Socially shared metacognition of pre-service primary teachers in a computer-supported mathematics course and their feelings of task difficulty: a case study

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Collaborative learning assumes that knowledge is constructed through negotiation and discussion. This exploratory study focuses on 2 groups of 3 pre-service primary teachers solving 2 mathematical tasks in a text-based and asynchronous WorkMates learning environment. This case study describes the group processes, and the different patterns of group interaction are analyzed. The assumption is that the process of socially shared metacognition is especially effective in learning how to solve problems in groups. Socially shared metacognition emerges when a group member regulates a group’s problem-solving process and the other group members react to the initiative. Individuals’ retrospectively reported feelings of difficulty during the task are taken as a measure to show whether group interactions contribute to individual learning. The results suggest that, when socially shared metacognition emerges, individuals’ feelings of difficulty decrease. Important is that individual group members with adequate (meta)cognitive skills take the initiative and other members react upon it. Suggestions for future research are discussed.

Keywords: socially shared metacognition; metacognitive regulation; collaboration; CSCL; problem-solving; mathematics

Introduction

Socially shared metacognition

This exploratory study examines how socially shared metacognition emerging in group problem-solving is related to group members’ retrospectively reported individual feelings of difficulty.

Drawing on the theory of an individual’s metacognitive processes (Brown, 1987; Efklides, 2006; Flavell, 1979; Nelson, 1996) and recent discussions about shared regulatory processes during collaborative learning (Hadwin, Oshige, Gress, & Winne, in press; Järvenoja & Järvelä, 2009), Hurme, Merenluoto, Salonen, and Järvelä (2008) proposed an operational definition of the process of socially shared metacognition in computer-supported collaborative learning (CSCL). In their definition, socially shared metacognition occurs when a group member’s metacognitive regulation message contributes to the joint discussion about how to process a
task and takes effect in group problem-solving when other group members acknowledge and further develop the message. Socially shared metacognition requires that the aim of a metacognitive message is to regulate, that is, to interrupt, change, or promote, the ongoing process of carrying out a group task. The process of socially shared metacognition has the intention of steering the discussion rather than exchanging ideas about possible ways to finish a task. Messages that only present ways to analyze or solve a task are seen as cognitive messages because they have no clear steering intentions for the group as a whole. During problem-solving, the process of socially shared metacognition requires intentionality on the side of a participant, reciprocity, and engagement of the other group members in order to finish the joint problem-solving process.

In computer-supported learning environments, collaboration among participants is based on contributing ideas and thoughts to a text-based discussion forum. Often, the group members have an overview of the sent messages that are recorded in computer log files (Kumar, Gress, Hadwin, & Winne, in press). Group members send cognitive, metacognitive, and social messages to each other (e.g., Hurme, Palonen, & Järvelä, 2006). For collaboration, it is essential that students reply to each other’s messages. For example, suppose a group member could send a metacognitive message in order to regulate and trigger the other group members’ comprehension monitoring (cf. Karabenick, 1996; Webb, Nemer, & Ing, 2006). If the group members do not reply to the metacognitive regulation message or submit only a quick response, it is not possible to recognize whether the metacognitive regulation message is meaningful to an individual or the group’s problem-solving process. Thus, it is possible that responses such as “Aha, that way” or “Now I get it” leave the other group members with false senses of mutual understanding because students’ reactions do not accurately represent their thoughts or feelings about a message from a group member (cf. Shavelson, Webb, Stasz, & McArthur, 1988). It is possible that the metacognitive regulation message enhances a student’s comprehension, or the student responds so as not to reveal a lack of understanding. Thus, for group processes and socially shared metacognition to be effective in CSCL, it is essential for students to provide rationale for their thoughts and communicate this in clear wording. In this case, interaction could make problem-solving easier and more instructive than individual learning.

Earlier research concerning metacognition in groups was conducted in face-to-face learning situations. Results suggest that, in groups, individuals need to monitor not only their own but also their peers’ problem-solving processes (Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003). The effective aspects of collaborative interactions are assumed to be the sharing of ideas and procedures about how to handle a problem and the discussions about which alternative to follow if the current problem-solving approach fails to produce a workable solution (Iiskala, Vauras, & Lehtinen, 2004; Tindale & Kameda, 2000). These interactions are very much in line with what we call “socially shared metacognition”.

During problem-solving, individuals experience feelings of difficulty in the group task. Some may experience difficulty with the task from the beginning, while others may only encounter difficulty halfway through the process. This depends on the individual’s prior knowledge of the elements of the task, and/or his or her ability to analyze the task at hand (e.g., Brown, 1987; Efklides, 2006). Feelings of difficulty may help or hinder a person’s contribution to solving a group task. At the end of the process, the feeling of difficulty with a task indicates how well a person thinks he or
she understands how the task can be solved (Efklides, 2006, 2009; Koriat & Levy-Sardot, 2000). Stock, Desoete, and Roeyers (2009) define an individual’s feeling of difficulty during a mathematics task as an aspect of the individual’s metacognition, which corresponds to the person’s ability to predict how well he or she can solve a mathematics problem. In their study, perception of difficulty was shown to be directly related to the skill of actually solving a task. If the perception of a problem’s difficulty is reduced in collaborative learning because students share knowledge and discuss how to solve the problem, students may be expected to perform better on that type of problem.

