Spontaneous Scientific Argumentation and Socially Shared Metacognitive Regulation of High- and Low-Performing Small Groups in Virtual Collaborative Science Learning

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Abstract

The present study examines the interconnectedness of spontaneous scientific argumentation and socially shared metacognitive regulation (SSMR) during a collaborative inquiry in which students are tasked to work in a virtual learning environment for marine biological issues. From a larger dataset of 39 groups, four small student groups were selected for this specific study. Of the selected groups, two were high-performing and two were low-performing based on their collaborative outcome. Moreover, students' videotaped discussions were analyzed in terms of argumentation and metacognitive regulation during three phases (planning, experimenting, and presenting). Finally, an in-depth video analysis was conducted, which was supported by qualitative excerpts that were transcribed. The results of the present study demonstrate that metacognitive regulation and argumentation spontaneously co-occur; in particular, SSMR appeared to co-occur with high-level argumentation. Moreover, SSMR was shown to be related to deeper argumentation and, thus, to the discussion of the high-performing group. Finally, the results hinted that students socially regulate their learning when they are asking questions related to a scientific topic, even though this was not shown to be statistically significant. To summarize, the interrelation of scientific argumentation and metacognitive regulation is under-researched and, therefore, the present study attempts to extend the understanding of this relationship and the co-occurrence of argumentation and metacognitive regulation.

Keywords: Scientific argumentation, metacognitive regulation, socially shared metacognitive regulation, collaborative learning, virtual learning environments

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1. Introduction

Collaborative learning has been one of the learning approaches to advance a shift away from previously so typical teacher-centered classrooms. In collaborative classrooms, listening to the teacher talk and note-taking may not entirely disappear, but it exists alongside other processes that are based on students' discussions and active work with the learning material. Teachers who use collaborative learning approaches tend to think of themselves less as transmitters of knowledge to students and more as designers of intellectual experiences for students as coaches (Gorgônio et al., 2017; Schoor & Bannert, 2012).

Collaborative learning encompasses a broad territory of approaches with variability in the amount of in-class or out-of-class time built around group work. Collaborative activities can range from classroom discussions with short teacher lectures to entire class periods. The goals and processes of collaborative activities also vary widely. Activities can involve small group work around specific steps or a more spontaneous agenda that may develop from student interests or questions. In certain collaborative learning settings, the students' task is to create a product; in others, the task is not to produce a product but rather to participate in a process, which becomes an exercise of responding to each other's work or engaging in analysis (Perry et al., 2021; Vuopala et al., 2016)

In its carefully structure form, collaborative learning is based on the social interdependence theories of Kurt Lewin and Morton Deutsch (Deutsch, 1949; Lewin, 1935). These theories and associated subsequent research explore the influence of the structure of social interdependence on individual interaction within a given situation, which, in turn, affects the outcomes of that interaction (Johnson & Johnson, 1989). In the present study, the approach to collaborative learning is that it involves students working together on specified activities or learning tasks in a group that is sufficiently small to ensure that everyone has the opportunity to participate. The learning environment comprises a virtual research vessel, an interactive laboratory, and tasks to be completed within the limits of the environment. Hence, this is kept separate from unstructured group work.

Earlier research in the field (Khosa & Volet, 2014; Muijs & Bokhove, 2020; Molenaar & Chiu, 2014; Perry et al., 2021; Vuopala et al., 2016) reveals that educational experiences that are active, social, contextual, engaging, and student-owned lead to deeper learning. The benefits of collaborative learning include the development of higher-level thinking, oral communication, self-management, and leadership skills; the promotion of student-faculty interaction; and an increase in student retention, self-esteem, and responsibility (Panitz & Panitz, 1998; Panitz, 1999). In addition, exposure to and an increase in the understanding of diverse perspectives and preparation for real-life social and employment situations are a few of the advantages of collaborative learning (Chandra, 2015). The carefully constructed virtual science learning environment in the present study aimed to guide and strengthen collaborative activities and learning of science content.

1.1 Spontaneous Scientific Argumentation in Virtual Collaborative Learning

1.1.1 Spontaneous Scientific Argumentation in Science

Scientific argumentation is at the very heart of science education and in the implicit structure of natural sciences. In previous science education literature (Sampson & Clark, 2009, 2011; Sampson et al., 2011), it is established that argumentation in science is a knowledge-building and -validating practice in which individuals attempt to establish or validate a conclusion, explanation, or claim on the basis of certain reasons. Therefore, a claim is supported by evidence, including measurements or findings, and the evidence is then justified with a rationale that justifies the individual's choice of that evidence and provides a link between the claim and the evidence. Therefore, argumentation is a natural means of teaching topics to students and introducing them into the scientific world (Berland & Hammer, 2012; Driver et al., 2000). In the present study, scientific argumentation is restricted to the spontaneous act of student debate over the duration of the virtual learning environment that occurs without the teacher providing specific instructions or structure to the students to make explicit arguments.

The benefits of argumentation demonstrated in earlier studies include the following aspects (Erduran & Jiménez-Aleixandre, 2008; Faize et al., 2017; Jiménez-Aleixandre & Erduran, 2007): 1) Argumentation can enhance motivation. A possible reason for this is that students have more autonomy over what they say in argumentation-based discussions than in traditional teacher-led situations, where teachers limit students to answering only a few questions. Argumentation may simply offer more interaction with peers, which in itself can be rather motivating. Moreover, students' engagement in argumentation allows them to become aware of their peers' ideas and, in this manner, to become interested in which of the ideas are the most defensible ones. 2) Argumentation can support content learning in several ways, such as engaging in explicit elaborative processing (e.g., explanation, which is known to promote learning) and modification of ideas (Nababan et al., 2019). When engaging in argumentation, students engage in a variety of explicit elaborative processes or receive learning support from their peers. In the process of argumentation, students learn from their peers or give them reasons to believe in their arguments. This is because the process of providing evidence for claims can not only give learners a better understanding of the ideas they are learning about but also more reason to believe the claims they are developing (Ping et al., 2020). 3) Argumentation can improve general argumentation skills, specific argumentation skills, and knowledge-building practices. This benefit is explained by the students engaging in argumentation and, therefore, learning to argue and better evaluate arguments (Sari & El Islami, 2020). Thus, the students must regulate their learning and argumentation as well.

Previous studies on argumentation have mainly focused on written argumentation in relation to science teaching (Bathgate et al., 2015; Berland & Hammer, 2012; Wallon et al., 2018), and only a few studies have focused on spoken argumentation, which makes spoken argumentation in this context an interesting topic. Two of the few studies on spoken argumentation in science teaching (Chen et al., 2016; Varelas et al., 2008) have revealed that the use of written argumentation has the potential to promote students engagement with science and foster spoken argumentation. Therefore, both spoken and written argumentation are positively connected to knowledge construction and critique in scientific community. Chen et al. (2016) videotaped an entire classroom discussion during a whole-class discussion focused on group presentations to analyze the different patterns in students’ discussion in a very similar manner as that in the present study; consequently, they found that oral and written arguments relate to engagement in scientific writing and awareness of the usefulness of critique from peers. Again, spoken argumentation was not studied in isolation but as a counterpart of written argumentation. Varelas et al. (2008) studied younger students during a science activity during normal lessons, but the results were similar to those of Chen et al. (2016). The students learned to articulate their arguments and extend each other’s thought processes. Similar to the setting of the present study, the students were not given strict rules or instructions on how to argue, and the students’ discussion was videotaped. In both these cases, there were limitations regarding the generalizability of the results, and the students were not of the same age as the students in the present study.

