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Socially Shared Metacognitive Regulation in Asynchronous CSCL in Science: Functions, Evolution and Participation

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Abstract

The significance of socially shared metacognitive regulation (SSMR) in collaborative learning is gaining momentum. To date, however, there is still a paucity of research of how SSMR is manifested in asynchronous computer-supported collaborative learning (CSCL), and hardly any systematic investigation of SSMR's functions and evolution across different phases of complex collaborative learning activities. Furthermore, how individual students influence group regulatory effort is not well known and even less how they participate in SSMR over the entire collaborative learning process. The multi-method, in-depth case study presented in this article addresses these gaps by scrutinizing the participation of a small group of students in SSMR in asynchronous computer supported collaborative inquiry learning. The networked discussion, consisting of 640 notes, was used as baseline data. The sets of notes, which formed nine SSMR threads, were identified and their functions analyzed. Several analytical methods, including social network analysis, were used to investigate various aspects of individual participation. The findings show that some SSMR threads lasted over an extended period, and they sometimes intertwined or overlapped. Furthermore, SSMR threads were found to play different functions, mainly inhibiting the perceived inappropriate direction of the ongoing cognitive process. Finally, SSMR was found in all phases of the process – but with some variation. The use of different analytical methods was critical as this provided a variety of complementary insights into students' participation in SSMR. The value of using multiple, rigorous analytical methods to understand SSMR's significance over the entire course of an asynchronous CSCL activity is discussed.

Keywords: Socially shared metacognitive regulation; Collaborative processes; Asynchronous CSCL; Inquiry learning; Multi-method approach

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1. Introduction

Over the last decade, there has been growing shift in the study of learning as a socially and culturally embedded (individual or collaborative) activity (Salomon & Perkins, 1998). This has led many researchers to argue that a focus on individual regulation of learning is insufficient for understanding learning that takes place in social contexts and, in particular, collaborative learning environments (e.g. Efklides, 2008; Grau & Whitebread, 2012; Hogan, 2001; Järvelä & Hadwin, 2013; Molenaar & Chiu, 2014). On the grounds that collaborative learning environments bring together "multiple self-regulated agents [who] socially regulate each other's learning" (Volet, Summers, & Thurman, 2009a, p. 129) and at times engage in genuinely shared regulatory processes (Salonen, Vauras, & Efklides, 2005), research on social regulation in collaborative learning needs to integrate interpersonal processes and individual cognition (Greeno, 2006; Vauras & Volet, 2013). This approach is critical since, according to Winne, Hadwin and Perry (2013), the quality of learning in collaborative settings is not only dependent on individuals' distributed regulation but also on the co- and shared regulation that emerges in situated interactions.

This paper contributes to and extends the growing literature on the significance of social regulation in collaborative learning by presenting the findings of an in-depth, micro-level and multi-method exploratory study of the socially shared metacognitive regulation of one small group of students engaged in an asynchronous, computer-supported collaborative inquiry learning process. Although research on computer-supported collaborative learning (CSCL) is extensive, there is still a paucity of fine-grained empirical studies on the manifestations, functions, and evolution of socially shared metacognitive regulation processes as they unfold over the duration of collaborative inquiry learning. It is argued that this insight is essential to understanding fully the significance of socially shared metacognitive regulation in collaborative learning and the role of individual contributions in the process. This dual focus on group-level, socially shared regulatory processes and individual-level contributions to the group regulatory effort, required a combination of qualitative and social network analytical methods.

1.1 Socially shared metacognitive regulation (SSMR)

Socially shared metacognitive regulation (SSMR thereafter) refers to participants' goal-directed, consensual, egalitarian and complementary regulation of joint cognitive processes in the collaborative learning context (see Iiskala, Vauras, & Lehtinen, 2004; Iiskala, Vauras, Lehtinen, & Salonen, 2011). This definition focuses on the regulation aspects of metacognition (i.e. see Brown, 1987, on regulation of cognition; see Brown & DeLoache, 1983, on metacognitive skills) geared towards achieving goals (see Wertsch, 1977). This can refer to activities such as identifying task requirements and expectations (e.g. what has to be done); planning (e.g. time allocation); keeping track of the process and mindfully changing it if needed; monitoring comprehension (e.g. questioning the direction of the cognitive process) or evaluating the quality of the task outcome (see Veenman & Beishuizen, 2004). Hence, in SSMR, students jointly regulate their ongoing cognitive learning process towards the common goal. In contrast, knowledge co-construction involving processing the content knowledge (e.g. gathering additional information or establishing concepts' scientific meaning) and task co-production involving generating the tangible outcome (e.g. justifying the features of the outcome such as 'content knowledge x' causes 'content knowledge y' and, hence, they are connected to each other) are not conceptualized as metacognitive regulation but rather cognitive activity (see Khosa & Volet, 2014).

Research on SSMR originates from the metacognition research tradition which focuses on regulation of cognition, whereas research on self-regulation and self-regulated learning is further concerned with behavior and motivation regulation (see Dinsmore, Alexander, & Loughlin, 2008). Overall, the literature on regulatory processes displays a confusing instability in the use of terms that originate from different research traditions (Dinsmore et al., 2008). Hence, the term SSMR makes the focus on cognition regulation quite explicit. SSMR provides a solid conceptual basis on which to gain insights into how collaborating dyads or groups regulate their cognitive activity and, at a fine-grained level, their understanding of the specific requirements of tasks and content knowledge. While the concept of SSMR is solidly grounded in the metacognition tradition, the research focus is on the regulation component of metacognition, in other words, the executive function of regulating the cognitive activity (see Brown, Bransford, Ferrara, & Campione, 1983; Flavell & Miller, 1998) and, therefore, on the procedural component of metacognition (Veenman, 2011). In turn, the term 'socially shared' seeks to capture collective, mutually shared metacognitive regulation that unfolds on the social plane when a group engages in co-constructing knowledge and understanding of the task and its content. In their comprehensive review of different forms of regulation, Winne and colleagues (2013) and Hadwin, Järvelä and Miller (2011) defined co- and socially shared regulation by describing the regulation of collaborative study processes in general, but they did not elaborate on micro-level, unfolding metacognitive regulation processes involved in problem solving and knowledge construction in real time.

To date, empirical SSMR studies are still scarce as compared to the comprehensive research on metacognitive regulation in individual learning. Studying social regulation in collaborative learning – where the core unit of analysis is the group's learning process rather than solely individual's learning process – presents important conceptual and methodological challenges. A number of researchers have proposed that, in the context of collaborative learning, metacognitive regulation can be best understood as both an individual and a social process, in which participants' metacognitive regulatory activities are interdependent and often shared (e.g. Efklides, 2008; Hadwin et al., 2011; Iiskala et al., 2004; Volet, Vauras, & Salonen, 2009b). As a consequence, conceptualizations of metacognitive regulation during collaborative learning – and derived analytical approaches in empirical work – must consider self- and socially-regulated systems as operating concurrently (Volet et al., 2009b; Winne et al., 2013).

1.2 SSMR in face-to-face collaborative learning

SSMR manifestations in face-to-face collaborative learning have identified tasks and contexts across age groups. This includes, for example, studies of face-to-face mathematical problem-solving processes in high-achieving primary school student dyads (Vauras, Iiskala, Kajamies, Kinnunen, & Lehtinen, 2003; Iiskala et al., 2004, 2011; Volet, Vauras, Khosa, & Iiskala, 2013), young children working in naturalistic educational settings (Whitebread, Bingham, Grau, Pino Pasternak, & Sangster, 2007; Whitebread et al., 2009), veterinary science students' working on authentic clinical cases (Volet et al., 2009a; Summers & Volet, 2010; Volet et al., 2013), elementary school student triads' collaborative learning in different instructional design environments (Molenaar, 2011) and primary school students' collaborative activities in science classes (Grau & Whitebread, 2012).

SSMR has been found to play different functions in the flow of collaborative learning processes. For example, a study of collaborative mathematical problem-solving processes of high-achieving dyads revealed that SSMR either facilitated (through confirming or activating) the perceived appropriate direction in the dyads' cognitive activities or, alternatively, inhibited (by slowing down, changing or stopping) the perceived inappropriate direction of activities (Iiskala et al., 2011). Therefore, SSMR's functions either promote the continuation of appropriate cognitive learning processes or, conversely, prevent the ongoing cognitive process from moving in an adverse direction. SSMR's overall function, therefore, is to ensure that the group cognitive activity develops in the appropriate direction. As a result, the quality of the ongoing cognitive process is constantly monitored and controlled (e.g. Whitebread et al., 2009). Understanding SSMR functions at the micro level, therefore, is essential to gaining greater insight into SSMR's significance in collaborative learning.

One under-researched aspect of SSMR in face-to-face collaborative learning is its evolution over an extended period and across phases of problem solving or inquiry learning processes. Systematic investigations of the emergence are rare, as are studies of the subsequent evolution over, and the metacognitive regulation of, time and through different phases of collaborative learning processes (see Azevedo, 2014; Molenaar & Järvelä, 2014). For example, Grau and Whitebread's study (2012) revealed that individual self-regulated behavior increased within the groups during the process but the number of shared regulation episodes varied across sessions. Rogat and Linnenbrink-Garcia (2011) also found no evidence of a systematic change in regulation quality within small groups of sixth-grade students. Lajoie and Lu's (2012) findings for medical students indicated that the timing of metacognitive activities varied so that engagement in these activities early in the problem solving process led to a greater percentage of executive processes in latter sessions, especially in teams supported by technology, as compared to non-technology supported teams. Rogat and Linnenbrink-Garcia (2011) also suggested that sub-processes, such as planning and monitoring, mutually influence each other and overlap; for example, students monitor the group's understanding of the task directions and plan enactment. These studies' findings provide preliminary support for the importance of better understanding SSMR manifestations and functions in the context of evolving cognitive learning processes.