In the measurement of the feelings of difficulty, both prospective and retrospective research methods have been used. Either before or after solving the task, learners are asked to assess how easy or difficult they found the task, for example, by using questionnaires (e.g., Efklides, Samara, & Petropolou, 1999). The use of these methods relies on the accuracy of an individual’s knowledge of his or her behavior (Veenman, 2005). In addition to questionnaires, other subjective measures like rating scales have been shown in cognitive load research to be reliable in assessing the subjective perception of task processing (e.g., Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Paas & Van Merriënboer, 1994). Thus, retrospective assessment was used in this study. An individual’s retrospectively assessed perception of the task difficulty is considered as a relevant outcome of CSCL that indicates whether group interactions contribute to individual’s learning.

Analyzing students’ messages in CSCL

In the past 10 years, much research has been conducted to code and analyze students’ interaction and participation using written messages during CSCL. Researchers have utilized a broad spectrum of behavior categories to study the processes and outcomes of collaboration (Strijbos & Fischer, 2007). An ongoing methodological challenge is to find ways to capture the situational dynamics of online discourse (Hmelo-Silver & Bromme, 2007) and features of interaction researchers value most highly in CSCL. We discuss a few of these studies in Table 1.

The overview in Table 1 gives an indication of the recent state of affairs. Formal recordings in computer systems can provide information on learning interactions. However, these recordings are not classified automatically into different behavior categories, such as the examination of self- and co-regulation among learners (see also Hadwin et al., in press). Instead, the researcher or teacher must categorize the recordings. The overview shows several coding schemas are available to categorize students’ interactions during problem-solving. Still, few studies have investigated the underlying sequences of behavior, such as socially shared metacognition, during the process and how these can be related to individual learning.

This study explores how socially shared metacognition in group problem-solving can be related to group members’ individual feelings of difficulty during mathematics tasks.

Method

A case study was undertaken with two groups of three students among 45 Finnish pre-service primary teachers taking their first university-level course in
teaching mathematics at primary school. The two triads worked in a computer-supported collaborative learning environment. The aim of the course was for new trainees to experience what collaborative learning entails in solving mathematics problems, as well as how to formulate discussions with other trainees in order to profit from their knowledge. Participation in this study was voluntary, and the pre-service teachers were provided with a course credit for their participation.

**Participants**

For this study, two triads were chosen at random from the group that worked with computers. The Triads A and B both had two women and one man. In Triad A, we named the students Alina (female), Anna (female), and Tapio (male), aged 18, 22, and 21 years, respectively. Triad A members reported they did not like mathematics and thought they were not good at mathematics, but they liked to work with others. In Triad B, we named the students Liisa (female), Aino (female), and Antero (male), aged 20, 20, and 29, respectively. Triad B members reported they liked to work in groups and liked mathematics, but they felt they needed time to solve mathematical problems.
WorkMates learning environment

The triads participated in weekly 2-hr joint problem-solving sessions over 4 weeks. The triads worked at an appointed time in the university’s computer classroom through an asynchronous and text-based learning environment, WorkMates (WM). WorkMates allowed the triads to work in a similar situational context. At the beginning of each session, the number of tasks was announced, and the triads were instructed to “solve the problem as a group” for a total of 16 different mathematical tasks. The researchers ensured participants used their own mathematical knowledge without additional resources such as mathematics workbooks. The rationale for withholding other resources was that the pre-service teachers should explain and discuss their mathematical thinking with others. In the WM learning environment, each triad had a private folder to log into, with an individual user account and password. The mathematical problems were published in the discussion area of a group’s folder just before the joint problem-solving session started. The problems were also given in paper format, and the participants were allowed to make notes with a ballpoint pen.

The WM interface (Figure 1) provided the group members with a common text area featuring a description of the task; no hints were provided to help the group solve the problems. Discussion could begin when a group member clicked “Add your comment” underneath the given problem and submitted his or her message.

![The WM interface.](image-url)
Submitting a reply was done similarly. The group members interacted only through WM, including discussions how to start and when to finish problem-solving and draw their individual difficulty graphs.

The two triads worked in a computer classroom at the same time as other participants working with computers, and group members were situated on different sides of the classroom. The interaction among participants was more synchronous than asynchronous due to the organization of the meeting. Each group received the problems in the same order. A principal researcher followed the groups’ interaction online in the computer classroom and gave the subsequent problem in paper format to the group after assessing their feelings of difficulty. The researcher was responsible for keeping time of the 2-hr session, but the groups were responsible for timing their own problem-solving.