1.1.2 The Implementation of Spontaneous Scientific Argumentation in a Virtual Collaborative Learning Setting

The other aspect of the spontaneous spoken argumentation studied in this research is its implementation in the context of computer-supported collaborative learning. A thorough review of argumentation-based computer supported collaborative learning environments (Noroozi et al., 2012) demonstrated that small groups (dyads and triads) have been prioritized, which is also done the present study. However, in the previous studies reviewed, the selected group size has depended on the learning goals, time constraints, complexity of the learning task, and the technical design of the study. Further, synchronous and asynchronous forms of communication have been used in other study settings that are similar to those of the present study. The depth and accuracy of external collaboration instructions typically varies, and the present study represents the broader end of the instructional continuum. However, the use of not-so strict instructions have been shown to aid the students to focus on collaborative argumentation with the goal of learning (Stegmann et al., 2012). In addition, small multidisciplinary groups as a studied unit are a minority, even though the emphasis in science teaching is on interdisciplinarity. In these regard, the environment of the present study encouraged the students to argue in interdisciplinary terms. Interdisciplinary small groups or tasks engage students in transactive discussions, which has been studied as a crucial aspect of university students' mathematical argumentation skills (Vogel et al., 2016). The study by Vogel et al. (2016) revealed that learners' engagement in responding to their partner's contribution in an argumentative manner mediated the effects of scaffolding, whereas any other measured collaborative learning activity did not. Thus, the pedagogical setup of computer-supported collaborative learning fostering argumentation is important because all the activities, distributions of roles, instructions on how to use tools, and collaborative design has a significant influence on the learning outcomes (Scheuer et al., 2010). In his dissertation, Veerman (2000) summarized that the initiation of argument is related to task characteristics—such as multiple acceptable solutions, competitive instructions, and a required joint product—rather than the features of the environment. Moreover, argumentation is an effective factor in computer-supported collaborative learning, particularly in discussions that focused on the meaning of concepts, information checks, and constructive activities. Therefore, the discussion is often indirectly argumentative and can be divided into discussions that focus on the interpretation of theories and concepts, use of theories and concepts, and meaning and application of concepts. Further, the study by Akpinar et al. (2015) demonstrated that using a multimedia-enhanced learning setting supports the argumentative processes but does not necessarily provoke debate. Thus, computer-supported collaborative learning environments may encourage students to engage in argumentative knowledge construction (Weinberger et al., 2007) by collecting evidence through discourse, with the goal of acquiring knowledge specific to a domain. It was revealed that a few important features of the learning environment include the structure of how the learners handle the task, which concepts they use, as well as the social component that facilitates how students interact with each other. These components highlighted the essential nature of transactivity in argumentative knowledge construction in a similar manner as that in the study by Vogel et al. (2016).

Further, Vuopala et al. (2016) compared the best-performing groups to the low-performing groups and found that even in the three best-performing groups, the discussion was more group-related than task-related and that the evaluation of collaborative learning was rare. Discussion was oriented toward success in the learning task, and included little or no off-task discussion. These aspects set these groups apart from the low-performing groups. In another study by Sampson and Clark (2011), two high- and low-performing groups were compared with regard to collaborative scientific argumentation. In their study, it was emphasized that the low- and high-performing groups differed in terms of the number of unique ideas introduced into the conversation, how students responded to these ideas, how often students challenged ideas proposed by other group members while engaging in the discussion, the criteria the students used to distinguish among ideas, and how the group members used the available data. These differences explicitly imply that the students in the high-performing groups had an opportunity to consider the pros of a wider variety of viewpoints as a group, whereas the students in the low-performing group examined the explanations independently and did not bring new ideas to the discussion. Therefore, the low-performing groups had fewer opportunities to exchange ideas, challenge each other, and discuss solutions as a group. The students in the high-performing group were also more likely to discuss an idea and contribute oppositional comments as compared to the students in the low-performing group, thereby generating an argument. Thus, in contrast to the low-performing group, the high-performing group was able to eliminate explanations that relied on personal beliefs and included common misconceptions.

1.1.3 The argumentation analysis frameworks

While the argumentation frameworks (e.g. Toulmin, 1958; Chinn & Clark, 2013) differ in terms of the types and numbers of structural components, many of them agree on the structure of an argument as a pair of claims and justification. Thus, in the present study, argumentation is also seen as a chain from a claim made through observation and evidence, moving to the interpretation of the claim. Accordingly, we attempted to achieve a balance between the different approaches in our model. In addition, the material consists of videotapes and, thus, spoken argumentation instead of written arguments, which also had to be taken into account. The argumentation framework in the present study is emphasized in greater depth in this section. In the present study, argumentation is defined as the means through which students reach a common understanding regarding a certain scientific topic.

Toulmin's framework is applied as a basis for the framework, but since its proper use involves reliably distinguishing between claims, data, warrants, and backings, it has been simplified as the comments made by students can often be classified into multiple categories. The other reason is the fact that, although the student argument would be considered relatively strong structurally according to most Toulmin-based frameworks, the content may be inaccurate from a scientific perspective.

In the present study, the argumentation coding category attempts to account for socio-emotional aspects as well. When analyzing studies using video-taped material, it has been found that claims, rebuttals, and justifications are the critical features for developing and evaluating argumentation in classroom situations (Osborne et al., 2004). With younger students, it has been found that in video-taped sessions only one pair typically engages in the socio-scientific topic during the science lesson (Evagorou et al., 2013). Furthermore, it has been shown that a socio-scientific topic on its own does not lead to engagement in argumentation because the socio-scientific problems can be solved differently by different students, which makes some students feel ownership but not all students (Evagorou et al., 2013). In another study setting, groups of three students prepared a report for other students as part of a video-taped peer review practice, and the study demonstrated that students' argumentation skills were improved as a result of this argumentative scientific inquiry (Kim et al., 2006).

Much of the earlier research (Chinn & Clark, 2013; Toulmin, 1958; Van Eemeren et al., 2004) on argumentation has focused on written arguments or arguments constructed by a single speaker. Therefore, the focus has usually been on the evidence and reasons with which writers or speakers support their claims rather than on the collaborative nature of argumentation. This so-called collaborative argumentation refers to an interchange of statements, questions, or replies in a dialogue that involves two or more participants (Van

Eemeren et al., 2004). Participants in such a dialogue usually make claims and support these claims with reasons. The participants may disagree and attempt to resolve this disagreement, but this is not necessary. In the context of the present study, it is also more appropriate to discuss collaborative argumentation dialogue, in which the participants do not disagree with each other (Chinn et al., 2013). For example, students may collaboratively develop reasons to support a scientific explanation that all can agree with, or they may collaborate to use evidence to develop and refine their scientific explanation. Evidence is also naturally used in this situation to support their developing ideas. In the nature of collaborative argumentation it is that the students are jointly participating in the construction of arguments.

Thus, three data- and theory-driven components of spontaneous verbal argumentation were recognized: questions (Q), observations (O), and interpretations (I). These components resemble the main components of Toulmin's model that are data (the facts students appeal to in support of their claim), claims (conclusions whose merits are to be established), warrants (the reasons justifying the connections between the data and knowledge), and backing (basic assumptions that are commonly agreed upon). These categories were modified to suit the framework illustrating the components of a scientific argument presented by Sampson and Schleigh (2013). The framework emphasizes the nature of the evidence and the claim as well as the interpretation of the data and the analysis method. The depth of this model was sufficient in this context of spontaneous spoken argumentation. For the purpose of the statistical analyses in the present study, the categories of observation (O) and interpretation (I) were combined as one category reason. This is supported by the literature (Mercier & Sperber, 2011), since the reasons are expected and in the case of the present study the real answer to the hypothetical challenge are the answers to the questions expressed by the other students in the group. In this sense, the reason includes both the observations and their interpretations.

Thus, the spoken spontaneous argumentation is also classifiable as collaborative argumentation that refers to argumentative conversations groups of students have when they are required to collaborate jointly on a common task (Li et al., 2024) despite them not being asked to construct and present an argument (Asterhan et al., 2016). Key charecteristics of collaborative argumentation are group members' intellectual openness, profound shared thinking (Isohätälä et al., 2018), and social co-construction of scientific knowledge (Evagorou et al., 2013). Although argumentation illustrated in the present study meets most of the criteria of collaborative argumentation, it is still different from it since the most definitive attribute of it is its spontaneity and the lack of explicit instructions.

1.2 The Role of the Socially Shared Metacognitive Regulation in Collaboration

Socially shared metacognitive regulation (SSMR) is a social process employed by students participating in small group learning. It is a useful framework in explaining how small groups align the current status of small group work with a desired goal. SSMR has been found to be crucial in regulating collaborative work and coordinating multiple small group tasks (De Backer et al., 2015; DiDonato, 2011; Iiskala et al., 2011; Järvelä et al., 2016).