1.3 SSMR in asynchronous CSCL

Empirical studies of SSMR in asynchronous CSCL environments are still scarce. Research conducted in CSCL environments have tended to adopt a more general view of socially shared regulation of motivation and learning strategies, paying limited attention to the detailed metacognitive regulatory processes taking place in real time during the course of learning activities but, at the same time, incorporating other forms of regulation. For example, Järvelä and Hadwin (2013) located their approach within the self-regulated learning tradition, which takes into consideration motivation and emotions regulation. Network mediated asynchronous communication is a particularly challenging environment for groups to engage in SSMR because the multiple verbal and non-verbal channels of reciprocal interaction available in face-to-face situations are limited. However, CSCL environments provide learners with some new tools, such as structuring supports, mirroring and metacognitive tools, as well as guiding steps that can support reciprocal regulation of learning processes (Soller, Martinez-Monés, Jermann, & Muehlenbrock, 2005; see also Järvelä & Hadwin, 2013).

A major advantage of studying SSMR in asynchronous CSCL is that part of the individuals and the group's metacognitive thinking become 'visible' through computer-based traces of interactions. This means students can return to previous thinking and follow earlier trains of thoughts. Hence, some researchers (e.g. Hurme, Palonen, & Järvelä, 2006) have explored how engagement in joint discussion metacognition can vary between participants in secondary school dyadic activities. They found dyads that monitored and evaluated their ongoing discussion achieved a more optimal position in the communication network than other dyads. Prinsen, Volman and Terwel's (2007) study of primary-school classes, also conducted in an asynchronous CSCL environment, revealed evidence of mutual engagement in discussing, monitoring, and evaluating group processes and in instructing fellow students, but limited time was spent regulating the cognitive activities' direction (6%). The authors interpreted their findings in terms of the task's well-structured nature.

Since SSMR of difficult learning or problem solving can be highly demanding, some students can reasonably be expected to engage more than others do in the social regulation of group cognitive process. This was illustrated in Palonen and Hakkarainen's (2000) study, in which they re-analyzed previous data from 11 to 12- year-old students' computer-supported learning, using social network analysis (SNA). Interestingly, the findings obtained with SNA revealed that average- and high-achieving female students dominated social interactions in CSCL environments and took on the main responsibility for collaborative knowledge building. This contradicted the researchers' original qualitative content analysis, which found that the culture of inquiry was rather homogenous across students. SNA, therefore, appears particularly well suited to exploring the presence of relationships patterns among interacting units (see Wasserman & Faust, 1994). This type of investigation has been successfully applied beyond single participants to collective-level analysis in elementary and secondary schools (Toikkanen & Lipponen, 2011).

These researches show that in-depth explorations of within-group differences in SSMR contributions benefit from a combination of analytical methods. For Toikkanen and Lipponen (2011), combining SNA and qualitative analysis can potentially provide more accurate results and a stronger foundation for interpretation.

1.4 SSMR in asynchronous CSCL inquiry over time and across phases: A case study

Group inquiry learning provides a useful research setting to study SSMR in asynchronous CSCL because this is a challenging, research-like approach with the goal of processing and deepening explanatory knowledge, rather than merely acquiring factual knowledge (e.g. Hakkarainen, 2003; Scardamalia & Bereiter, 1994). A number of studies have shown that inquiry learning stimulates students' active engagement in learning processes that require metacognition to monitor understanding (e.g. Khosa & Volet, 2014; White & Frederiksen, 1998). In pedagogically well planned and technology-supported inquiry learning environments, even young students are able to engage in constructive peer interaction and knowledge building processes that go beyond the typical cognitive demands of regular school learning (e.g. Hakkarainen, 2003; Zhang, Scardamalia, Reeve, & Messina, 2009). Hence, some prior research implies that joint engagement in demanding, asynchronous CSCL inquiry can trigger SSMR.

1.5 Research aims and expectations

The first aim of the present study was to explore the manifestation and functions of socially shared metacognitive regulation (SSMR) in an asynchronous CSCL environment of a small group's inquiry in science learning. The second aim was to examine the SSMR's evolution through different phases of the group's asynchronous CSCL inquiry process. The third aim was to determine how individual group members participate in SSMR during asynchronous CSCL inquiry and how specific individuals' contributions influence the group's regulatory effort.

Since the study was exploratory in nature, no predictions could be made about the SSMR's manifestation and functions in an asynchronous CSCL environment of inquiry learning. In light of the high cognitive demand imposed by inquiry learning on school-aged students, evidence of SSMR was expected throughout all phases. However, the SSMR's functions in different phases could not be predicted. Regarding how individual group members would participate in SSMR and how specific individuals' contributions would influence the group's regulatory effort, since individuals are self-regulating agents and asynchronous exchange allows time for reflection, some members were expected to play a pivotal regulatory role in initiating and sustaining the process. Alternatively, they could inhibit the current direction of the group's cognitive process. The investigation's exploratory nature at the individual level (third aim) led to the use of a combination of several methods of analysis.

2. Method

2.1 Participants

This case study focused on a small group of four 12-year-old girls (Iina, Piia, Sonja and Julia). The girls were attending an urban Finnish primary school with high standards and a good reputation. The class from which the small group was selected, had a language enriched curriculum, and an entrance examination was used to select students for program admission. Because of the school's high criteria for admission, the students could be described as above average in their overall academic skills. However, the students had only some experience of CSCL and inquiry learning, and, from this point of view, their usual learning context could be described as traditional. The students' parents gave written consent for them to take part in the study, and the students themselves were willing to participate.

The small group studied was formed at the beginning of the process under the teacher's guidance, based on the students' similar interests in the topic of inquiry chosen for the science-based activity. These four students were also disposed to working together.

2.2 Collaboration environment

The theoretical ideas underpinning the learning process as a collaborative inquiry, as proposed by Hakkarainen (2003) (see also Brown & Campione, 1994, 1996; Brown et al., 1993; Hakkarainen & Sintonen, 2002; Scardamalia & Bereiter, 1994, 2006), formed the conceptual basis of the present study's collaborative inquiry environment. In this study, the collaborative inquiry process was applied to the scientific exploration of the universe. The teacher introduced the subject at the process's beginning, after which each small group was responsible for collecting further scientific information from other sources, such as textbooks, experts and the Internet, and working together to develop meaning out of this material. Each group worked during the process on complex, ill-defined questions that they had set for themselves at the process's beginning.

The whole process involved five phases: I – Setting up the research question; II – Constructing a hypothesis; III – Developing a work plan; IV – Searching for and processing knowledge; V – Summarizing findings and concluding (see the Appendix for a full description). At the beginning of each phase, the students were reminded to collaborate with each other and to regulate their group's learning process.

At the activity's beginning, students were introduced, in a face-to-face situation, to the expectations for the collaborative inquiry process. They were informed that they needed to work like scientists, and then the process's different phases were presented. In addition, the students were encouraged to make their thinking visible to each other by sharing their ideas and jointly regulating the group inquiry process. At the start of each phase, the researcher presented the current phase's aim to the entire class, once again in a face-to-face environment. After that, in each phase, the students collaborated within their small groups in the asynchronous CSCL environment WorkMates (for detailed information about WorkMates, see Nurmela, Lehtinen, & Palonen, 1999). Although the students had access to WorkMates at all times and, hence, the chance to write notes outside their science class, they collaborated mainly during the time specified by their teacher during class. Some discussions were close to synchronous (chat-like) discussions, whereas, in other cases, longer time lags appeared between notes. All the students were acquainted with the WorkMates environment, as they had used it a few times beforehand. In WorkMates, students can send written notes to each other, and they can reply to one another's notes. All the notes sent during a particular phase are visible on the computer screen, and students can also return to previous phases' notes. Data for this study were the four group members' discussions in this asynchronous CSCL environment.

2.3 Data analysis

To address the aim of exploring students' SSMR engagement, the analysis unit was a *thread*, that is, a sequence of interconnected notes. When a student posted a message to the public space where other students in the small group could see it and react, this was counted as a note. A sequence of interconnected notes was classified as an SSMR thread if students, through their notes, demonstrated evidence that they were jointly regulating the progress of their inquiry learning process towards their common goal (e.g. Student 1: "We want to address the task's goal but we don't yet have enough knowledge of this issue because…", Student 2 (reacting to Student 1's note): "Hmm, let's think about this issue more in detail. So far, we have evidence that … but we still don't have knowledge about…", Student 3 (reacting to Student 1's and/or Student 2's note(s)): "So, let's try to fill in these gaps before concluding. First, we have to find out … Next, we have to…" The interaction continues in further notes). Hence, small group's learning process was identified through the students' regulatory acts, whenever a minimum of two students were involved in the process, and the students' reciprocal notes were interdependent, together affecting the course of the ongoing cognitive process.

Furthermore, although each thread had to involve a minimum of two notes, no upper limit was set to the number of notes included. Consistent with Iiskala and colleagues (2004), each note's meaning, whether it was a part of an SSMR thread or not, was thus dependent on the flow of other preceding or subsequent notes, which means these notes were interconnected. Each note included in an SSMR thread had to be a reaction to some previous note(s) or had to be followed by a note(s) reacting to it. The notes in the SSMR thread did not necessarily follow each other immediately, but other notes could appear in between or in parallel that were unconnected to the SSMR threads.

Each SSMR thread was analyzed in terms of its overall facilitative regulatory *function* in the development of the overall inquiry learning process, as adapted from Iiskala and colleagues (2011). Hence, depending on the group's perceived appropriateness of their cognitive process's direction, the SSMR's specific function was either to 'Continue' or 'Inhibit' their evolving cognitive process. Both functions sought to achieve a better performance and understanding of the task. A Continue SSMR thread captured situations when the group confirmed that the direction of their current thinking was appropriate or they activated further cognitive processes in the same direction. For example, the students identified gaps in their group's thinking and, on this basis, planned to maintain their current direction, as this would bring them closer to their common goal. In contrast, an Inhibit SSMR thread captured situations when the group slowed down, changed or stopped its cognitive process's direction because the students perceived it as inappropriate and decided to re-think their approach. For example, some interconnected notes revealed how the students jointly interrupted their current train of thought and re-oriented this thinking. If a student's cognitive note (e.g. a proposal) triggered an SSMR thread, the first regulatory note reacting to it was analyzed as the thread's starting point. The end was signalled by the note that ended the SSMR process, and the thread displayed its executive function of continuing or inhibiting the direction of the group's thinking process.