**Mathematical tasks**

For this explorative study, we chose 16 mathematical problems of different difficulty levels but within the limits of the distribution of skills. Most tasks were closed problems with only one correct answer, but there were also some open-ended problems. In this article, we focus on two different kinds of mathematical tasks related to the first (Task 1) and fourth (Task 2) working session. The first task was a brain-teasing task with one correct solution, and it was chosen to engage the participants in the process of joint problem-solving. The second task was a more complex algebraic problem with fractions requiring a conceptual understanding of infinity, with multiple possible solutions. The tasks were as follows:

**Task 1. The Dark Stairs**

Matt, Grandmother, Little Sister and Dad are standing upstairs in the dark and they need to go downstairs. The stairs are really narrow and are in bad shape and about to crash, so they can take only two people’s weight at a time. The stairs will collapse in 18 minutes. The family has only one flashlight and it is impossible to use the stairs without the light being on. The sinuous stairs are also so long that it is impossible to throw the flashlight upstairs from down the stairs. The members of the family are aware of how much time it requires them to get down the stairs. Because Grandmother is in poor health it takes 7 minutes for her to go down the stairs. The Little Sister walks down the stairs in 5 minutes and Dad does it in 3 minutes. Matt runs the stairs in 2 minutes. Is it possible for everybody to get downstairs in 18 minutes? (Modified, Björklund, Lehto, Pasanen, & Viljanen, 2002).

In this task, the most obvious but incorrect strategy is to choose Matt, who is the fastest one to run up and down the stairs. One of the crucial elements for a solution is that the two slowest ones, Little Sister and Grandmother, go downstairs together. Further, Dad and Matt take turns running up or down the stairs.

**Task 2. The equation problem**

Find one pair of numbers that satisfies the following equation:

\[
\left(\frac{3}{4} + x\right) \div 5 - 4 = y + \frac{1}{2}
\]

Can you find another solution?
How many solutions you can find?
This mathematically more challenging task provides opportunities for discussions about infinity. The easiest way to find one pair of numbers that satisfies the equation is to substitute $x = -3/4$ to the equation and solve for $y$.

**Data collection and analysis**

Data were collected from the participants’ messages in WorkMates. For the two tasks reported here, the discussion forum data consist of the pre-service teachers’ 565 posted messages. Triad A and Triad B posted a total of 225 messages, 120 in Task 1 and 105 in Task 2. Triad A wrote 58 messages in Task 1 and 50 messages in Task 2. Triad B wrote 62 messages in Task 1 and 55 messages in Task 2. Analysis of the data focuses on knowledge and thinking made visible in the messages.

**Individual feelings of difficulty graphs**

Group members assessed their individual feelings of difficulty retrospectively immediately after the joint problem-solving sessions. Individuals drew graphs of their feelings of difficulty with a ballpoint pen on a coordination plane where the y-axis illustrated the increase of difficulty level on a scale of easy-difficult. To draw the graphs, four time points were assigned on the x-axis; at the beginning of the task, Time point 1, Time point 2, and the end. The time points were not determined, but they acted as points of reference for the participants in drawing the graph (Merenluoto & Hurme, 2008). In the analysis, responses 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.

**Development of a reliable coding system**

In the analysis of the messages, a qualitative content analysis (Chi, 1997) was followed by two independent coders. The unit of the analysis was one message, and the rater independence coefficient, Cohen’s kappa, was calculated (Cohen, 1960).

To establish the process of socially shared metacognition (Hurme et al., 2008), a two-step procedure was followed. First, in the qualitative content analysis of the messages, a distinction was made between metacognitive regulation and cognitive and social statements (Efklides, 2006; Veenman, Van Hout-Wolters, & Afflerbach, 2006). Secondly, it was specified whether a metacognitive regulation message contributes to and takes effect on discussion.

**Metacognitive regulation messages**

A message was considered metacognitive regulation if it fulfilled the three following criteria. First, the message should be related to and focused on the earlier or ongoing discussion. Second, the message should have an intention to interrupt, change, or promote the progression of the joint problem-solving process. Third, the message should also have an explicit expression as to why the group should, for example, consider another feature of the task.
In light of the operational definition of socially shared metacognition and metacognitive regulation messages, the 120 messages from Task 1 and 105 messages from Task 2 for the two triads were coded accordingly. Two independent coders trained with a number of trial messages coded the messages of the triads. The coders reached a satisfactory level of agreement (\( \kappa = .78 \); Landis & Koch, 1977).

**Cognitive messages**

A cognitive message was defined as a note related to the mathematical problem-solving that did not include any explanations. Messages relating to the mathematical problem-solving process (Schoenfeld, 1985) were categorized as *analysis*, *exploration*, *implementation*, and *verifying*. The *analysis* category consists of comments where the group member tried to fragment the problem into smaller parts and recall how he or she had previously solved similar kinds of problems and to clarify what was asked in the problem. A message identifying *exploration* brings up concrete ways to solve the problem. In the *implementation* messages, a group member suggested a result or the outcome of a calculation. The *verification* category consists of messages that evaluate either the ongoing problem-solving process or the result itself.

**Social messages**

Messages that were *social* in nature, for example, comprised comments unrelated to the problem, agreement, or disagreement without visible argumentation or humor.

Given the operational definitions of cognitive and social messages, the 120 messages from Task 1 and 105 messages from Task 2 for the two triads were coded accordingly. Two independent coders were trained and then coded the group members’ messages. The coders reached a satisfactory level of agreement (\( \kappa = .83 \); Landis & Koch, 1977).