Since the seminal work of John Flavell and Ann Brown (Flavell, 1979; Brown & Smiley, 1977), the concept of metacognition has long been a framework for explaining how individual students regulate their learning (De Backer et al., 2015; Iiskala et al., 2004). However, metacognition at the individual level does not fully explain a dynamic learning process of individuals placed in a social cognitive system (Volet et al., 2009). In empirical studies, researchers have attempted to explain how an individual’s metacognition expands to the social level (e.g., Iiskala et al., 2004; 2011; Isohätälä et al., 2017; Volet et al., 2013). In this attempt, metacognitive regulation has been divided into five categories: no metacognitive regulation, verbalized metacognitive self-regulation (VMSR), ignored metacognitive regulation (IMR), metacognitive other-regulation (MOR), and SSMR (Iiskala et al., 2021). Moreover, in literature, metacognitive regulation is implemented as a repercussion of aspects such as metacognitive learning strategies, awareness, and knowledge in several definitions (Avargil et al., 2018; Kallio et al., 2018; Ku & Ho, 2010; Schraw, 2001), but in the present study metacognitive regulation is considered a supporting part of the spontaneously aroused metacognitive regulation spectrum examined in the context of the virtual learning environment.

SSMR refers to a process in which multiple small-group members regulate their collective activity and the metacognitive regulation is goal-directed, shared, and egalitarian. (Iiskala et al. 2011, 2021; Vauras et al. 2003). Within the SSMR framework, a small group is conceptualized as a social system within which small group members influence and regulate each other's and the group's learning (Järvelä et al., 2016; Khosa & Volet, 2014). SSMR affects students' participation in small group work and small group effectiveness (De Backer, et al., 2015; DiDonato, 2013; Volet et al., 2013). For example, interaction is suggested to be facilitated by SSMR and makes small-group learning processes, such as problem-solving, easy and productive (Hurme et al., 2009).

From the perspective of the present study, Järvelä et al. (2013) studied 18 graduate students (aged 24–30 years) working in small groups (three to four students per group) over eight weeks using collaborative planning software and producing varied outcomes in SSMR. They concluded that successful collaboration enables group members regulate their learning individually and collectively, which is crucial information for the aims of the present study. Further, Kim and Lim (2018) provided guidance for SSMR through collaboration scripts studied in a complex team project, thereby demonstrating positive effects of SSMR on planning and knowledge construction. The role played by SSMR in different collaborative learning environments is even more crucial in the challenging disciplinary area of science (Vauras et al., 2021).

In the setting of the present study, the comparison between the low- and high-performing groups is the leading idea. Recent literature has revealed a relationship between metacognition and academic success—that is, a weak metacognitive regulation was associated with lower academic performance, and vice versa (McGuire, 2015). Embedding metacognitive regulation instruction and practice in the course resulted in stronger student metacognitive regulation by the end of the semester relative to sections that did not include a metacognition intervention (Santangelo et al., 2021). The results of the present study provide further evidence to indicate that metacognitive regulation is closely related to the group's performance and the outcome. In another study by Volet et al. (2013), collaborative learning groups comprised medicine students with incompatible goals and the focus was on understanding how group members negotiate, coordinate, and regulate their collaboration to reach a shared understanding of the task and shared goals to complete the task.

Apart from SSMR, other forms of metacognitive regulation also manifest in a collaborative learning context with small groups. However, not all forms of metacognitive regulation support the successful collaborative learning process. For example, IMR refers to a student's attempt to regulate the group's cognitive learning processes, but that attempt is ignored by other students of the group (Iiskala et al., 2021; Molenaar et al., 2014). Rogat and Adams-Wiggins (2014) showed how IMR acts as low-quality metacognitive regulation in collaborative learning and does not enable the development of the group's joint collaboration. Moreover, in VMSR—another form of metacognitive regulation—students regulate only their own thinking processes despite the collaborative learning context (Iiskala et al., 2021). Moreover, previous research (Grau & Whitebread, 2012) has showed that the group that displays more shared metacognitive regulation than self-regulation in collaborative learning processes focuses more on the fundamental rather than the superficial aspects of a task. Moreover, Panadero et al. (2015) found that high metacognitive self-regulation does not necessarily lead to a high-level learning outcome for groups. These findings imply that metacognitive self-regulation is not a sufficient prerequisite for high-level collaborative learning.

SSMR also differs from MOR, where one or many students regulate another students' or the group's cognitive processes; this causes the metacognitive regulation to not be egalitarian or shared among the students (see Iiskala et al., 2021). Other-regulation can be manifested as a directive in a group's learning process, representing low- or moderate-low-level metacognitive regulation within the group (Rogat & Adams-Wiggins, 2014). In this case, other-regulation is not beneficial for the group's collaborative learning. However, other-regulation can also sustain shared focus on the task (Rogat & Adams-Wiggins, 2014) and, thus, serve SSMR. However, other-regulation itself is seen as an unequal situation among students (Iiskala et al., 2004; Whitebread et al., 2009) and, thus, is not an optimal situation for a longer period of time if the attempt is to achieve genuine collaboration and metacognitive regulation toward the common goal. Thus, SSMR is a more common effort toward achieving the joint learning goal.

1.2.1 The metacognitive regulation analysis framework

Previous research (De Backer et al., 2015; Iiskala et al., 2004; Volet et al., 2017) has conceptualized and empirically studied distinct forms of metacognitive regulation investigating the significance of regulation processes in collaborative learning. Based on this previous literature, metacognitive regulation is divided into four established categories to be used in analyses: verbalized metacognitive self-regulation (VMSR), ignored metacognitive regulation (IMR), metacognitive other regulation (MOR) and SSMR. In no metacognitive regulation, the group verbally expressed cognitive functions. The no metacognitive regulation category included, for example, reading, counting, or conducting the task without observable metacognitive regulation. In VMSR, a student regulated and referred to own-thinking. In IMR, a student attempted to regulate the group's thinking process, but that effort was ignored by the other students in the group. In MOR, one or many students regulated another student's, many students', or the group's thinking process. Finally, in SSMR, at least two students regulated the group's thinking process so that the metacognitive regulation was shared, complementary, and goal-directed. In SSMR coding, at minimum, two turns had to be coded as such (for details, see Iiskala et al., 2021). Most significant for research purposes is the manifestation of SSMR involving several group members' contributing to regulation of the joint cognitive activity. When regulated in a socially shared way, the learning process involves at least two students' regulatory involvement, as they interdependently affect the course of the cognitive learning process (e.g. Iiskala et al., 2004, 2011, 2015; Volet et al., 2013). The socially shared nature of metacognitive regulation has been argued to be crucial because it represents a genuinely collective effort to regulate the progress of the group's cognitive activity (Iiskala et al., 2004, 2011; Järvelä et al., 2013; Volet et al., 2009). Empirical research has shown that SSMR helps small groups develop a shared understanding of the task, and sustain ongoing knowledge co-construction. In the current study, the focus is on the interconnectedness of argumentation and SSMR; thus, SSMR coding is used to obtain the results.

Metacognitive regulation was divided into five categories: no metacognitive regulation (such as *"Just put it directly there so it grows..."*), verbalized metacognitive regulation (VMR, such as *"I understood this*), ignored metacognitive regulation (IMR; for example, in the following example, a student attempts to make the group stop to think about what they are thinking: *"What do we hypothesize?*"; however, no one reacts to this attempt.), metacognitive other regulation (MOR; in the following example, student 2 shows awareness of the answer "*No, but the answer is actually the other way around, because…*"; based on this metacognitive regulation, student 1 attempts to understand the thinking process—"*so, there is something…*"—and student 2 continues to making the thinking process visible*: "Yes, but if one looks at these, there are …"* so that the group continues based on student 2's metacognitive regulation and in line with this thinking process.), socially shared metacognitive regulation (SSMR; for example, student 2 said, *"So, can it be that the lowest pH… but we don't know what happens to…"*; student 1 continued, "*We should need more materials and deeper knowledge…";* in the example, the students together attempt to regulate their knowledge and become aware of having insufficient knowledge of the issue).

1.3 The Interconnectedness of Spontaneous Scientific Argumentation and SSMR

In previous studies (e.g., Panahandeh & Asl, 2014; Zheng et al., 2023), the results have indicated that the instruction of metacognitive learning strategies affect learners' argumentative writing skills. In other words, in that study, the argumentative writing ability of the students who had utilized metacognitive learning strategies surpassed that of the control group. Therefore, metacognition appears to be a significant predictor of written argumentation proficiency. Since implementing metacognitive strategies implies transferring certain responsibilities to learners, which in turn might increase the pressure on them—particularly on the less proficient ones—explicit and direct instructional modeling is, therefore, important. Argumentative writing is an important academic skill and the developmental cognitive processes of argumentative writing has thus been studied earlier in science education. The spoken form of argumentation in relation to SSMR has not been studied in the context of science education.