2.4 Inter-coder agreement

Determining a thread is complex, and, as argued by Strijbos and Stahl (2007), represents an interpretation of the discussion's structure. Inter-coding, therefore, was a necessary part of the analysis. It was conducted in two steps.

First, after the principal coder had reviewed all the notes and identified the SSMR threads, the other coder, a scholar with extensive experience in learning research, independently analyzed the threads in the context of all notes. The second coder's task was to assess whether or not, in his opinion, the threads identified by the principal coder represented SSMR. The second coder could also suggest adding or removing note(s) to a thread, and propose new threads. This researcher was also asked to define the threads' function according to the coding scheme. Only a few disagreements arose between the two coders, and these were resolved in discussions. If the disagreement was whether or not the proposed thread represented SSMR, the thread was automatically abandoned. This happened in only two instances. In addition, one thread, whose function was originally defined as 'activation' by the principal coder, was, after a discussion, re-classified as 'stop'. All other SSMR threads were agreed upon by both coders. Overall, this means that eight of 11 threads were accepted as such, two threads were removed and one thread's function was re-classified. Hence, all nine threads illustrated in the present article were recognized as SSMR threads and their function were fully accepted by both coders. The inter-coder agreement was 82% in the identification of SSMR threads, and 89% in classifying these threads according to their function.

Second, related to SNA and research aim 3, the inter-coder agreement was calculated on the basis of how notes outside the SSMR threads were connected with each other. After the principal coder had finished the coding process, two phases of the inquiry learning process (i.e. 'Setting up the research question' and 'Developing a work plan') were randomly selected, and 33% (n = 189) of all 566 notes outside the threads were coded by the second, trained coder. The coders agreed on 233 of 263 connections, so an agreement of

89% (Cohen's κ = .88) was reached, which can be considered substantial (see Landis & Koch, 1977, p. 165). All disagreements were resolved by negotiation, and, conservatively, only connections that both coders had agreed on before the negotiation were used in analysis.

3. Results

3.1 SSMR manifestation and functions in an asynchronous CSCL environment of a small group's inquiry process

A general overview of the findings is provided first. Table 1 summarizes the main features of the nine SSMR threads, including their function and behavioral indicators, the phase of the inquiry process in which they were located, and the number of notes and participants.

Table 1

Summary of SSMR threads

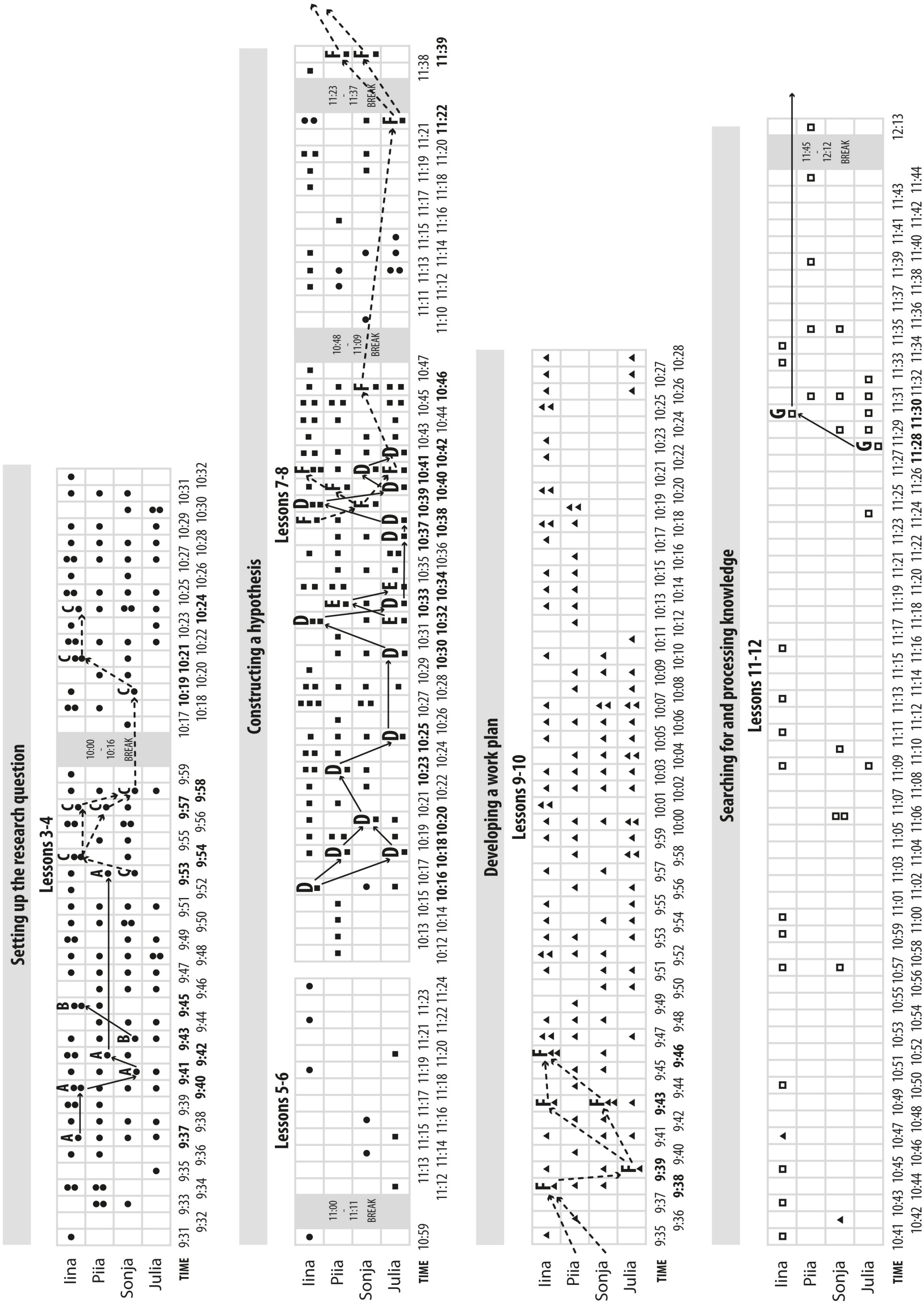
Thread	Function	Phase	Number of notes	Number of students	Names of students
A	Inhibit/ Stop	Setting up the research question	5	3	Iina, Piia, Sonja
B	Inhibit/ Stop	Setting up the research question	2	2	Iina, Sonja
C	Continue/ Confirm	Setting up the research question	8	3	Iina, Piia, Sonja
D	Inhibit/ Slow	Constructing a hypothesis	15	4	Iina, Piia, Sonja, Julia
E	Inhibit/ Slow	Constructing a hypothesis	3	2	Piia, Julia
F	Continue/ Activate	Constructing a hypothesis/ Developing a work plan	14	4	Iina, Sonja, Piia, Julia
G	Inhibit/ Slow	Searching for and processing knowledge/ Summarizing findings and concluding	10	3	Iina, Sonja, Julia
H	Inhibit/ Change	Summarizing findings and concluding	8	3	Iina, Sonja, Julia
I	Continue/ Activate	Summarizing findings and concluding	9	4	Iina, Piia, Sonja, Julia

As shown in Table 1, both specific SSMR functions (Continue or Inhibit the current direction of the cognitive process), and all five behavioral indicators of these functions (Confirm, Activate, Slow down, Change and Stop) were found in the data. SSMR threads that continued or inhibited the cognitive process's direction were found across all phases of the inquiry learning process, but the majority (six out of nine) of the threads functioned to inhibit the process's perceived inappropriate or overly rushed direction (Stop, Slow or Change). Most of the threads (seven out of nine) were contained within one phase, and two of the threads spread over two phases. Only three of the nine threads displayed the participation of all four students, but only two threads had only two students contributing. Table 1 presents the threads in groups of three (A, B, C / D, E, F / G, H, I) because each set of three included threads that were connected to each other. This will be discussed below (in section 3.2), when addressing the second research aim.

Figure 1 presents a comprehensive and dynamic visual display of all the data for this small group, over the evolution of its asynchronous CSCL inquiry process. This figure captures the emergence of the nine SSMR threads (A–I) and their respective functions in the inquiry process's different phases and among all written notes. The figure also shows how each individual contributed to SSMR threads and other non-SSMR activities. Therefore, the figure identifies the four girls, each phase of the inquiry process, the number of lessons, all the written notes with symbols and the timeline (as hour:min). For example, in Iina's row, a symbol '●' features at 9:31, located in lessons 3–4 of the 'Setting up the research question' phase, which means that Iina wrote one note at that time. However, this note is not a part of any SSMR threads because no arrow (→) links this note to other notes. As illustrated in the figure, all notes that are part of an SSMR thread are linked by arrows, which show the progression of the girls' thoughts throughout the thread. Moreover, the letter (A–I) illustrates to which SSMR thread that note belongs. For instance, five notes appear in SSMR thread A (inhibit/stop), two from Iina, one from Sonja and two from Piia. Furthermore, the notes generated during the same phase of the inquiry process are assigned the same symbol. For example, the symbol '●' is used to represent the 'Setting up the research question' phase. Moreover, the girls could also return to some topic (e.g. setting up the research question) later during the inquiry process (e.g. Sonja wrote a note regarding setting up a research question during the 'Constructing a hypothesis' phase, which the symbol '●' indicates in lessons 7–8 at 11:14). Altogether, 74 out of 640 notes (12%) were classified as belonging to SSMR threads. All nine SSMR threads (A–I) shown in Figure 1 are also qualitatively illustrated at the micro level (see section 3.2).