After determining that the different behaviors in the recordings of WorkMates could be reliably categorized, a sequential graph of group member’s behavior during problem-solving was drawn. Each participant had an individual symbol. The y-axis represented the characteristics of the social- and cognitive-level messages, and the x-axis represented the time used for problem-solving, coded in 1-min intervals. A straight line between an individual’s symbols at two levels in the y-axis identified messages coded into two different categories. An arrow was used to identify a message that referred back to a former message sent by a peer.

In the sequential graph, the process of socially shared metacognition was marked as follows: A metacognitive regulation message was surrounded by a cloud with the letters MR. If the metacognitive regulation message contributed to and took effect on the discussion, it was marked with a dashed arrow pointing from the metacognitive regulation message to the message it influenced. A dashed line without an arrow indicated that a metacognitive regulation message was acknowledged by a peer who was unable to develop the idea further, hindering the process of socially shared metacognition. The sequential graph of all three students’ behavior over time and the content of the message in a discussion forum allow the researcher to draw the arrows in the graph to show who influences whom, which student(s) steered the thinking process, which student(s) followed, and which student(s) contributed very little.
Results

**Triad A Task 1**

In this first example, we show how the process of socially shared metacognition unfolded twice while Anna, Alina, and Tapio try to solve the first task. The group’s problem-solving process is visualized in Figure 2.

At the beginning of the process, Anna and Alina analyze the task (see Anna’s (0:00) and Alina’s (0:01) comment at analysis level in Figure 2). They are thinking about the best way to reach a solution, which they consider to be if Matt runs upstairs and downstairs each time. Tapio also joins the discussion, suggesting that, “The fact is that there is no need for Matt to run all the time” (0:03, exploration) and “I think, otherwise, this would be too easy” (0:03, social, added to his previous comment). His first comment consists of features important to the solution, but his idea is not acknowledged. The group continues to work as Anna and Alina suggest. The first 10 min show (Figure 1) they are all engaged in the joint problem-solving and contribute to each other’s messages even though they are unsuccessful. After 12 min and their first solution attempt, Anna encourages (0:12, the screwed arrow at social level) the whole group to carry on with the problem-solving process by writing, “Let’s try again, have strength”; thus, she invites the others to jointly regulate and explore new solution efforts.

**Socially shared metacognition in the interactions**

Anna’s encouragement engaged the group in a second attempt to solve the task. At 19 min, Alina sent a metacognitive regulation message (0:19, includes both cognitive (exploration and implementation) and metacognitive aspects) to the discussion forum, “Matt is the fastest one to run the flashlight up and down, but should it be someone slower to go together with Grandmother . . . ? I’ve tried several ways to solve this but I always get more minutes than 18.” In her message, Alina provides the rationale for her thinking, and with the word “but” she interrupts the group’s joint problem-solving. Her message also regulates the group’s problem-solving process by providing an essential component of the solution; that is, Grandmother goes downstairs with another slow person. Tapio (0:20, exploration) acknowledges the importance of Alina’s idea, though he is unable to develop the idea further at that moment. Anna (0:21, exploration) also joins this discussion by writing:

I noticed that there is an error in my thinking. So, for Grandmother, it takes seven minutes anyway, it would be reasonable, for example, to put Little Sister to go with her, because for Little Sister, it takes five minutes. But, now the Grandmother and Little Sister are going together, and it takes altogether seven minutes. The little sister goes up – five minutes. Sister goes down with Dad, and it takes five minutes . . . does this sound reasonable . . . ?

By contributing this message, Anna not only shows how Alina’s idea made her change her thinking, she also develops Alina’s idea further by suggesting it should be Little Sister who goes with Grandmother. At this point, a process of socially shared metacognition becomes visible. The group continues to develop presented ideas, but after 27 min the groups’ second attempt was not successful. This made the group members withdraw from the group discussion. From minute 30 to minute 42, some remarks were made that were hardly answered by the others. After this relatively
Figure 2. The process of socially shared metacognition in Triad A.
silent period, the group rejoins the discussion again. They continue to work with the idea that Matt should be running upstairs and downstairs even though it was obvious to them the current way of thinking was not working. Anna brings up a new idea for the solution:

**Anna** (0:49) Did you try one of the possibilities being that e.g. Matt takes Grandmother down and runs back up. The next to come down is not Matt but the others. Or about the pair would be changed upstairs . . . ?

**Tapio** (0:51) I’ve tried to work it out but could someone slower be the last one in the end.

**Alina** (0:50) I tried . . . But if someone else dribbles the flashlight, so the time is wasted when taking the flashlight upstairs. That’s why Matt would be the fastest one.