However, in science education and teaching, the interconnectedness of argumentation and metacognition has been studied (Hofstein et al., 2008). Consequently, a strong link between argumentation and metacognition has been found (Mason & Santi, 1994) in the form of four levels of reflection: awareness of what one knows, awareness of why one knows something, awareness of the knowledge construction procedure, and awareness of changes in one's own conceptual structure. In addition, the deepest steps of argument are connected to the higher level of metacognitive strategies. It is suggested (Schraw, 1998) that metacognitive regulation is accomplished if a student regulates cognition by planning, monitoring, and evaluating the learning task and, as a product of this process, forms an argument that is persuasive and includes adequate evidence and scientific principles. The laboratory-like environment has been especially proposed to coerce student to monitor one's knowledge to be able to construct an argument, bring about evidence to support one's arguments and find the appropriate scientific principle to the argument (Hofstein et al., 2008). Thus, the virtual learning environment could suit perfectly the needs of these ambitions. Moreover, it is suggested (Flavell, 2005; Flavell et al., 2001) that in presenting an argument one has to know about one's peer's knowledge on which the argument is based in order for the argument to be impactful. This is a metacognitive awareness component that is needed for metacognitive regulation (Schraw, 2001). Thus, it is important that the students are given a complex scientific task where they are provided opportunities to enable the abovementioned to occur.

As a continuation of this tradition, the study by Jin and Kim (2021) revealed that students continuously refined their knowledge of argumentation, particularly the norms of argumentation, through discussing and negotiating with group members. It was also noted that this development would continue of the students continued to participate in reflective argumentation by establishing their argumentative practice through social interactions with the teacher and other students as well as through metacognitive regulation. This is particularly true in complex problem-solving contexts, which developed students' performance in a science classroom as a community through argumentative practice and metacognitive regulation. In their review of research on metacognitive regulation in science education, Zohar and Barzilai (2013) emphasized that metacognitive strategies are often integrated with additional instructional interventions, such as collaborative learning, problem-solving, and inquiry learning; this implied that the specific contribution of metacognition cannot be easily isolated. The usual means to observe metacognitive regulation is by employing self-reported measures of metacognitive regulation as a source of data, thereby raising the need for controlled designs, which isolate the component of metacognitive strategy from other instructions and that pay more attention to the objective assessment of metacognition. Antonio and Prudente (2021) continued this line of work by investigating the effectiveness of the metacognitive argument-driven inquiry approach in developing students' conceptual understanding of antimicrobial resistance and argumentation skills. They drew three findings: students' conceptual understanding changed, students' argumentation skills significantly changed, and students' development of argumentation skills was evident after exposure to the approach. Therefore, students' development of conceptual understanding, argumentation, and metacognitive regulation was significant. Therefore, the present study aims at studying this interconnectedness which has not been carried out in this way earlier.

2. Research Questions

As described in the introduction, argumentation, metacognition, and their simultaneity is crucial for science learning. The ability to argue and use metacognitive regulation are important aspects in science teaching (Falvell, 2005; Flavell et al., 2001; Hofstein et al., 2008; Mason & Santi, 1994; Schraw, 1998), but both have not often been studied together in the same study setting. To offer a deeper understanding, they were selected as the foci of the present study. Scientific argumentation can enhance motivation (Andriessen & Schwarz, 2009), offer more interaction with peers (Weinberger et al., 2007), enable students to become aware of their peers' ideas (Schwarz & Baker, 2017), support content learning in several ways (Schwarz et al., 2009), as well as improve general argumentation skills, specific argumentation skills, and knowledge building practices (Walker & Sampson, 2013).

Therefore, in the present study, students' argumentation was analyzed using video data. In the context of a collaborative virtual learning environment, it is also more appropriate to discuss collaborative argumentation dialogue in which the participants may not primarily disagree with each other. For example, students may collaboratively develop reasons to support a scientific explanation that everyone can agree with or they may collaborate to use evidence to develop and refine their scientific explanation. Evidence is also naturally used in this situation to support their developing ideas. Thus, there is collaborative argumentation because the students are jointly participating in the construction of arguments. During the initial analysis of the students' spontaneous on-task argumentation, it was noticed that the chains of argumentation usually began with a question, which often included a claim. Then, the argumentation continued with one or more observations, which provided evidence or offered an interpretation that linked the claim or evidence to the theory.

On the other hand, the development of learners' conceptual understanding has been a focus of science education research, but the role of metacognition in developing students' understanding of science concepts still requires more research (Zohar & Barzilai, 2013). To evidence this, metacognitive regulation was analyzed from video data in the present study.

In any case, metacognition appears to be a significant predictor of deeper argumentation and discussion within a student group. This is because certain responsibilities are transferred to students, which in turn may increase the pressure on them to provide arguments (Panahandeh & Asl, 2014). As an open-end-task, the virtual environment can encourage students to reflect their arguments, ideas, and reasons, thereby promoting the development of students' understanding of the task goals and evidence-related norms of argumentation and abilities of metacognitive awareness during argumentation (Jin & Kim, 2021).

In particular, there is a gap in the knowledge of the interplay between metacognitive regulation and scientific argumentation. However, weak metacognitive regulation is demonstrated to be associated with lower academic success and argumentation (Santangelo et al., 2021). Based on the previous literature, the high- and low-performing groups do not differ that much with regard to no metacognitive regulation nor the proportions of different forms of metacognitive regulation (VMSR, IMR, MOR, and SSMR), but do differ qualitatively (Lobczowski et al., 2021). In both group levels, the discussion has been shown to be more group-related than task-related and the evaluation of collaborative learning will be rare; however, in the high-performing group, orientation toward success in the learning task as well as little or no off-task discussion may be observed (Vuopala et al. (2016). The low- and high-performing groups differ in the number of unique ideas introduced into the conversation, student responses to these ideas, challenges made by other students, the criteria the students used to distinguish among ideas, and the use of the available data (Sampson & Clark, 2011). However, with regard to SSMR, there is not much prior evidence on which to build upon the theoretical framework. Thus, it is still natural to think that SSMR would co-occur with argumentation.

In collaborative science learning settings, as in the present study, particularly the SSMR in relation to argumentation is of interest in understanding the development of conceptual understanding. Spontaneous argumentation and SSMR most likely alternate, as the students evaluate the data, argue over ways to accomplish the task, and interpret the results (Kalemkus et al., 2021). Students who make spontaneous argumentation also demonstrate metacognitive regulation (Marthaliakirana et al., 2022); thus, patterns of argumentation and metacognitive regulation should be following each other as students delve deeper into the task. The patterns in the groups will most probably be similar, but the quality of argumentative and regulative turns will be lower in the low-performing group than those in the high-performing group. Again, there is little to no prior literature on this topic.

As stated before, the interconnection of argumentation and metacognitive regulation has not been the central goal of prior studies. To fill these gaps in the literature and increase understanding of the common role of argumentation and metacognition, the following research questions have been formulated.

Research question 1 (RQ1). How does spontaneous argumentation and metacognitive regulation co-occur in small groups during the process?

Research question 2 (RQ2). How does spontaneous argumentation and SSMR co-occur between the high- and low-performing small groups?

Research question 3 (RQ3). What kinds of patterns of sequences do spontaneous argumentation and SSMR form during the process and between the high- and low-performing small groups?

3. Methods

3.1 Participants and the Collaborative Learning Context

Four groups with 12 students (4 boys and 8 girls; two three-girls groups, one three-boys group and one two-girls, one-boy group) aged 16–17 years were ultimately selected for the present study out of a bigger data set. The main criterion for selection of the four groups was that they had differing science outcomes (two high- and two low-performing groups). The following were the additional inclusion criteria: (a) How intact the groups remained over the entire activity—that is, over three different lessons; and (b) that the quality of the video data is sufficiently high to enable reliable analysis. In authentic educational circumstances, only the “best possible” option could be used, which implied that in one group, one member was absent from the final session. Data was collected during biology and chemistry lessons. This included biology compulsory, and chemistry compulsory courses; these were all arranged according to the Finnish national core curriculum. Therefore, the students had only basic knowledge of the topics and concepts discussed in the virtual collaborative tasks. All student activities for the present study involved performing experiments in the manner that scientists typically conduct them. The spoken argumentation and metacognitive regulation, in particular, SSMR were observed during the collaborative task in the virtual learning environment.