In summary, as illustrated in Figure 1, SSMR in the small group's asynchronous CSCL inquiry learning process was manifested as follows:

a) SSMR threads appeared mainly at the start and the end of the overall inquiry learning process, with intensive and quiet periods where no SSMR took place. This stresses the importance of looking at what students are doing at the process's different phases and what may trigger SSMR.
b) Some SSMR threads overlapped or intertwined (A, B, C / D, E, F / G, H, I), which may have played an important role in the evolution of the overall inquiry learning process.
c) Because of the asynchronous nature of the CSCL process, some SSMR threads took place over an extended period, and other notes that were not part of the SSMR thread could be found in between SSMR notes. This highlights the importance of studying SSMR manifestations over a long period when dealing with asynchronous CSCL process.



Setting up the research question
Lessons 3-4
Constructing a hypothesis
Lessons 5-6
Lessons 7-8
Developing a work plan
Lessons 9-10
Searching for and processing knowledge
Lessons 11-12
Iina
Piia
Sonja
Julia
TIME
BREAK

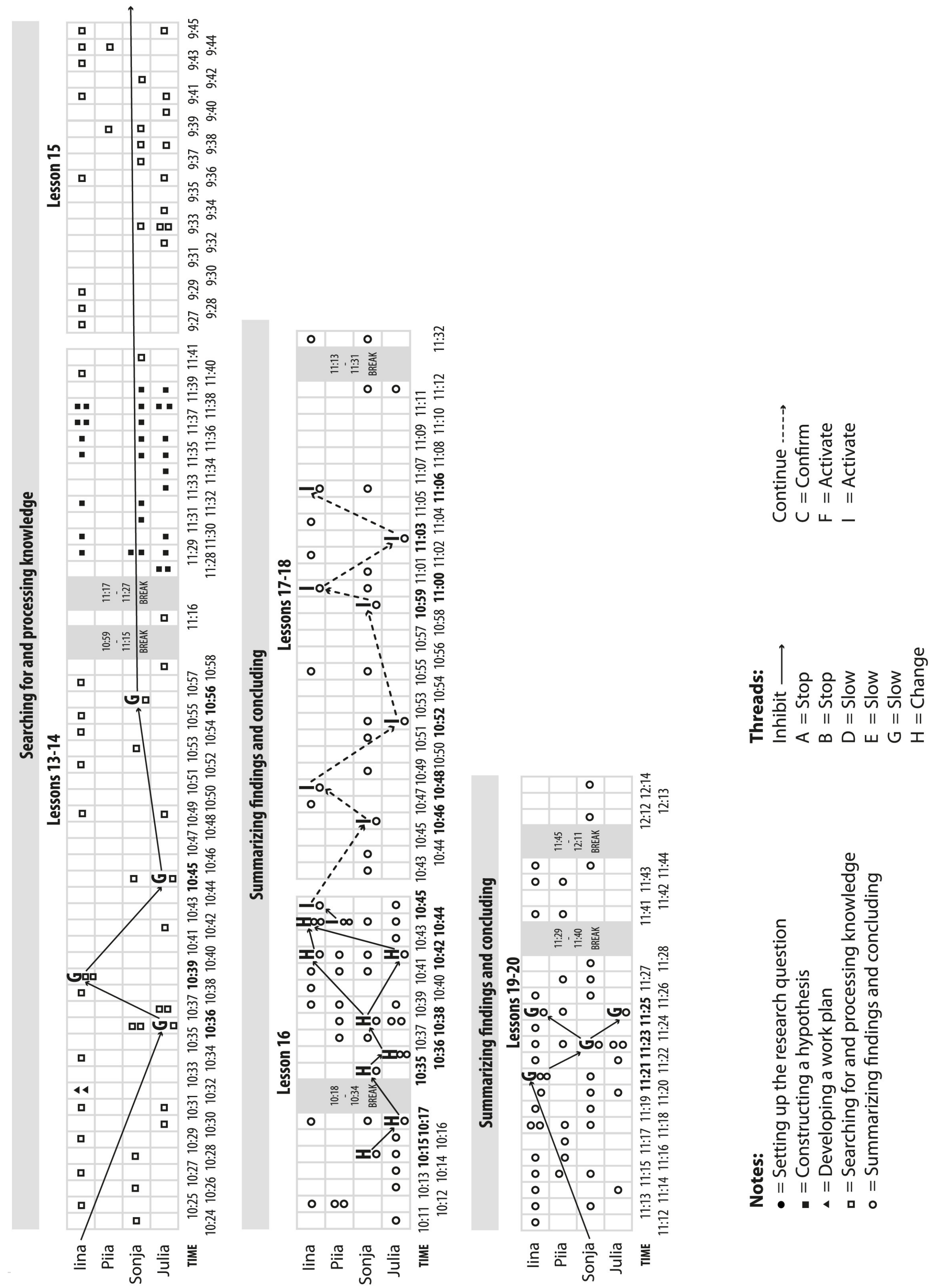


Figure 1. SSMR threads among all notes in the small group's inquiry CSCL process.

3.2 Evolution of SSMR across different phases of the group's asynchronous CSCL inquiry learning process

As shown in Table 1 and illustrated by Figure 1, the SSMR's distribution varied across phases of the inquiry learning process. SSMR threads were found especially in the first two phases, 'Setting up the research question' and 'Constructing a hypothesis', and then when 'Summarizing the findings and concluding', with limited SSMR during 'Developing a work plan' and 'Searching for and processing knowledge'. The SSMR threads found in each phase are presented in turn, with a narrative describing their behavioral indicators and their functions in the inquiry process.

3.2.1 Phase I: Setting up the research question

Three inter-related threads (A, B and C) were found in this stage, illustrating the function of inhibiting the perceived undesirable direction of the group's current cognition process and, alternatively, the function of continuing in a promising direction. Figure 2 illustrates how the three SSMR threads interact.

Both threads A and B illustrate the specific SSMR functions that *inhibit* current undesirable thinking directions. In these threads, the girls realize that the research questions they had in mind would not address the overall aim of their inquiry process. In thread A, three of the girls (Iina, Sonja and Piia) think about a potential research question to address the project's aim, taking into account their prior knowledge. The SSMR thread *stops*, with the group concluding that the theme is too complex. This means that, through SSMR, the girls stopped developing their initial question and, accordingly, rejected their related thinking for this question. In thread B, two of the girls (Iina and Sonja) consider ambivalently why it is possibly not judicious to pursue their second proposed idea as a research question. The thread leads them to *stop* (a behavioral indication of inhibiting SSMR functions). In contrast to threads A and B, thread C reveals how the girls, through SSMR, *confirmed* their new question's feasibility (a behavioral indication of continuing SSMR functions) and, thus, continued to pursue their current thinking direction. Interestingly, thread C's starting point was the same as for threads A and B, namely, that a potential research question was scrutinized. The third research question was eventually adopted through SSMR in thread C. Three of the girls (Sonja, Iina and Piia) were involved in this last thread, which unveils how they regulated the suitability of their new theme against the research aim and how they scrutinized possibilities for upcoming efforts.

Lessons 3-4, Setting up the research question

h:min	Iina	Piia	Sonja	Julia
9:35				*...how the universe is infinite?* A
9:37	... otherwise good but how is it possible to get a project from it? ... it has been discovered and known. Maybe it would be possible to modify it some-how ... A			
9:40	But how are you going to study how the universe is infinite? A			
9:41			A How would it be possible ... to make it a broader problem ...?	
9:42	*I think that the moons of the planets are a really interesting idea ...* B	I say, it is a bit difficult topic ... A		
9:43			B Yes, they are ... interesting ... but in fact, what would be the problem ...?	
9:45	It would not probably be an issue because it would be possible to study it anyway. It is possible to think Why ... However, it is also so that I don't know if there is a logic explanation for that question. B			
9:46			*Or we could think of the future ... for example, if the earth will be destroyed sometime because a meteorite hits it ...?* C	
9:53		I think that the infinity is A ... too tricky issue ...	It would be possible to design a nice project based on it ... there are so many different kinds of theories ... C	
9:54	It's OK with me but the theme can't just be the "future", it should be some part of it. C			
9:57	... We should decide the more elaborate theme ... C	C I think that the meteorite topic would be good because it has been assessed that it will be happening ... so we could study that from where it ... will come or why?		
9:58			C ... and then various theories related to it ...	
10:19			C Would it be now it ... topic, and then we could make sub-problems and to broaden it ...?	
10:21	So, that is, the future so that it will be both defined and broadened? C			
10:24	Future, asteroid, destruction ...! It is a recapped version of our problem ... C			

Note. The text in italic and a letter in a gray box is not analyzed as a part of the SSMR threads but it illuminates the overall view of the process.

Threads: A ——▶ A = Stop   B ——▶ B = Stop   C - - - -▶ C = Confirm

Figure 2. Inhibition function of stop (A and B) and Continue function of confirm (C) of SSMR threads in 'Setting up the research question'.

As illustrated in Figure 2, *threads A, B and C* followed each other consecutively, but partly overlapped as well, each thread playing a specific function in the evolving inquiry learning process. Threads A and B demonstrate how the girls discarded some of their ideas by regulating their respective usefulness, while thread C revealed how the group moved forward with another idea. Thus, the group stopped or confirmed the direction of their ongoing thinking process through SSMR. In summary, the analysis of the three SSMR threads showed that, in the first phase of the asynchronous CSCL inquiry process that sought to define the research question, some SSMR threads' function was to inhibit (stop as the behavioral indicator) the direction of their cognitive process, since they perceived this as going in an unwanted direction. Another SSMR thread enabled the group to continue (confirm) their line of thought.