Thus, after 49 min, a third attempt is made. Anna provides a new idea in the discussion in order to change the group’s thinking (0:49, exploration, metacognitive regulation). The modified idea for the solution is that it is not necessary for the same person to run upstairs and then immediately back downstairs with someone slower. Her idea is acknowledged by Tapio (0:51, exploration), who develops the idea further by integrating it with a previously presented idea that the two slowest persons should go together to save time. Alina also acknowledges Anna’s point (0:50, implementation) but has difficulty giving up her previous way of thinking that only Matt could run back and forth all the time. At this point, there is *socially shared metacognition*. When the group has worked collaboratively for 55 min, Anna provides a group solution to the problem influenced by the whole group’s thinking. The solution is correct:

<table>
<thead>
<tr>
<th>Time</th>
<th>Person(s)</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 min</td>
<td>Dad + Matt</td>
<td>go down</td>
</tr>
<tr>
<td>2 min</td>
<td>Matt</td>
<td>runs up</td>
</tr>
<tr>
<td>7 min</td>
<td>Grandmother + Little Sister</td>
<td>go down</td>
</tr>
<tr>
<td>3 min</td>
<td>Dad</td>
<td>goes up</td>
</tr>
<tr>
<td>3 min</td>
<td>Dad + Matt</td>
<td>go down</td>
</tr>
</tbody>
</table>

**Triad A Task 2**

Tapio, Anna, and Alina had their fourth session in the computer classroom. They were solving Task 2, which was an algebraic problem dealing with fractions and two unknown parameters, $x$ and $y$: \( \frac{3}{4} + x ) \div 5 - 4 = y + \frac{1}{2} \). The group’s problem-solving process is visualized in Figure 3.

*The process of socially shared metacognition is hindered during the problem-solving*

Alina (0:01, analysis, Figure 3) suggests they could solve the equation for $x$ and then substitute the value of $x$ into the original equation. Anna (0:01, social) and Tapio agree, and Tapio provides another suggestion that they could multiply the equation by 5 (0:02, exploration). This was unsuccessful because none of them were willing to do the calculation (Anna and Tapio’s messages, 0:03 and 0:04, social), and Alina began to solve the equation for $x$ (0:04 and 0:06, implementation, and 0:07, social). After 10 min, Tapio contributes his more advanced thinking to the discussion, suggesting they should substitute $x = 3$ into the equation (0:11, exploration and implementation). Tapio composed two messages (0:13, exploration and
Figure 3. Tapio’s metacognitive regulation messages are not developed further.
implementation) to model the procedure of substituting $x = 3$ for Anna and Alina, confusing Alina (0:12, social). In addition, Anna (0:13, social) reported to the others, “I left my equation thoughts home . . . I don’t remember much”. At this point, when Anna and Alina were struggling together with their method of thinking, Tapio (0:16, exploration) suggests that “the relation [between $x$ and $y$] stays the same no matter what the $x$ values”. The females do not acknowledge this more advanced comment and begin to solve the problem all over again for $y$ (Anna’s messages, 0:18, analysis, and 0:20, exploration; Alina’s message, 0:19, exploration). They faced serious difficulties after solving $y = (3/4 + x):5 - 4 - 1/2$ (Alina’s message, 0:23, implementation), and they did not know what to do next (Anna and Alina’s messages, 0:24 social). Tapio had acknowledged that his peers were not able to focus on his modelling at that point and he had been behind the scenes (0:21, social). He started to model his thinking again by using a detailed step-by-step procedure (0:25, cognitive and metacognitive) to show how $y$ can be solved when substituting $x = 3$ to equation. After his modelling, Alina (0:28, exploration) realized that “so the $x = 3$ is just any number” and by this comment made sure she had understood the procedure correctly, but she was not able to steer the group’s thinking. At the same time, Anna (0:27, social) is making her individual thinking visible by writing in parentheses “(I would have thrown $y$’s to the one, and the numbers to the other side [of the equation])”.

Tapio continued to support Anna and Alina’s thinking by continuing his step-by-step procedure (Tapio’s message at 0:31). At the same time, Tapio contributed a metacognitive regulation message (0:29) to change the group’s problem-solving process by providing explicit explanations of how to think.

**Tapio** (0:29) Yeah, but I think we just have to take some number if we wish to have a pair of numbers. It is only one point in the number line. And the relation between $x$ and $y$ does stay the same, doesn’t it?

**Anna** (0:30) So what answer did you get, I got an impossible one.

**Alina** (0:30) Not a clue????

**Tapio** (0:31) 6. $15/20 - 4 - 1/2 = y - >$ and then we build $1/2 - > 10/20$ and then we combine the fractions

7. $5/20 - 4 = y$, where $-4 = -80/20$

8. $y = -3 15/20$ then reducing it

9. $y = -3\frac{3}{4}$

**Anna** (0:32) . . . aha . . .

**Alina** (0:33) Yeah . . . well, I wouldn’t be able to do that.

**Tapio** (0:32) But when we take another point in the number line so we get different numbers, now we had $x = 3$ and $y = -3\frac{3}{4}$