The students studied in groups of three in the virtual laboratory (Virtual Baltic Sea Explorer, ViBSE, built in the dominant science language—that is, English) on a shared laptop. These four student groups included a mix of different types of learners, established in collaboration with the teachers, to diminish individual differences. They were required to conduct a virtual experiment on the effects of pH on copepods in the Baltic Sea’s food chain. ViBSE was a platform installed on students’ laptops and comprised a library explaining the structure of the research and a scientific background of the phenomena, photos, interviews with the crew and researchers of the real research vessel (Aranda), laboratory tasks, and links to external web pages that provide real-time data of the Baltic Sea. This virtual exploration acquainted the students with the manner in which real scientists conduct research. The software emphasized hypotheses formation, the experimental phase, and interpreting the results. All the experiments were based on studies by real marine biologists. After completing the experiment, the students were asked to prepare a PowerPoint presentation that included the research plan, results, and conclusions, which was considered the outcome of collaborative learning. Thus, the collaborative inquiry project had three distinct argumentative phases: first, planning; second, experimenting; and third, drawing conclusions and reporting the results. At the outset of the ViBSE studies, the teachers were encouraged to promote the scientific argumentation in the student groups, but no explicit guidelines were provided to the teachers in this regard.

The virtual laboratory task was designed to foster argumentation. In planning and generating their written study and experimental plans, students had to discuss topics that they were not familiar with before the lessons and also had to decide on several key aspects of the experiment (e.g. pH and oxygen level). The teachers intervened and provided help only if the project was not progressing adequately and the group was having difficulty in a certain phase of the virtual study.

Two qualified science professionals in biology and chemistry evaluated the overall quality of the groups' PowerPoint presentations, taking into account the students' written research plan, hypotheses, understanding of the task and presentation structure, actual presentation, conclusions, and quality of the scientific language used in the presentation. To ensure reliability and quality of the outcome assessment, established assessment criteria were used to categorize presentations into six levels (graded from 1 to 6). According to the assessments, the student groups were divided into high-, average-, and low-performing groups (high = grades 5–6, average = grades 4–3, and low = grades 2–1). From groups with high- and low-levels of performance, the videos of two groups were selected for closer analysis in the present study. All the selected groups consisted of three students.

As part of the study courses, the actual virtual learning environment was implemented in three lessons. The spontaneous argumentation and metacognitive regulation were captured on video, and the three phases of the Virtual Baltic Sea Explorer lessons were then analyzed.

3.2 Coding of Data in Relation to Argumentation and SSMR

The video analysis proceeded so that three distinct, meaningful, and self-contained interaction segments (approximately 10–16 min) were selected from each of the four groups. The criteria for the selection were that the selected segments were crucial for task performance and completion, demanded student collaboration, and were representative of all three phases. Therefore, a science expert selected the video segments from the same steps of each phase of the study to ensure their comparability with each other. First, the videos were edited using the "MovieMaker" software. Subsequently, the videos were added into the Observer XT 12 software program as new observations. As the analysis focused on verbal communication among the students, the first stage of the analysis involved differentiating the verbal communication from the non-verbal communication. Instances of verbal communication were marked as "verbal," and the silent parts were marked as "non-verbal." The entire video was coded in this manner from beginning to end. After this categorization, the parts of the video with verbal communication were further analyzed. Thus, one verbal comment is regarded as one turn, which is then coded according to the coding scheme. After this preparatory analysis, the same data set was simultaneously coded by different experts with regard to argumentation and SSMR. These steps are addressed in the following sections and are summarized in Table 1.

Table 1

Flow Chart of Argumentation and Metacognitive Regulation, Coding, and Analyses of Data

1. Selection and editing of three distinct and self-contained interaction segments (approx. 10–16 min) from each of the four groups (high- and low-performing)
2. Transfer to Observer XT software for analyses
3. Differentiating verbal communication from non-verbal communication

4. Separate coding of argumentation and metacognitive regulation for the parts of the video with verbal communication

5. Coding and analyzing argumentation	5. Coding and analyzing metacognitive regulation
- Distinguishing argumentation from other verbal communication - Analyzing on-task argumentative verbal communication	- Distinguishing metacognitive regulation from cognitive activity (no metacognitive regulation) and SSMR from other forms of metacognitive regulation - Analyzing on-task metacognitive regulatory verbal communication

6. Merging of the coding and analysis schemes of argumentation and metacognitive regulation

3.2.1 Coding of Argumentation

The second stage of analysis after the preparatory first step described above involved distinguishing argumentation from other verbal communication. Each instance of communication was categorized as “off-task,” “on-task non-argumentative,” or “on-task argumentative.” The “off-task” category included student discussions of issues that were totally irrelevant to the topic at hand. For example, students discussed why the roof of a house across the street was red or what they had done on the weekend. The “on-task non-argumentative” category included students’ dialogues that were concentrated on scientific content and the task, but without scientific argumentation. For example, students discussed how to prepare a presentation, how to cut and paste a picture, or where to save their materials. The instances of verbal communication categorized as “on-task argumentative” were selected for closer analysis. All these codes were mutually exclusive, which implied that the codes could not occur simultaneously. In practice, inserting a new code automatically ended the previous one.

The third stage involved analyzing on-task argumentative verbal communication as questions, observations or interpretations according to the introduced framework based on Toulmin's (1958) argumentation theory, and modified to suit the observed virtual learning situation. Additionally, these three components were in line with the three phases of the task that the students implemented. The quality of argumentation in each of these components was evaluated based on the nature and function of the argumentation. The quality of argumentation in the "questions" was evaluated based on how well the claim included in the question fit the theory as well as on whether it led to the continuation of the argumentative chain. Thereafter, instances of communication categorized as "observations" were evaluated based on how strong and relevant the evidence was as well as whether it led to the continuation of the argumentative chain. "Interpretations" were analyzed based on how strong and relevant the link to theory was as well as on whether it led to the continuation of the argumentative chain.

Employing this analysis framework, the videos were coded by the first author of this paper, and parallel coding was performed by another science teacher with pedagogical competence. The percentage agreement of the coding was 81%, and Cohen's kappa was 0.713. Thus, the inter-rater agreement can be considered substantial (see Landis & Koch, 1977). The differences in analysis were discussed until a common agreement was achieved.

3.2.2 Coding of SSMR

Metacognitive regulation was coded from students' verbal communication based on the video recordings of the small groups' learning processes as argumentation coding. However, metacognitive regulation was coded independently from argumentation coding, which implies that the argumentation coding was not visible in the metacognitive coding. Moreover, the coder did not know which one of the groups was a high-performing or low-performing group. Further, in the present study, all off-task behavior was excluded from analysis; thereafter, each instance of verbal communication—that is, a student's spoken turn—was divided into five categories. In metacognitive coding, first, off-task behavior was omitted from analysis (see argumentation coding) and then, each instance of verbal communication—that is, a student's spoken turn, was categorized as no metacognitive regulation, VMSR, IMR, MOR, or SSMR (see Iiskala et al., 2021).