3.2.2 Phases II and III: Constructing a hypothesis and Developing a work plan

Three inter-related threads (D, E and F) were found in these two phases, once again illustrating both continuing and inhibiting functions in the girls' current cognitive process. Consistent with the evolving inquiry process, after setting up its research question, the small group proceeded to construct a hypothesis to address that question. The question itself, which had been confirmed in the previous phase, was subsequently elaborated as follows: 'How can it be concluded that an asteroid will hit the earth, and what will then happen to the earth?' Some sub-questions were also generated: 'Where does an asteroid come from?, 'Will the whole earth be destroyed?', 'How can the hit be prevented?' and 'When will the hit be projected to happen?' Figure 3 illustrates the three SSMR threads (D, E and F) found during the phases of 'Constructing a hypothesis' and 'Developing a work plan'.

Both threads D and E are illustrations of SSMR inhibiting undesirable directions of the group's cognitive process (slowing down as the behavioral indicator), in this case, due to the group realizing their ideas' limitations. In these two SSMR threads, both taking place in the phase of constructing the hypothesis, the girls question their inquiry process. These particular SSMR threads captures a *slow down* in the group's thinking process, rather than a change in their thoughts' overall direction, since their hypothesis remains the same. By stating their uncertainty and slowing down their thinking process the students became aware of their ideas' inadequacies and the unresolved issues, thus they realized the importance of not rushing and making decisions in a hurry. In thread D, the girls' notes show that, although they were aware that a reliable hypothesis could not be constructed, they were nevertheless unable to revise their line of thought. All four girls participated in this SSMR thread, which highlights its importance. Subsequently, thread D focused on some aspects of the hypothesis, whereas thread E briefly brought to light difficulties, while considering the hypothesis, with how to construct a situation at a general level. In thread E, the regulation process was shared by only two of the girls (Julia and Piia). Thus, these threads had to be analyzed separately.

In turn, thread F illustrates another behavioral indicator of SSMR's continuing function, namely, the *activation* of other ideas while pursuing a single line of thought. This thread spreads over the phases of 'Constructing a hypothesis' and 'Developing a work plan'. In this thread, the girls identified gaps in their thinking by an ongoing regulation of the kind of knowledge they thought was needed. The notes show how the knowledge they thought was required was co-constructed through SSMR. In this thread, the girls demonstrated their ability to regulate their cognitive process jointly towards a common goal and to co-construct a shared awareness of the knowledge they needed and the sources they could access. Finally, thread F led the girls to organize their plan's implementation, with a division of labor based on identified gaps in their knowledge. All four girls participated in this thread, which was pivotal for their subsequent work plan and for searching for and processing knowledge, as illustrated in Figure 1, but which involved minimal SSMR.

Lessons 7-8, Constructing a hypothesis				
h:min	**Iina**	**Piia**	**Sonja**	**Julia**
10:13		*do you have any suggestion for the hypothesis?* D		
10:16	I think ... It has been calculated that ... that they would crash in the year ... I think so because D it has not been seen, how can it be concluded that ...?			
10:18		if ... it hits the earth then ..., if D not ... I think that it is possible to know that because if ...		D how can it last so long a time? ... years?
10:19	*Maybe it can be so that it is ... but ...* D			
10:20			D It has probably been seen ... and estimated ... I don't know much about this topic ...	
10:23		but how has it been found D out that how ... ?		
10:25				maybe Iina is right that there are more than only one ... D why don't they go then, for example ...? when I was ... in a museum there ... was how is .... if I remember right ... then it was ... but why don't they show others ... ?
10:30				D no ... it can't be so ...?! or can it?
10:32	Because ...! (PROBABLY) And if ..., so ..., in which case it surely D ...! And then if ... so why not ...? But I don't know if it is even possible although it would be ...			oh, the universe is such a E difficult topic
10:33		this would be a good E hypothesis:?????		D I don't know anything of it, it was just an assumption ...
10:34				E I agree with you Piia but this could be at the end!!!
10:37				D where does it come from!?
10:38	We need knowledge of ... and ... how can it be concluded ... how is it supposed to ... We F also need knowledge of how ...			D if they have made a mistake in these interpretations??
10:39	So what is the end result? D		We need to get a lot of information about these kinds of things, and supposedly, on this kind of topic, it's not so easy to find because this has come to our knowledge not so far in the past and many books have been written F long, long ago!	
10:40		And also to where ... it has been calculated ..., although no-one knows it for sure ... and then why ... F		D If it is wrong? Let's check this before we write it into the project ...

h:min	Iina	Piia	Sonja	Julia
10:41	But there is knowledge that ... And if I remember right my Dad knew the name of it ... F		It's not necessary to find the end result right now. We still have time ... let's think other possibilities ... D	Maybe from internet? F
10:42			*I don't really find other ... STRONG possibilities ...* D	can't it be so that it hasn't come off yet...
10:44	*I can't design any better ...* D			*it's OK with me!!* D
10:45		*It's OK with me as well* D		
10:46			Internet is that kind of thing that although someone thinks that you can find anything from the net, sometimes it's very difficult. Especially these kinds of things ... there is so much knowledge that is NOT really true. It is necessary to know from where to try to find! F	
10:48-11:11	*lunch break*			
11:22				F we need knowledge of: -meteorites: #what is it ... #where does it ... ... -research #how to study it #how it can be known that ...
11:39		we need to get knowledge of that how ..., or could it be at all ...? knowledge is also needed about from what direction ... is assessed ..., and to where ... it is also needed to think that how ... it is important that what will happen if ..., and that ... or only ...? However, the most important question is how can it be concluded that ... and ...???? F	We need much knowledge. It doesn't make sense that I just repeat everything that Julia said. F	

Lessons 9-10, Developing a work plan

h:min	Iina	Piia	Sonja	Julia
9:38	We need knowledge of ... , that have earlier been said about ... and that how are they ..., or why don't they ... How it can F be concluded that ..., or what is the result if ... Is ... never before ... and if is so then ...			
9:39				it is necessary to acquire knowledge of it that what ... is? what other sources of information could there be other than internet? maybe not a library; because it's a rather new thing that ... so apart from that ... could be to find knowledge from a library as well. Knowledge could be to apply from it that why it ... is ...? and also is it ... or ...? and what is the F difference between them?
9:41				*I could seek out ...* F
9:42		*If everyone would take one or* F *two points to study a meteorite?*		
9:43	*So I could search knowledge of ...* F ... generally ... because this thing is possible to study in a F library.		It is possible to find knowledge of previous ... F	
9:45		*I could acquire knowledge about it that ...* F		
9:46	... in a library ... knowledge about it that has there ... ever before been ..., and if there has where ... I'm not sure if it's F possible to acquire knowledge about it from the net as well.			
9:48			*I could apply that ...* F	

Note. The text in italic and a letter in a gray box is not analyzed as a part of the SSMR threads but it illuminates the overall view of the process.

Threads: D ——— D = Slow E ——— E = Slow F - - - - - F = Activate

Figure 3. Inhibition function of slow (D and E) and Continue function of activate (F) of SSMR threads in 'Constructing a hypothesis' and 'Developing a work plan'.

A key feature of SSMR threads D, E and F is that they were closely intertwined. In thread D, which features the group slowing down their thinking process (slow down as a behavioral indicator of the process being somewhat inhibited), the girls questioned their hypothesis and hesitantly pursued the development of this hypothesis. Partly coinciding with thread D, the girls disclosed in thread E that they were uncertain about how to proceed and thus slowed down and reconsidered their options. In contrast, thread F illustrates how the group was eventually able to move forward by activating the ideas they had reconsidered and found suitable in threads D and E. Taken in combination, these SSMR threads illustrate how the group regulated the progress of their inquiry process and eventually agreed on what knowledge they needed. This provided evidence that previous threads could influence subsequent threads, an aspect of SSMR that may be characteristic of asynchronous CSCL processes in which students can go back to previous discussions. Furthermore, this influence became visible only through analysis of CSCL processes over an extended period.

3.2.3 Phases IV and V: Searching for and processing knowledge and Summarizing findings and concluding

After developing a work plan, the group moved to the final phases of its CSCL inquiry process, namely 'Searching for and processing knowledge' and, finally, 'Summarizing the findings and concluding'. Three SSMR threads (G, H and I) identified in these phases are shown in Figure 4.

In the course of searching for and processing knowledge and summarizing findings and concluding, one SSMR thread (G) appeared to *slow* down the group's inquiry learning process substantially. In thread G, the group discussed if the exact time of the asteroid hit could be determined and whether this information should be provided when summarizing the findings and concluding. The thread shows that the group's SSMR of this issue prevented overly hasty decisions (slowing down as the behavioral indicator of inhibiting function) over an extended period and across several phases of the inquiry process. Notably, thread G, which slowed down the process of searching for and processing knowledge, as well as summarizing the findings and concluding, took place over a much longer period than threads D and E (discussed in section 3.2.2). Their respective function was also to inhibit undesirable or hastily selected directions in the group's cognitive process, but they were contained in a single phase. All of the girls, except Piia, participated in this extended SSMR thread.

In addition, SSMR thread H appeared during the 'Summarizing findings and concluding' phase, which led to a *change* in the group's course of action (another behavioral indicator of inhibiting functions). In this thread, the group regulated their searching for, and processing of, knowledge in relation to the research question. The students became aware of a mismatch: the knowledge they had activated did not answer the research question. As a consequence, the group changed its research question so that this would correspond better to the knowledge they had gathered during the phase of 'Searching for and processing knowledge'. Thread H shows quite explicitly how the girls changed their previous research question to a new one by consensual regulation. Sonja, Julia and Iina were all actively involved in this discussion. The final SSMR thread (I) functioned to move the inquiry process forward (a continue function), with all the girls jointly engaged in shared regulation of their idea, *activating* all three concepts (i.e. an asteroid, a meteorite and a meteoroid) that were needed to explain their summary findings and conclusion. Piia's first note (10:39) appeared to have been discounted when the other three girls changed the research question. However, her second note (10:44), where she repeated the thought in her first note by clarifying what she meant, showed that she was closely monitoring the group's cognitive process. As she was not satisfied with the other girls' changes in the research question (thread H), she posted a new note starting a new thread during which the group eventually agreed to include the difference between the three different concepts in their findings and conclusion.