**Anna** (0:34) OK, I think I’m following :)

**Alina** (0:34) So, $x$ can be any number . . . so there are an infinite amount of answers???

Tapio’s metacognitive regulation message (0:29, cognitive; exploration and implementation) was not acknowledged by Anna and Alina, who were mostly focusing on Tapio’s explanations of how to solve the problem mechanically (Anna and Alina’s messages 0:30, social). Tapio continues to model his thinking by
contributing another metacognitive regulation message (0:33). This message and his previous messages promote Anna and Alina’s thinking. Alina (0:34, exploration) acknowledges Tapio’s idea and also starts to understand the equation task but is unable to develop the presented idea further. Thus, it could be argued that the process of socially shared metacognition was hindered during the joint problem-solving because of a lack of mathematical knowledge. At the end, Anna (0:36) and Alina (0:35) are verifying the task at the cognitive level to ensure the idea of having multiple solutions fulfils the task requirements, but they do not engage in a discussion about infinity. The group reaches the solution, and, to describe the issues of infinity in more detail, Tapio provides an explanation of how the equation can be described as a function of a straight line in the plane (0:40, metacognitive regulation, exploration, and implementation), but Anna and Alina do not reply to that message anymore. The last note in the discussion forum was Tapio’s (0:41, social) message, “I hope I’m right”. This could indicate that Tapio was not sure about his thinking because Anna and Alina were unable to contribute to his messages at all.

Summary of the data Triad A

To sum up, the qualitative description of the joint problem-solving and the findings for the students (Table 2) indicate that short periods of metacognitive exchange helped them decrease their feelings of difficulty at the end of the problem-solving process. Feelings of difficulty seem to decrease if metacognitive regulation was distributed among the group members and metacognition became socially shared. However, metacognitive regulation did not steer the group’s problem-solving if only one group member was responsible for solving the problem. In that case, metacognitive regulation supported the other group members’ understanding, decreasing their feelings of difficulty, whereas the responsible person’s feeling of difficulty increases. Thus, it can be argued that feelings of difficulty could be related to the interactions that take place in the group. The discussions were equally participated in, although the quality of discussion varied among these two tasks. In the first task, socially shared metacognition was a key factor for successful group problem-solving, resulting in a low number of social messages. In the second task, the amount of social messages increased, whereas the amount of cognitive messages was relatively decreased. That is, students who interact actively at the cognitive and metacognitive levels in computer-supported collaboration could learn the most.

In Triad A, collaboration seems to reduce feelings of difficulty for most of the students. There could be several reasons for this outcome. One possible explanation

<table>
<thead>
<tr>
<th>Students</th>
<th>Social messages</th>
<th>Cognitive messages</th>
<th>Metacognitive messages</th>
<th>Difficulty at the end</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anna</td>
<td>8</td>
<td>17</td>
<td>1</td>
<td>Decreased</td>
</tr>
<tr>
<td>Alina</td>
<td>5</td>
<td>12</td>
<td>1</td>
<td>Increased</td>
</tr>
<tr>
<td>Tapio</td>
<td>7</td>
<td>9</td>
<td>0</td>
<td>Decreased</td>
</tr>
<tr>
<td><strong>Task 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anna</td>
<td>12</td>
<td>4</td>
<td>0</td>
<td>Decreased</td>
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<tr>
<td>Tapio</td>
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<td>13</td>
<td>6</td>
<td>Increased</td>
</tr>
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</table>
could be related to that kind of collaboration which was typical for Triad A. The group worked as a whole, and their attempts were not based on obtaining a solution as soon as possible. During the discussions, they acknowledged important questions and ideas and described their thinking processes accurately and clearly, establishing intentionality in participation. The collaboration required and allowed the group members to make their thinking and feelings visible, increasing not only their individual awareness of the task at hand but also awareness of each other’s thinking and feelings. Getting support from other group members and being able to influence the group’s problem-solving could activate individuals’ conscious monitoring to adjust their thinking to coincide with group processes. As a result, an individual could experience reduced feelings of difficulty.

**Triad B Task 2**

In their fourth session, Aino, Liisa, and Antero dealt with fractions and two unknown parameters, $x$ and $y$, when solving Task 2: \((\frac{3}{4} + x) \div 5 - 4 = y + \frac{1}{2}\). The lack of mathematical content knowledge became evident from the beginning of the problem-solving when the group members tried to figure out what the pair of numbers meant. The group’s problem-solving process is visualized in Figure 4.

*Socially shared metacognition is hindered by a lack of conceptual knowledge*

This group took 35 min to solve the problem (see Figure 4). The group used a mechanical method to solve the problem for $x$. During their interactions, they focused on comparing their results and providing guidelines on how to think, rather

![Figure 4. The problem-solving process of Triad B in Task 2.](image-url)
than jointly analyzing the task or verifying their thinking. For example, the group members performed individual calculations and reported $0 = 0$ as a result (Liisa, Aino, and Antero’s implementation messages at 0:08, 0:12, and 0:15, respectively). Their lack of mathematical knowledge became visible because they were unable to interpret the result mathematically. In the case of equations, $0 = 0$ means it is possible to find values for both $x$ and $y$ so they each satisfy the equation. Being unable to interpret the result, Antero (0:16, analysis) began to rethink the problem: “What does that pair of numbers mean? Is it this $0 = 0$”. This key question was not acknowledged, and Liisa and Aino continued reporting the results of their individual task processing (Liisa and Aino’s implementation messages, 0:15–0:20). When the group had used 21 min for problem-solving, Liisa metacognitively regulated (0:21 including both cognitive and metacognitive aspects) the group’s joint process and explained that the zeros could not be considered to be the pair of numbers:

Liisa (0:21) Those zeros are not the pair of numbers, but the results should be decided with those we first solved, $x = 5y + 21\frac{1}{4}$ and $y = $ something

Aino (0:21) Aha, hey, should we construct a pair of equations?