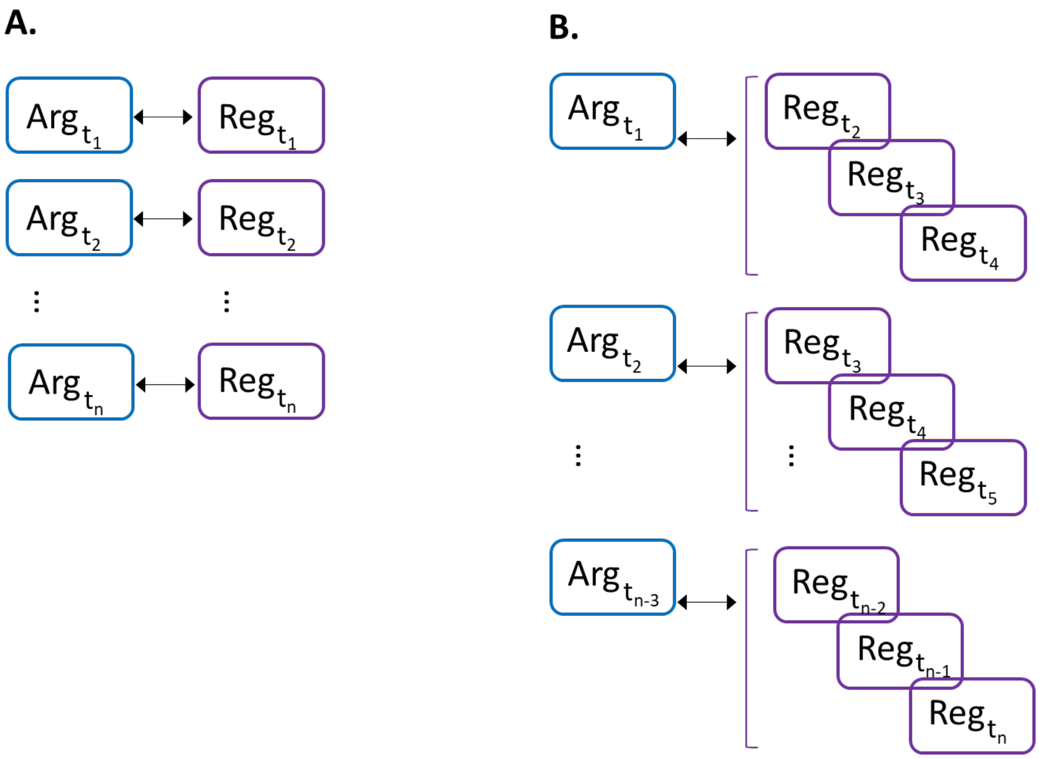
After the principal coder (the second author of the present paper) had finished the coding of two phases from two groups (one high- and one low-performing group), the inter-rater coded 26% of that data. The inter-rater agreement was 86.2% and Cohen's kappa was 0.75 (for details, see Iiskala et al., 2021), thereby indicating the substantial strength of agreement (see Landis & Koch, 1977). The principal coder coded the two last groups on the same principle as the two first groups. After all the coding was completed, argumentation and metacognitive regulation coding were scrutinized side by side.

3.3 Statistical Analyses

All the statistical analyses were performed using IBM SPSS Statistics 28. Associations between argumentation and metacognitive regulation were described and examined using two-way contingency tables (cross tables) including observed and relative frequencies. The Chi-square test of independence was conducted as a test for statistical significance of the association. In case of small expected frequencies in crosstabs ($e_{ij} < 5$), the Chi-square test was substituted with Fisher's exact test. As a follow-up analyses in situations with significant values of the Chi-square test (χ^2), Z-tests for differences between percentages were conducted, and Bonferroni adjusted Z-tests for differences between percentages were conducted when appropriate (i.e., the table with larger dimensions that 2 × 2 crosstabs). Z-tests give a detailed comparison of in which regulation categories percentual frequencies differ between different argumentation types. Effect size assessment—that is, the strength of the association—was performed in the form of Cramer's V and odds ratios (OR) with 95% confidence intervals. Cut-offs for the interpretation of Cramer's V were small, 0.10; medium, 0.30, and strong, 0.50—for example, a value with $0.10 < V < 0.30$ indicated small or weak interaction (Cohen, 1988). The effect sizes were used to evaluate how strongly the argumentation type affected on the incidence of different regulations without, however, any expressions on a causality between these phenomena. Analyses for associations between argumentation regulation and metacognitive regulation were first conducted for all time-points, as both argumentation and metacognitive regulation were examined at the same moment of time, t. Thus, this analysis gave information about the observations of argumentation and regulation from the same time point t_i, $i = 1, \ldots, n$ (from first to last). Then, the same kind of analysis was performed for the association of the argumentation at time t in relation to the metacognitive regulation at time-windows t_1 to t_3. Specifically, argumentation was observed at time t, whereas metacognitive regulation is observed in the time window t+1 to t+3 (next three turns after an observed argumentation at time t) to give an insight of how an instance of spontaneous argumentation provokes socially shared metacognitive regulation in the following three turns.

Figure 1

The dataset structure when treating argumentation in relation to metacognitive regulation at all time points. A describes argumentation and regulation occurring in different time points. B describes argumentation with the following three turns including different regulation.



Note. t_i is the i^{th} instance of communication in time sequence, i = 1, …, n (first to last). Arg = Argumentation, Reg = Regulation.

4. Results

Our results revealed that SSMR appears to coincide with spontaneous scientific argumentation, but this is not the case every time. This coincidence was partially predicted from the basis of previous literature. In particular, argumentative questions and observations are present when students begin a discussion that is coded as an instance of SSMR. Similar to the interconnection between deep argumentation and SSMR, it was noted that there are differences in terms of argumentation and metacognitive regulation between high- and low-performing groups. Low-performing groups are lacking both in terms of quantity and quality when it comes to argumentation and the same can be said of SSMR to a certain extent. However, discussion of scientific topics and tasks will lead to metacognitive regulation, as supported by the data that demonstrates that SSMR occurs even in the low-performing group. The results section is divided according to the three research questions.

4.1 Research Question 1: The Co-occurrence of Spontaneous Argumentation and Metacognitive Regulation in Small Groups During the Process

Spontaneous argumentation was observed both in the low- and high-performing groups from phase one to phase three and provided an overview of different forms of regulation that occurred as part of certain types of argumentation. Argumentation in all forms of metacognitive regulation at time t is presented in Table 2.

Table 2

Cross tabulation of argumentation at Time t in all Forms of Metacognitive Regulation. Z-tests were used to delineate statistically significant Chi square test results.

Argumentation at T	SSMR	MOR	VMSR	IMR	NoMr	Total
	n (%)	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*
Questions	31_a (41.3)	15_a (20.0)	0_a (0.0)	3_a (4.0)	26_a (34.7)	75 (100)
Reasons	79_b (21.2)	103_a (27.6)	1_a (0.3)	8_a (2.1)	182_b (48.8)	373 (100)
Total	110 (24.6)	118 (26.3)	1 (0.6)	11 (2.5)	208 (46.6)	448 (100)

Each subscript letter denotes a subset of argumentation at time t_i (the results of the Z-tests separately for each column): Questions vs. Reasons categories whose row proportions do not differ significantly from each other at the 0.05 level.

When comparing argumentation type questions to an argumentation type reasons that include observation and interpretation within all categories of metacognitive regulation, there was a statistically significant association between argumentation and metacognitive regulation (Fisher exact test, p = 0.003; V = 0.19). This result demonstrated that there is a relationship between different types of argumentation (questions and reasons) and metacognitive regulation, and this nature is further interpreted in the following sections under the different research questions. From Table 2, it is evident that the prevalence of the metacognitive regulation forms SSMR and NoMR was significantly different between different types of argumentation. However, the effect size of association was considered weak signaling, however, that the relationship between argumentation and metacognitive regulation was weak.

4.2 Research Question 2: The Co-occurrence of Spontaneous Argumentation and SSMR Between High- and Low-Performing Small Groups

In order to answer this research question, the same analysis as that for research question 1 was conducted but excluding the other forms of metacognitive regulation, except SSMR and no metacognitive regulation (no visible metacognition). The foci of the analysis was a comparison of high- and low-performing groups' argumentation and metacognitive regulation—that is, in the subgroups low and high. Therefore, the connection between argumentation and metacognitive regulation was first tested, and then the Chi-square test was performed for the crosstab. Thereafter, the same connection was tested separately in both groups low and high. Again, the Chi-square test was performed for the crosstab. When observing argumentation at different group levels, it was noted that the proportion of questions was slightly higher in high-performing groups (18.8% vs. 12.8%); however, this is not statistically significant (χ^2 (1, N = 448) = 2.64, p = 0.104; V = 0.08). In the case of metacognitive regulation, it is evident that the proportion of SSMR is significantly greater in high-performing groups (15.8% vs. 9.8%), which is statistically significant (χ^2 (1, N = 1900) = 14.86; p = 0.004; V = 0.09).