Lessons 11-12, Searching for and processing knowledge				
h:min	**Iina**	**Piia**	**Sonja**	**Julia**
10:41	*(writes information that she has searched) Possibly ... researchers have discovered ... that it may hit ... February 1, 2019. Estimations ... are still imprecise information because there are not enough findings ... to be an accurate calculation.* G			
10:57	*... According to estimations ... if it doesn't hit ... If the asteroid doesn't hit ... then it can be anticipated a bigger crash in 2060. It would come to the earth July 1 at 6 p.m. ... If it doesn't hit, then the next possibility is in 2078.* G			
11:28				G it's nice that you found so much important knowledge! but the time may not be correct. Someone just estimates so ... I'm not sure at all but it's quite strange if it can be assessed so exactly
11:30	That's right it is odd. G			
Lessons 13-14, Searching for and processing knowledge				
10:36				G It's so exciting that it's not certain whether it will hit in February 2019, however it's known that it will hit at 13:45:36 if it hits at all ...
10:39	From where have they got such an exact time? Are you sure? From where did you get the information, is it reliable? G			
10:45				G I found the information ... but I think that they can't know it because it is not known even if it will hit! So maybe we don't put the time into the project ...
10:56			... I believe anyway that the time can be calculated ... If it's known where and how fast an asteroid goes, experts may deduce what time it would hit. So it can be described in the project! G	

Lesson 16, Summarizing findings and concluding				
h:min	**Iina**	**Piia**	**Sonja**	**Julia**
10:15			We have a rather extensive problem because there are so many sub-problems. We have more answers to the sub-problems than to the main problem. H	
10:17				H so could we take one sub-problem and substitute it for a main problem? So, such (a sub-problem) of which much knowledge is known
10:35			Our problem could be changed a bit ... H	
10:36				H so we change the (main) problem into a sub-problem?? Any suggestions for the sub-problem??
10:38			We could combine sub-problems so that they form a main problem? H	
10:39	*Do we change our problem? ...* H	*what is a meteorite? what is a meteoroid? what is an asteroid?* I		
10:41			*A suggestion for a problem: (writes a problem and sub-problems)* H	
10:42	Yes! A really good thing! To this we have answers already! Still, the hypothesis should be changed. H			H Maybe it's no use changing it because then the hypothesis must be changed as well, perhaps some changes could be made to it as well??
10:44	I think that the problem needs to change because it's much better in that new form. Changing the hypothesis may not be so difficult here in the net working ... H	*ONE OF THE SUB-PROBLEMS HAS TO BE WHAT IS THE DIFFERENCE BETWEEN AN ASTEROID, A METEORITE AND A METEOROID.* I		*it's okay with me!* H
10:45	That asteroid/meteorite stuff may be explained somewhere there ... I			
Lessons 17-18, Summarizing findings and concluding				
10:46			I ... We can't set sub-problems that ... They are too small problems. They may be described as some sub-problems ...?	
10:48	It's true, we need to add them there as so-called "detail". Right? I			
10:52				I I disagree with you Sonja, we can explain the difference between the asteroid, the meteoroid and the meteorite!
10:59			Naturally, we can explain it there but it doesn't need to be one of the problems! I	

h:min	Iina	Piia	Sonja	Julia
11:00	I think that it's better there as "detail". I			
11:03				I I think that we can add these details to that part of the question ... because there is also that ... so it could be a place to write this matter ...
11:06	Look at ... this: It should be added to the text in this kind of way: ... That is, such as a "detail" I			
Lessons 19-20, Summarizing findings and concluding				
11:18		*It's OK with me as well ...* I		
11:20				*... at that place we could add that a meteoroid that hits the earth is called a meteorite. Further, time and dates!* G I
11:21	Do we need to put all kinds of times? I think that it's much more explicit that way. G		*Does someone know times and dates?* G	
11:23			G Are we going to add some-thing to this? They cannot all be put, that's unnecessary!	
11:24	*I have them, even seconds ...* G			
11:25	I think that these times are completely pointless! They make this more unclear. I think that the year is enough but if it is needed, we can write the month ... G			G Time is not pointless ...!
11:28			*Let's put it.* I	
11:41	*OK. Julia, let's put it now* G			

Note. The text in italic and a letter in a gray box is not analyzed as a part of the SSMR threads but it illuminates the overall view of the process.

Threads: G ——— G = Slow H ——— H = Change I - - - - - I = Activate

Figure 4. Inhibition functions of slow (G) and change (H) and Continue function of activate (I) of SSMR threads in 'Searching for and processing knowledge' and 'Summarizing findings and concluding'.

A most interesting characteristic of threads G, H and I, was their deep intertwined nature. During the phase of 'Searching for and processing knowledge', only one SSMR thread (G) appeared. In that thread, the girls regulated the issue of whether having the exact time was important, as well as if this would be reliable. However, at that time, they had not yet realized that their inquiry would not address their research questions. Thus, because of insufficient regulation while 'Searching for and processing knowledge', need for regulation emerged later (threads H and I), at the time the findings were summarized and a conclusion was drawn. Hence, together, threads G and H demonstrate how insufficient regulation in one phase can necessitate making up for lost time in a latter phase. Threads H and I also displayed strong interconnections, with Piia's neglected note in thread H triggering thread I.

3.3 Individual group members' participation in SSMR during an asynchronous CSCL inquiry process and the influence of specific individual contributions on the group's regulatory effort

3.3.1 Distribution of students' notes contributing to SSMRs

The first analysis was to determine if the four students' contributions to the SSMR effort was similar or different. Although SSMR participation appeared to vary across students, Iina participated the most (25 out of 74 notes or 34% of the group's notes in the SSMR threads), followed by Julia (22 notes or 30%), Sonja (18 notes or 24%) and, finally, Piia (9 notes or 12%).

Table 2 displays the number (and percentage) of each student's notes in the SSMR threads and, non-SSMR (Other) interactions and their totals, within the whole asynchronous CSCL inquiry process. A cross tabulation and a Pearson's chi-square test were performed. Cramer's V correlation was used to test associations (see Siegel & Castellan, 1988). The relationship between the number of notes within and outside SSMR threads across students was not different, $\chi2(3, N = 640) = 3.79$, $V = .08$, ns (see Table 2). Z-tests with Bonferroni correction also showed that the differences in the proportions of notes between the students were not significant.

Table 2

Frequencies (and percentages) of each student's notes

	Student				
Notes	Iina	Piia	Sonja	Julia	Total
Other	201 $(89)_a$	110 $(92)_a$	132 $(88)_a$	123 $(85)_a$	566 (88)
SSMR	25 $(11)_a$	9 $(8)_a$	18 $(12)_a$	22 $(15)_a$	74 (12)
Total	226 (100)	119 (100)	150 (100)	145 (100)	640 (100)

Note. Other = Notes outside SSMR threads. SSMR = Notes that are included in SSMR threads. Each subscript denotes a subset of the process phases whose column proportions do not differ significantly from each other at the .05 level.

3.3.2 Distribution of students' notes in SSMR threads that functioned to Continue or Inhibit the direction of the group's evolving cognitive process based on perceived appropriateness

Table 3 displays the number (and percentage) of each students' notes contributing to SSMRs that played different functions.

Table 3

Frequencies (and percentages) of each student's notes in terms of SSMR functions (Continue, Inhibit)

	Student				
Function	Iina	Piia	Sonja	Julia	Total
Continue	13 $(52)_a$	4 $(44)_a$	9 $(50)_a$	5 $(23)_a$	31 (42)
Inhibit	12 $(48)_a$	5 $(56)_a$	9 $(50)_a$	17 $(77)_a$	43 (58)
Total	25 (100)	9 (100)	18 (100)	22 (100)	74 (100)

Note. Each subscript denotes a subset of the process phases whose column proportions do not differ significantly from each other at the .05 level.

As can be seen, individuals' participation in SSMR threads that played a different overall function seemed to vary across students. Iina, Piia and Sonja participated with an equal number of notes, contributing to SSMRs with the functions of continuing and inhibiting the direction of the group's cognitive process, but Julia contributing three times as many notes, contributing more to SSMR inhibiting the group's process (slow down, stop or change) than to SSMR continuing the process. The relationship between students' notes in SSMR threads and the function category they contributed to (Continue, Inhibit) was however, not statistically significant based on Pearson's chi-square test and Cramer's V correlation, $\chi^2(3, N = 74) = 4.88$, V = .26, *ns*. The non-significance was confirmed, using z-tests with Bonferroni correction. However, Julia's strong contribution to making the group stop, slow down or change the direction of their thinking is noteworthy. It contrasts with Iina's contributions to the SSMR, which were as frequent as Julia's (respectively 22 and 25 notes out of 74) but which differed qualitatively in terms of the nature of each girl's contributions to the group's regulatory effort.

3.3.3 Distribution of students' notes contributing to SSMRs the inquiry process's different phases

Table 4 displays the number (and percentage) of each student's notes contributed to SSMRs in different phases.