Liisa (0:21) I think so =)

Antero (0:22) Ok, let’s try

Antero (0:23) But I get $y$’s disappeared

Liisa’s metacognitive regulation message (0:21) causes Aino to acknowledge her misunderstanding. Aino’s (0:21) reply to Liisa provides a new suggestion for the group. However, Aino’s suggestion is ambiguous for the emergence of socially shared metacognition. The idea could have just occurred to her, and this is why she does not use clear wording to explain the use of constructing a pair of equations. It could also be that a lack of conceptual understanding prevented her from formulating her idea precisely, hindering the emergence of socially shared metacognition. In mathematics, a pair of equations would be, for example, $2x + y = 1$, $x + 4y = -2$. The lack of mathematical knowledge and thus the lack of metacognitive skills can be seen in Antero’s (0:23, implementation) comment, “but I get the $y$’s disappeared”, after he had performed the calculations. After using their pair of equations, the group does not know how to proceed, so they choose $0 = 0$ as their solution as follows:

Aino (0:23) We can not make a pair of equations.

Liisa (0:24) I did not get any reasonable answer.

Aino (0:25) It will only be $0 = 0$.

Liisa (0:26) Let’s take that for our solution =)

Liisa (0:25) I don’t have solution efforts anymore.

Aino (0:26) I was just thinking the same, that there are no tools left.

Antero (0:26) I don’t get it. I do also get $0 = 0$ as a reasonable result.

Aino’s (0:23, verification) comment ends the discussion about pairs of equations. Liisa (0:24, implementation) reports the results she obtained from her calculations, and Aino (0:25 implementation) suggests that $0 = 0$ could be the only possible solution. Due to the lack of conceptual knowledge and number sense, the group
finished their joint problem-solving and chose \( 0 = 0 \) as their result. In their social-level comments (Liisa, Aino, and Antero’s messages at 0:25–0:26), the group displays a joint understanding of failure. The group lacked the metacognitive skills to take time and look at the equation sentence to see that substituting \( x = -3/4 \) into the equation would eliminate the first terms in brackets so it would be easy to solve \(-4 = y + \frac{1}{2}\).

**Summary of the data Triad B**

For Triad B, the qualitative description of the group’s problem-solving and the findings for the individual students (Table 3) indicate that social and cognitive interaction among group members is not a sufficient condition for successful collaboration. In this group, the interaction was superficial at the cognitive and social levels in both tasks. The group members reported the results of their individual calculation processes; only one clear steering intention emerged for the group as a whole. The feelings of difficulty of the most active student, Liisa, increased in both tasks possibly because, during the interaction, she realized her own and other group member’s lack of conceptual knowledge and/or metacognition, which augmented her experienced difficulty.

The findings indicate that collaboration induced individual feelings of difficulty among most members in Triad B. The rationale for this can be found in the interaction among the students. In Triad B, collaboration was mainly used to compare results of their individual calculation processes. The students provided no arguments for their way of thinking and were not concerned with how to proceed as a group. Further, the group members did not acknowledge messages that were crucial to analyzing the problem or reaching a solution. This could indicate not only a lack of mathematical knowledge but also a lack of some individual metacognitive skills. Therefore, they eventually guessed at a solution.

In conclusion, in Triad A, most students’ feelings of difficulty decreased during the interaction, whereas they increased for most students in Triad B. The difference between the groups cannot be explained explicitly. It corresponds to a combination of students’ prior metacognitive knowledge and skills, the balance of those skills among group members, and the quality of interaction among group members. As shown in the examples, the students in Triad A could be considered to have better metacognitive skills than those in Triad B. When faced with difficulties, the students in Triad A took a different approach to solving the problem, whereas Triad B made a guess at a result. In Triad A, the students brought up their prior metacognitive

<table>
<thead>
<tr>
<th>Students</th>
<th>Social messages</th>
<th>Cognitive messages</th>
<th>Metacognitive messages</th>
<th>Difficulty at the end</th>
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<tr>
<td><strong>Task 1</strong></td>
<td></td>
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<td>Antero</td>
<td>8</td>
<td>9</td>
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</tbody>
</table>

Table 3. Number of messages per student and their feelings of difficulty in Triad B.
knowledge and acknowledged each other’s thinking. This behavior could indicate that metacognition and domain-specific knowledge were more balanced among the group members in Triad A than in Triad B. In Triad B, the students were aware of their inability to solve the problem, and only one of them tried to steer the group. This could indicate that, although they had some individual metacognitive skills, they were not able to clearly explicate the thinking behind their calculations to the others. This, combined with the lack of domain-specific knowledge, prevented them from meaningfully monitoring and controlling their processes.