When comparing the question argumentation type to the reasoning argumentation type in SSMR and no metacognitive regulation, there is again a statistically significant association between these two argumentation types (χ^2 (1, N = 318) = 12.03, p < 0.001; V = 0.19;). The odds ratios revealed that the likelihood of SSMR was 2.75 times higher if argumentation was of the questioning type rather than the reasoning type (OR for SSRM when Q vs. R: OR = 2.75; 95% CI: [1.53; 4.93]). However, the frequency of no metacognitive regulation is almost double the size of SSMR. This is probably due to the mechanical nature of working in the virtual environment. These results are present when the reasoning argumentation type is found 182 times (69.7%) in no metacognitive regulation and 79 times (30.3%) in SSMR; the question argumentation type is found 26 times (45.6%) in no metacognitive regulation and 31 times (54.4%) in SSMR. These results powerfully proved that when students in high-performing groups ask topic-related questions they also socially regulate their learning. A result that was hinted in the interpretation of the research question 1 and now properly demonstrated.

Table 3

Cross tabulation of SSMR and No Metacognitive Regulation at Time t in Question and Reason Argumentation Types and Divided into Subgroups High and Low

Group performing level	SSMR	NoMR	Total
	n (%)	*n (%)*	*n (%)*
High			
Questions	25 (56.8)	19 (43.2)	44 (100)
Reasons	58 (35.8)	104 (64.2)	162 (100)
Low			

Questions	6 (46.2)	7 (53.8)	13 (100)
Reasons	21 (21.2)	78 (78.8)	99 (100)
Total	110 (34.6)	208 (65.4)	318 (100)

E.g. 56.8 % is calculated in the following way: (25/44)·100 %.

Then, when comparing the questioning argumentation type to a sum containing observation and interpretation in SSMR and no metacognitive regulation (Table 3) and considering the performance level of the groups, a statistically significant difference (χ^2 (1, N = 206) = 6.35, $p < 0.05$; V = 0,18) was found in the high-performing group. Odds ratios revealed that in high-performing groups, the likelihood of SSMR was 2.36 times higher if argumentation was of the questioning type than if it was the reasoning type (OR for SSRM when Q vs. R: OR = 2.36; 95% CI: [1.20; 4.65]). However, in the low-performing group, such a difference is not statistically significant (Fisher's exact test, $p = 0.079$; V = 0.19). In low-performing groups, the likelihood of SSMR was not significantly different for the questioning argumentation type as compared to that for the reasoning argumentation type (OR for SSRM when Q vs. R: OR = 3.18 [0.97; 10.49]). Moreover, again, there is a significant difference in the frequency of no metacognitive regulation when compared to the number of SSMR, which is almost half of the number of the latter. In low-performing groups there is a similar trend but clearly the questions are more related in situations where students do not start to socially regulate their learning.

4.3 Research Question 3: The Patterns of Sequences of Spontaneous Argumentation and Socially Shared Metacognitive Regulation During the Process and Between the High- and Low-Performing Small Groups

From here on, we interpreted the results in a time window of three turns, which is in accordance with a similar study setting of Kuvalja et al. (2014). Thus, argumentation is observed at time t, whereas metacognitive regulation is observed in the time window t_1 to t_3. Based on these statistical analyses, there is no statistically significant difference between the questioning argumentation type and the reasoning argumentation type when compared with SSMR and all other regulation forms at times t_1, t_2, and t_3 (χ^2 (1, N = 448) = 3.07, p = 0.080; V = 0.08; OR = 1.57, 95% CI:[0.95, 2.60]). Despite the impressiveness being close to significant, this result hinted that students socially regulate their learning when they are asking questions related to the scientific topic and, thus, engaging in argumentation.

When comparing the questioning argumentation type to a combined variable containing observation and interpretation (reasons) in SSMR and no metacognitive regulation, and taking into account the relative time in three turns, there is no a statistically significant difference (χ^2 (1, N = 291) = 1.31; p = 0.252; V = 0.07). The odds ratio was not significantly different from one indicating that the likelihood of SSMR was not significantly different for the questioning argumentation type as compared to the reasoning argumentation type (OR for SSRM when Q vs. R: OR = 1.42; 95% CI [0.78; 2.58]). This can also be noted in the frequencies of these two measures (Table 4), which are rather close to each other. In other words, these results are found in three time intervals when observation and interpretation argumentation types (reasons in the nomenclature of the present study) are found over 120 times in SSMR (50.6 %) and 117 times in no metacognitive regulation (49.4 %). Whereas in the same time interval, the questioning argumentation type is found 32 times (59.3 %) within SSMR and 22 times (40.7 %) within no metacognitive regulation.

Table 4

Cross tabulation of SSMR at Time t and No Metacognitive Regulation during Three Following Turns through the Whole Data in Questioning and Reasoning Argumentation

Group performing level	SSMR	NoMR	Total
	n (%)	*n (%)*	*n (%)*
High			
Questions	24 (63.2)	14 (36.8)	38 (100)
Reasons	85 (53.5)	74 (46.5)	159 (100)
Low			
Questions	8 (50.0)	8 (50.0)	16 (100)
Reasons	35 (44.9)	43 (55.1)	78 (100)
Total	152 (52.2)	139 (47.8)	94 (100)

Again, when comparing the questioning argumentation type to a combined variable including observation and interpretation (reasons) in SSMR and no metacognitive regulation, there is no statistically significant difference (χ^2 (1, N = 197) = 1.17, p = 0.28; V = 0.08) in the high-performing group when the relative time in three time intervals and the performance level of the groups have been taken into account. In high-performing groups, the likelihood of SSMR was not significantly different if the argumentation type was a question compared to a reason. In this case, in the low-performing group, such a difference is not shown (χ^2 (1, N = 94) = 0.14; p = 0.708; V = 0.04) either. In the low-performing groups, the likelihood of SSMR was not significantly different from the one indicating that the likelihood of SSMR was not significantly different for the questioning argumentation type as compared to the reasoning argumentation type (OR for SSRM when Q vs. R: OR = 1.23; 95% CI [0.42; 3.60]). These results further strengthen the viewpoint of argumentation and metacognitive regulation intertwined in collaborative learning, but also demonstrate that argumentation type questions is present in both SSMR and NOMR. This shows that the same type of argumentation can potentially to either lead or not to higher level metacognitive regulation.

4.4 Qualitative Examples of Student Discussion Revealing Spontaneous Argumentation and SSMR

In explaining the complex nature of this interrelation of spontaneous argumentation and SSMR, the results were supported by qualitative transcriptions of students' discussion during the three phases (planning, experimentation and conclusion) of the virtual learning intervention. The qualitative examples revealed how spontaneous argumentation and SSMR unfolded during the small group inquiry, thereby emphasizing the co-occurrence of argumentation and SSMR. In the following section, typical examples from both the discussion pertaining to both the high- and low-performing groups are provided in Tables 5, 6 and 7. These excerpts strengthen the statistical results as well as help to understand the nature of argumentative and metacognitive discussions among students within groups.

To summarize, in the high-performing groups, spontaneous argumentation and SSMR co-occurred, thereby supporting the statistical analyses. The virtual inquiry task requires the student to collaborate and consider their approach to the goal, and these small groups that achieved good outcomes engaged in spontaneous argumentation using appropriate concepts. Simultaneously, the students in these high-performing groups metacognitively regulated their learning, and the chains of argumentation and metacognitive regulation stretched even beyond these excerpts of transcriptions.

On the other hand, the low-performing groups had glimpses of metacognitive regulation in the beginning of each of these excerpts, but they did not continue this line of metacognitive regulation. On the contrary, they abruptly stopped the metacognitive regulation and just went through the step of the task in question. They even had spontaneous argumentation with questions containing claims, but this did not lead to argumentation chains that would have promoted their task performance, metacognitive regulation, and, ultimately, learning.

During small group work phase 1 (Table 5), the students of the high-performing group are checking and metacognitively regulating their understanding of the topic right before writing the hypothesis. Simultaneously, they are arguing on the form of the hypothesis with questions; most importantly, the other students grasp these questions and this leads to both metacognitive regulation and better performance in relation to the task. This excerpt reveals that they are also continuing the metacognitive regulation process later, which is evident from the fact that they do not write the hypothesis right away but continue to regulate their learning. In contrast, the student of the low-performing group initially attained metacognitive regulation before beginning to write the hypothesis by selecting their hypothesis and being aware of the difficulty of the task. But then it all came down to writing their hypothesis without thinking, which is characterized by metacognitive regulation. It appears that the metacognitive regulation did not have any effect on the writing of the hypothesis. In addition, spontaneous argumentation was observed in the form of questions hinting to possible claims, but the other students did not adhere to these; this evidently terminated the discussion. Thus, the argumentative and metacognitive regulation chains did not continue.