Table 4

Frequencies (and percentages) of each student's notes in different phases

	Student				
Phase	Iina	Piia	Sonja	Julia	Total
Setting up the research question	7 (47)	3 (20)	5 (33)	0 (0)	15 (100)
Constructing a hypothesis	5 (19)	5 (19)	5 (19)	12 (43)	27 (100)
Developing a work plan	3 (60)	0 (0)	1 (20)	1 (20)	5 (100)
Searching for and processing knowledge	2 (33)	0 (0)	1 (17)	3 (50)	6 (100)
Summarizing findings and concluding	8 (38)	1 (4)	6 (29)	6 (29)	21 (100)

As can be seen, some students appeared to make a substantial contribution to SSMR in some phases and less (sometimes none) in others. For example, Julia made no contribution to SSMR in the 'Setting up the research question' phase but played a dominant role in the phases 'Searching for and processing knowledge' (50% of the notes in this phase) and 'Constructing a hypothesis' (43%). Another example is Piia, who contributed to SSMR almost exclusively in the first two phases (with no contributions in Phases III and IV and one single contribution in Phase V), while Iina contributed substantially throughout all phases (respectively, 47% of all notes in Phase I, 19% in Phase II, 60% in Phase III, 33% in Phase IV and 38% in Phase V). A significant relationship was found in the distribution of students' notes by phases (Fisher's exact test = 17.17, $p < .10$).

A number of observations can be made based on these findings. First, they reveal that Piia, who was identified as the group member who contributed least to the SSMR effort overall (see section 3.3.2), was in fact active in the early phases of the inquiry learning process, and she contributed as much as Iina and Sonja towards the group's SSMR of the construction of their hypothesis (5 notes each). One may wonder why Piia hardly contributed to the group regulatory effort after that and whether the other girls' perhaps more assertive statements may have played a role, in particular, Julia's questioning approach illustrated in SSMR threads D, F, G and H (Figures 3 and 4). Second, this analysis also shows that Julia, who played such a dominant role overall in inhibiting the group cognitive process moving in an unwanted direction, had in fact not contributed at all in the first phase of 'Setting up the research question'. Given that the original research question was eventually modified, understanding why Julia did not participate in the first phase may be necessary in order to understand her subsequent dominance in regulating the process of constructing the hypothesis.

3.3.4 Connections between students across the whole CSCL inquiry process

SNA was used to explore further individuals' contributions to SSMR, offering a different analytical approach. Consistent with SNA, each note was considered in relationship to other notes; that is to say, each note was studied for whether it reacted (respondent or, in SNA terms, 'in-degree') to other notes (initiator or, in SNA terms, 'out-degree'). The directional information generated by SNA, therefore, provided useful information on how each individual was positioned in reference to her peers during the joint regulation process.

Density, centrality and centralization measures were established based on these data. *Density* is a group level measure that indicates how lively interaction is among the students. It measures the average strength of connections in the network (Wassermann & Faust, 1994). In the data, six dyad ties were present (Sonja-Julia, Sonja-Iina, Iina-Julia, Iina-Piia, Piia-Sonja, Piia-Julia), which can be divided into 12 relationships in actor level analysis, distinguishing between the initiator and respondent roles. In turn, the actor level analysis produced 60 connections between students in the SSMR threads, generating a density value of 5 (60/12) for the connections within the SSMR threads.

While density indicates how lively the interaction is, *centrality* is an individual level measure for this, showing, who has the most or least contacts to other students (see Table 5). Using Scott's (1991) approach, centrality was measured with Freeman's degree (i.e. number of initiator or out-degree and respondent or in-degree notes). The results indicate that each student initiated and reacted on average to 15 notes (initiator SD 4.95, respondent SD 4.89) within the SSMR threads, with important individual differences. For example, as shown on the left hand side of Table 5, Pia was less at the center of the connections than other students (see Table 5).

Table 5

Frequency of connections between students and number of ties between pairs of students within the nine SSMR threads

	Frequency of connections					Ties between pairs of students		
	Respondent					Pair		
Initiator	Iina	Piia	Sonja	Julia	Total	Sonja-Julia	16	
Iina	-	2	5	8	15	Sonja-Iina	15	
Piia	3	-	2	2	7	Iina-Julia	15	
Sonja	10	3	-	7	20	Piia-Iina	5	
Julia	7	2	9	-	18	Piia-Sonja	5	
Total	20	7	16	17	-	Piia-Julia	4	Total 60; M=10

This means that Piia was less verbally active in the joint regulatory process. This finding is consistent with the differences tested with Pearson's chi-square tests (see sections 3.3.1 and 3.3.3), which were significant at the $p<.10$ level. Furthermore, Sonja's notes appeared to be the most frequently reacted to by others in the group. However, although Sonja did not generate as many notes (18) as Iina and Julia (respectively, 25 and 22) (see section 3.3.1), SNA indicates that her notes produced the most reactions, which implies an important role in the SSMR process.

Finally, *centralization* is a group level measure of how equally interaction is divided among the participants. The measure of centralization indicates how tightly connections are organized within this small group (see Scott, 1991; Wassermann & Faust, 1994) – the higher the percentage, the greater the difference between students. In a valued graph, the percentage can go over 100%. The results indicate that this small group was only very little centralized within the SSMR process (initiator 22.2%, respondent 22.2%), that is, the students' interactivity levels did not differ very much.

The six dyad ties between the four students (ignoring person initiator and respondent roles) also were computed and compared. As shown on the right hand side of Table 5, the dyad ties that did not include Piia were always stronger (15, 15, 16) and those involving Piia were always weaker, regardless of who was the other partner (5, 5, 4).

4. Discussion

The aim of the present study was to explore socially shared metacognitive regulation (SSMR) in a small group of students' collaborative inquiry process in an asynchronous CSCL environment. Although a substantial body of empirical research exists on asynchronous CSCL, in-depth micro-level studies of SSMR are still scarce. This study's main contribution is a novel micro-level analysis of SSMR processes and the demonstration of this methodology's use in a case study. Previous studies have dealt with these processes mainly on a theoretical or a much more generalized empirical level. This study provides evidence that SSMR manifestations are not only found in face-to-face collaborative learning environment but also in asynchronous CSCL environment (see also Hurme, Merenluoto, & Järvelä, 2009; Volet et al., 2013), which is important since previous research pointed to the challenge of developing analytical methods that can be used reliably and validly across different contexts, such as CSCL environments (Beers, Boshuizen, Kirschner, & Gijselaers, 2007). This study's findings are consistent with other studies (e.g. Grau & Whitebread, 2012; Hurme et al., 2009; Molenaar, 2011; Whitebread at al., 2007; Volet et al., 2009a), which have documented the emergence of SSMR in a range of collaborative learning contexts. However, as revealed in this study, SSMR manifestations can look different in computer-supported asynchronous environments, when compared to face-to-face contexts in which SSMR takes place in real-time. In the asynchronous environment studied, we found evidence of SSMR threads that lasted over an extended period and notes within threads that did not follow each other immediately but were interspersed with non-SSMR notes and sometimes intertwined with other threads. This kind of non-linearity can be found in face-to-face discussions as well (Iiskala et al., 2004, 2011), but, in an asynchronous environment, this kind of longitudinal regulation is much more dominant.

The present study also examined each SSMR thread's function in the flow of cognitive process. Similar to what has been reported in face-to-face collaborative learning contexts (e.g. Iiskala et al., 2011), evidence was found that SSMR can play different functions. Some appeared to continue (i.e. activate, confirm) the current direction of the inquiry learning process, whereas others appeared to inhibit (i.e. slow, change, stop) its current direction, more specifically inhibiting its perceived ineffective or overly hasty progression. While these findings somewhat mirror the SSMR manifestations found in face-to-face mathematical word-problem solving by high-achieving student dyads (Iiskala et al., 2011), the dominant functions differed. In Iiskala and colleagues' (2011) study, the most common SSMR function was to confirm the direction of the cognitive flow (i.e. continuation of the problem-solving process). In contrast, substantial evidence appeared in the present study of inhibitive SSMR functions, mainly slowing down, stopping or changing the inquiry process's direction when this was perceived as inappropriate or rushed at that point in time. Hence, the findings of this in-depth case analysis indicate that, in an asynchronous CSCL environment, small groups can regulate of their cognitive activity's direction so that inappropriate processes are reassessed. In this study, limited evidence surfaced that the group was using SSMR to develop an appropriate way to proceed towards their common goal. One reason for this could be that, in computer-supported environments, small groups have the possibility of deepening their knowledge through long discussions (e.g. Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). In the present study, however, both short and relatively long SSMR threads were identified. When threads contained only a few notes, as is often the case in CSCL, the discussions soon ended (see Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003). This implies, that in short threads, SSMR is not sustained over long periods. Notably, although SSMR threads can be short, consisting of only a few notes, the discussions (e.g. on cognitive topics) in which SSMR intervenes can be longer. This means, that SSMR, for example, can change the direction of the group's thinking process even during a rather short SSMR thread. In addition, although SSMR might be visible for only short periods, cognitive implementation based on SSMR can last longer. Furthermore, the distinct findings in face-to-face and asynchronous CSCL environments could be due to the nature of the students' tasks. In Iiskala and colleagues' (2011) study, the problems had a single correct answer, although not always achieved by straightforward arithmetic calculations, which could lead the students to decide to check whether or not their solutions to the problems were correct. This was not the case in the present study because the problems were more multidimensional and ill-defined. Ill-defined questions could be one of the reasons the small group in the present study spent more time regulating their inquiry learning process (12% of all notes) than has been reported in other studies also conducted in asynchronous CSCL environments. For example, Prinsen and colleagues (2007) reported that only 6% of students' time was spent on regulation, and they speculated that the tasks' well-structured nature could be the cause. Although ill-defined questions and multidimensional tasks can create opportunities for SSMR in collaborative inquiry learning, the possibility of alternative explanations of variations in SSMR functions will have to be investigated more systematically, for example, changing the group size (e.g. dyad vs. small group).

One under-examined issue in previous research is how SSMR evolves over the duration of an extended collaborative learning activity. In the present study conducted in an asynchronous CSCL environment, SSMR was found in all phases of the process, but with some variation in the number of threads across phases, as well as the number of notes within threads. For example, fewer notes appeared within SSMR threads in the phase of developing a work plan than during constructing a hypothesis and summarizing findings and concluding. Hence, different phases triggered students to regulate the process to a different extent. This is consistent with Lajoie and Lu (2012), who found that the frequency of regulation varied with the learning process's different phases. Furthermore, in asynchronous collaboration, the present study found that SSMR threads were either contained in one phase or developed and evolved over several phases. These findings suggest that, although SSMR can emerge across a range of collaborative learning contexts, its manifestation over time can look different, depending on the mode of collaborative learning (CSCL vs. face-to-face). This indicates that simply extrapolating the findings from face-to-face environments to virtual learning environments is not possible.

