantly needed in academic performance.

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ISBN 978-951-42-6269-2 (Paperback)
ISBN 978-951-42-6270-8 (PDF)
ISSN 0355-323X (Print)
ISSN 1796-2242 (Online)

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