Discussion and conclusion

The aim of this exploratory study was to examine if socially shared metacognition emerging in group problem-solving is related to group members’ individual feelings of difficulty while performing mathematics tasks in a CSCL context. A qualitative analysis of students’ social, cognitive, and metacognitive messages in group mathematical problem-solving was combined with their individual retrospectively assessed feelings of difficulty. In CSCL, the process of socially shared metacognition occurs when a group member’s metacognitive regulation message contributes to a discussion about how to process a task and takes effects in group problem-solving so that other group members acknowledge and further develop the message.

The results of this study suggest that, if the process of socially shared metacognition emerges in group interactions, then most of the students will be able to reduce their individual feelings of difficulty. For socially shared metacognition to take place, group members must make their thinking visible by using clear wording and acknowledge important questions and ideas. To increase individuals’ awareness of the task at hand, the group work should be 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. In WorkMates (Figure 1) this can be done with social messages. Such 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.

The social features of collaboration observed above in our groups during problem-solving is in line with research on how shared knowledge is constructed in groups (Beers, Boshuizen, Kirschner, & Gijselaers, 2007; Van den Bossche, Gijselaers, Segers, & Kirschner, 2006). Our findings contribute to those studies by showing the important role of metacognitive regulation for constructing a joint solution. Moreover, our findings advance the understanding of how socially shared metacognition and collaboration among group members affects an individual’s metacognition. Earlier research has focused on feelings of difficulty as a part of individual’s metacognition that could help or hinder an individual’s contribution to group problem-solving (Efklides, 2006; Koriat & Levy-Sardot, 2000).

Further, the results of this study (Triad B) suggest that collaboration induces feelings of difficulty if the interaction among group members is superficial at the cognitive and social levels. In these kinds of situations, group members interact actively but lack domain-specific and/or metacognitive knowledge to provide elaborated explanations. Thus, 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). In these cases, students are not learning from each other. However, if feelings of difficulty decrease, this could indicate that, although the students are not actually learning from each other, they utilize each other’s thinking to compare results in order to select or even vote for their answer. 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, De Corte, & Borghart, 1997).

The results of this study (Triad A) also suggest that, if only one group member is responsible for the metacognitive regulation of group interactions, the other students experience reduced feelings of difficulty. In this case, group members interacted intentionally and were tutored by the more knowledgeable peer. At times, the tutees were aware of their lacking conceptual knowledge when they reported on their thinking and feelings of difficulty. This caused increased interaction at the social level but decreased feelings of difficulty. During the interaction, the other group members’ co-present cues was not a sufficient condition to decrease the more knowledgeable peer’s feelings of difficulty. The tutor had to be aware of his or her own and the others’ cognition and/or metacognitive experiences to control the collaborative learning situation (cf. Salonen, Vauras, & Efklides, 2005). In the situation described above, the tutees learn not only conceptual knowledge but also how to think about the same problem in a different manner (see Triad A, Task 2; thinking about the same problem at a mechanical and an algebraic level).

In summary, based on this study we put forward three hypotheses:

(a) Feelings of difficulty of a task will decrease during collaboration if students receive metacognitive messages and react upon them: share them socially.
(b) Feelings of difficulty will increase during collaboration if students do not receive metacognitive messages to solve a problem or if a person does not receive equal level feedback on his metacognitive suggestions.
(c) Changes in students’ feeling of task difficulty during collaboration will be related to interaction among students and their actual problem-solving skills.

There are some limitations that should be taken into account when interpreting the results. First, we used retrospective assessment of feelings of difficulty to find connections between socially shared and individual metacognition. As noticed in the literature, the accuracy of retrospective methods relies on the participants’ knowledge of his or her own behavior (Veenman, 2005). In future research, technological online research methods (e.g., online questionnaires) could be applied to examine changes in individuals’ feelings of difficulty during the collaborative problem-solving process. Thus, concurrent assessment methods could provide detailed information of the mechanisms by which metacognitive regulation and socially shared metacognition are related to individuals’ feelings of difficulty. Secondly, our case study is based on the interactions of freshmen in a teacher training at university, a specific group of students. Although we do not expect students from other teacher training colleges or in higher secondary education to behave differently from our group, more research is needed to confirm this assumption. Thirdly, the participants of this study were not chosen on statistical grounds. Thus, the only intention of this study is to structure the detailed observations of groups of students at work and put forward ideas for new research.
Finally, an interesting line to future research could be to examine whether training students to share metacognition with each other would have an effect on their individual feelings of difficulty. Training could be focused on elaborative explanations and questions focusing on analyzing the task and verifying the problem-solving. These essential processes for metacognition are mostly missing in spontaneous group problem-solving (King, 1999). Further, the training could include evaluation sessions where the students report their experiences and feelings of difficulty to each other in order to reinforce a sense of community (Kreijns, Kirschner, & Jochems, 2003) and awareness of each other's cognitive and/or metacognitive processes (cf. Karabenick, 1996; Webb et al., 2006). An experiment with a training group and an untrained control group could be conducted to determine if feelings of difficulty are lower among participants in a training group when socially shared metacognition is trained. Further, it could be hypothesized that, after doing a number of group tasks, members of the training group perform better in mathematics than those of the control group.

References