Differences in SSMR engagement across phases could also be related to variations in each phase's level of difficulty. For example, developing a work plan could be easier than constructing a hypothesis or summarizing findings and concluding, since planning is a generic activity that may not require as much content knowledge. This interpretation is consistent with other studies (e.g. Efklides, Papadaki, Papantoniou, & Kiosseoglou, 1998; Iiskala et al., 2004, 2011; Prins, Veenman & Elshout, 2006), which revealed that metacognition is more likely to appear when tasks are reasonably difficult. This may also help explain research findings (e.g. Khosa & Volet, 2014) pointing to a relationship between SSMR and construction of high-level content knowledge. Hence, in order to foster productive SSMR in school learning activities, an optimal difficulty level of tasks may be important, that is, sufficiently challenging but within the students' zone of proximal development (see Vygotsky, 1978).

One original contribution of the present research was to investigate students' participation in SSMR using different analytical methods. This approach proved valuable as it provided complementary insights into group members' SSMR participation. For example, no individual differences appeared in the number of SSMR notes themselves. However, SNA revealed that group members reacted the most frequently to one particular student's notes. Our findings concur with Palonen and Hakkarainen's (2000) study, in which SNA revealed information on students' participation in CSCL not revealed through other analyses. Hence, examining who has the largest number of notes in SSMR threads appears to be important, but so is pinpointing whose notes caused the other students to react the most. This finding suggests that SSMR is somewhat similar to the notion of distributed expertise (see Brown et al., 1993), in which members of a community of practice are recognized as critically interdependent, their expertise is shared between members and meaning negotiated within the group. Another interesting finding in the present study was that one student had fewer connections within the SSMR threads than her three fellow students did, even though all four were above average students in terms of their cognitive skills. The range of individual and contextual aspects that have an impact on SSMR participation needs to be better understood.

The present study also highlighted the different roles students play in different SSMR threads. The finding that one student played a dominant role in the SSMR threads that slowed down, changed or stopped the inquiry process's direction, and a minor role in the threads that continued the process, suggests that some students make different contributions from a metacognitive point of view. This supports the reasonable assumption that trying to inhibit the cognitive process's flow because those involved perceive that it is overly hasty or that it is going in an inappropriate direction is more demanding metacognitively than confirming the group activity continues. Previous CSCL research (e.g. Prinsen et al., 2007) also suggested that learners' characteristics and position among classmates might affect their participation in asynchronous CSCL. Therefore, how individual differences, and possibly individual position within groups, play out in regard to more or less demanding contributions to SSMR will need to be examined in future research.

Other individual differences emerged, in this study, focused on in which phases students participated most and in which they participated less or not at all. These findings highlight that analyzing individuals' total SSMR engagement during inquiry learning processes – as if these are single entities – is insufficient. Scrutinizing how each individual's SSMR engagement evolves in different phases is also important – similar to analyses undertaken at the group level. Variations in individuals' participation across phases, or in specific tasks carried out in different phases, should generate new insights into the emergence of SSMR, including the role of group dynamics. Studying students' contributions at different phases of problem-solving or inquiry processes may also reveal whether and how high-quality collaboration is sustained. This understanding is vital, since Rogat and Linnenbrink-Garcia (2011) found that high-quality regulation is characterized by frequent high-quality interactions. Similarly, based on their study of networked learning, Toikkanen and Lipponen (2011) suggested that students' participation needs to be distributed among many students.

One additional aspect to keep in mind when studying SSMR is that, sometimes, all group members and, at other times, only a sub-group is involved. How this aspect relates to the quality of the group process and outcome will need to be examined further. Summers and Volet's (2010) study provides support for this suggestion as they found evidence, in their most successful group, that half of all the contributions of every single group member reflected high-level engagement. The qualitative examples presented in the present study showed how a student's suggestion was ignored by the other students in the first instance but was taken into consideration later and eventually became the starting point of a new SSMR thread. This is in line with Molenaar's (2011) study, which reported 'ignored metacognitive activities' that represented situations in which other group members ignored a peer's input. These findings provide support for the assumption that SSMR is more than simply the sum of individuals' metacognitive regulation and, thus, cannot be reduced to each individual's level. Instead, as in all social systems (see Salomon & Globerson, 1989; Vauras, Salonen, & Kinnunen, 2008), including small groups, the reactions and subsequent interactions between participants play a crucial role.

The present study also provided support for the importance of using more than one method to analyze SSMR data, not only because different methods provide complementary insights but also because they prevent researchers from drawing conclusions from insufficient information. The use of SNA in this study created new insights into SSMR by revealing that, although all students participated in SSMR to some degree, the distribution of their participation was unequal and appeared to vary according to the method of analysis. However, SNA centralization percentages showed that the small group studied was minimally centralized, and only around some students, which was consistent with the results of the cross tabulation, which did not show any individual differences. Calls for the use of multi-method designs when studying metacognitive skills (Veenman, 2005) and computer-based learning environments (Azevedo, 2005) have been issued, and these methodological approaches need to pursue vigorously. The use of multi-method designs and alternative analytical methods is particularly critical when studying SSMR in CSCL since the additional information provided by nonverbal indicators in face-to-face SSMR is unavailable. This was particularly important in the present study, which relied on an in-depth analysis of a single case. As an example, SNA is typically used in the analysis of members' connections, providing critical insights into the nature of individual contributions, more specifically, individual positioning within interactions. As Toikkanen and Lipponen (2011) have suggested, the combination of qualitative analysis and SNA provides more accurate information about students' participation and, thus, a stronger foundation for interpretation.

When technology is introduced in classrooms, it does not just add a new element in the existing pedagogical practice and environment, but has larger consequences (Salomon, 1994). Information and communication technology, such as an environment supporting computer-mediated collaboration, can be seen as an affordance for new forms of interaction and, simultaneously, as a challenge or constraint for conventional forms of pedagogical communication, and this can result in intended and un-intended consequences (Kirschner, Strijbos, Kreins, & Beers, 2004; Suthers, 2006). In this article, we were able to deal with only some of these, but a more in depth analysis is needed in future studies of the multifarious consequences of information and communication technology in the regulation of social interaction. Furthermore, in the present study, it was not possible to test how well the analysis method could be used in varying situations because only one group was under scrutiny. Moreover, during the working process, direct face-to-face discussions could not be avoided among the participants. Therefore, it was not possible to control what kind of regulation happened in these discussions. In addition, when the entire analysis is based on written notes, little information is available about students' actual metacognitive experiences, which have proved to be important parts of SSMR processes in face-to-face situations (Iiskala et al., 2011).

Finally, while the study of a single group limits the generalization that can be made from the findings, a number of directions for future research emerged. For example, follow-up studies with multiple groups will need to incorporate more versatile indices (e.g. Toikkanen & Lipponen, 2011) in order to reveal group characteristics, as well as similarities and differences between small groups. Another research direction is to explore further the nature of, and relationship between, consecutive and concurrent SSMR threads in asynchronous CSCL. Calls have been made for sequential analyses (Molenaar & Järvelä, 2014) and analyses of individual participation across and within episodes or threads (Panadero & Järvelä, in press), which will provide further insights into SSMR. These analyses need also to focus on the entire flow of problem-solving or inquiry learning process, rather than analyses of single, isolated examples of SSMR, extracted from the process. By scrutinizing a small group's SSMR during their entire inquiry learning process, the present study has made a unique contribution by revealing the distinct impact of SSMR on particular phases and showing the ways in which some SSMR functions are more frequent than others are in specific phases.

Keypoints

- In asynchronous CSCL, SSMR manifests in threads of varied length, which can intertwine or overlap and affect the evolution of the learning process.
- Intensive periods of SSMR and periods of limited SSMR take place in asynchronous CSCL.
- In asynchronous CSCL, SSMR has different functions, with a dominance of SSMR functions that inhibit the process's perceived inappropriate direction.
- Combining analytical methods, including SNA, provides vital complementary insights into how students influence group regulatory efforts.
- Scrutinizing the entire CSCL process is essential to revealing the relationship between SSMR threads.

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Appendix

Description of the process (adapted from Hakkarainen, 2003)

Order of phase in CSCL[a]	Phase	Lessons	Introduction face-to-face/ CSCL[b]	Content
	Creating the context	1–2	Introduction	– Giving instructions for the process – Watching the documentary video of the universe – Discussing interests based on the video and previous knowledge/experiences – Forming small groups
I	Setting up the research question	3–4	Introduction CSCL	– Giving instructions for the explanation-seeking research questions – Setting up of small group's research questions
II	Constructing a hypothesis	5–8	Introduction CSCL	– Giving instructions for constructing hypothesis/es – Constructing small group's hypothesis for research questions
III	Developing a work plan	9–10	Introduction CSCL	– Giving instructions for making a work plan – Making small group's work plan
IV	Searching for and processing knowledge	11–15	Introduction CSCL	– Giving instructions for inquiring – Searching in small group for knowledge and processing it
V	Summarizing findings and concluding	16–20	Introduction CSCL	– Giving instructions for summarizing the findings and making conclusions – Summarizing small group's findings and drawing conclusions
	Common discussion	21–22	CSCL[c]	– Listening to students outside the small group comment on the summarized findings and conclusions of the small group and the small group's students reactions to the other students' comments

[a] Phases I–V were analyzed. [b] Introductions were face-to-face and not analyzed; SSMR was analyzed only during CSCL. [c] The two last lessons (21–22) were not analyzed because, in this phase, all students in the class connected to each other independently and, thus, the focus was not only on the selected small group's process but also on individual students.