Table 5

Qualitative Example of Differences between High- and Low-Performing Groups during Phase 1

High-performing group	Low-performing group
(S2): "So, when the pH is lower…" S1: "Yes, that's exactly what I'm thinking." S2:	S3: "What was our first hypothesis again?" S1: "The first assumption?" S2: "Or the best alternative?" S1: "It's difficult

"So, when they are hatching, the pH is lower." S1: "I think we can phrase it as our hypothesis." S3: "Yes, let that be our hypothesis.	to say." S3: "That doesn't affect… Oh, that's really good" S1: "That doesn't affect it at all." S1: "Maybe we just put all the values to be too high." S1: "Unless that value goes down when those are eating these?"

During the excerpt in phase 2 (Table 6), the students of the high-performing group stop to check on their study setting and consider which things they should take into account and which pieces of knowledge they are missing. It appears that they continue to metacognitively regulate even later on. The spontaneous argumentation is clearly evident in students' discussions, as they are pondering on the number of bottles in relation to completing their task in the best scientific way possible. Therefore, it is evident that metacognitive regulation and argumentation co-occur in the student discussion during this phase. Contrariwise, the students in the low-performing group stop to metacognitively regulate if their understanding on the topic is accurate, but then later it appears they form the hypothesis rather randomly. In terms of argumentation, questions are present but the students do not combine their answers with scientific knowledge. Instead of the integration of scientific concepts, they merely state their ignorance and leave it that way.

Table 6

Qualitative Example of Differences between High- and Low-Performing Groups during Phase 2

High-performing group	Low-performing group
(S3): "Don't we need to choose a bottle first, right? Quite a lot of bottles we have here…" S1: "It affects how many bottles we choose as well." S3: "Yeah, that's exactly how many bottles we want to compare	S3: "Are they now those?" S2: "Are these for sure?" S1: "But we are not sure." S3: "Hah, not for sure… nothing is sure" S1: "But it feels funny that… or I don't know, I have never dug into this." S3: "Me

with each other." S1: "Yes, how many bottles it requires." S3: "I doubt there is any point in including too many bottles in the analyses." S2: "Not too many, perhaps three at least. Then it would be easier to observe the results, since we don't know the values.	neither, seven is the water." S1: But it's clear water." S3: "Yeah it is. That's like there would be salt and…" S2: "It's difficult to say how much carbon dioxide is dissolved in the water." S3: "That has an effect on it as well."

During small group work phase 3 (Table 7), the students in the high-performing group stop to think about how they understand the results. It appears that they metacognitively regulate their understanding of the results as they write them down. Yet again, the students resort to several questions in their spontaneous argumentation, which creates a basis for high-level metacognitive regulation and performance in the task. Then, the students in the low-performing group stop to metacognitively regulate their work according to the goal that is set for them. It is evident that they know that the process does not meet the goal. Thereafter, they metacognitively regulate their understanding in the sense of the content, but then begin to write and describe what they have done. This excerpt clearly shows that they are unable to transfer this situation to the context of a research vessel. However, this is more striking for spontaneous argumentation, as they ask a few questions but the questions are not answered with the use of scientific concepts and knowledge. Therefore, the students list phenomena that come to their mind without binding them to the task and through that engage in metacognitive regulation.

Table 7

Qualitative Example of Differences between High- and Low-Performing Groups during Phase 3

High-performing group	Low-performing group
S1: “Aren’t the biological changes in ocean be the product of human activity and emissions?” S2: “Or does that mean the process in which animals are decomposing dead things?” S1: “But doesn’t that cause loss of oxygen, which is then a different thing from oxygen and the rise in pH?” S2: “Well… I don’t know. Or then they are releasing some toxins that cause acidification.” S1: “That’s okay.”	S1: “If we need to answer what would really have happened on a vessel, I don’t have a clue.” S3: “Yeah, not really.” S1: “No, this leads nowhere.” S3: “Dissolves in water… that is good.” S3: “Are there some other proposals?” S2: “What?” S3: “How do these affect? These … agriculture and nutrition?” S1: “What substances there might be then… in excrement?” S2: “Those methane gases.” S3: “And then there are some plants… And then there is the cyanobacteria… But it doesn’t increase the amount of oxygen in water.” S1: “Yeah.” S3: “Nothing, and then the next question.” S1: “And it drops. Then it basically destroys them... the cloudiness of water prevents the plants from growing in the bottom by taking away the light.” S3: “That’s right. Write it... the nutrition.”

To conclude the presentation of the qualitative examples, the high-performing group appears to have attained metacognitive regulation in all the three steps. They check on their understanding of the topic, and know what is crucial to understand in order to learn. In addition, more importantly, this regulative process continues. In contrast, the low-performing group occasionally attains the metacognitive awareness and shows that the members are aware of the difficulty and uncertainty of the task. However, it does not appear to affect their cognitive activity. The metacognitive regulation of the weak performing group mostly occurs on a more general level than that of the high-performing group. Most importantly, these qualitative excerpts demonstrate that students in both the high- and low-performing groups ask questions, which is the first part of spontaneous argumentation; thus, they reveal traces of metacognitive regulation, but there is a significant difference in the quality and in the manner that the discussion unfolds. Unfortunately, due to this aspect, the difference in not statistically significant in the descriptive analyses.

5. Discussion

In the present study, the focus was on the interconnection between spoken spontaneous argumentation and different forms of metacognitive regulation, mainly SSMR. This was observed from the perspective of the three research questions, which delved into different aspects of this possible connection. The research questions yielded interesting results of which some have not been demonstrated before and which therefore require discussion.

The first of the main results were that spontaneous argumentation connected to SSMR occurred both in the high- and low-performing groups over all three phases of collaborative small group inquiry. More importantly, the SSMR was strongly connected to the questioning argumentation type. This implies that when asking questions on how to proceed with the task and the topic, students in both groups also socially regulated their learning. As explained in previous literature (De Backer et al., 2020; De Backer et al., 2022; Lobczowski et al., 2021), metacognitive regulation is a predictor of deeper argumentation and discussion in the student group. This is due to certain responsibilities being transferred to students, which in turn might increase the pressure on them to argue and thrive to be successful in their learning task. As an open-ended task, the virtual environment encouraged students to reflect on their arguments, ideas, and reasons, thereby promoting the development of students' understanding of the task goals, argumentation, and metacognitive regulation (Panahandeh & Asl, 2014; Jin & Kim, 2021) Thus, it was expected and found that metacognitive regulation and spontaneous spoken argumentation co-occur when students are preforming their task. Other forms of metacognitive regulation (i.e., not achieving SSMR) was expected to be associated with lower group performance and argumentation in relation to the task.

Second, the high-performing groups distinctly differ in relation to the questioning and reasoning argumentation types (sums up observation and interpretation) in SSMR and no metacognitive regulation. However, the effect size of the association of no metacognitive regulation was almost double the size of SSMR. This division was also supported by the nature of the phases and the virtual learning environment. Interestingly, as opposed to the expectations of the previous literature, the high- and low-performing groups differed somewhat in terms of the proportions of different forms of metacognitive regulation as well as qualitatively (Santangelo et al., 2021; Lobczowski et al., 2021; Vuopala, et al. 2016; Sampson & Clark, 2011).

Third, there is a statistically significant difference between the questioning argumentation type and reasoning argumentation type when compared with SSMR and all other forms of metacognitive regulation. Therefore, students socially regulated their learning when asking questions related to the scientific topic and, thus, engaging in argumentation. Spontaneous argumentation and SSMR were observed as alternating in all student groups in both high- and low-performance levels, as the students evaluated the data, argued over ways to accomplish the task, and interpreted the results for their presentation. Students engaged in spontaneous argumentation, demonstrating and arousing metacognitive regulation; thus, patterns of metacognitive regulation and argumentation were closely interconnected, but were independent of the group's performing level. The patterns were rather similar at the both group levels, but the quality and number of argumentative and metacognitively regulative turns was lower in the low-performing groups than that in the high-performing group. The results were well in line with the previous results, even though the study setting here was different (see Kalemkus et al., 2021; Marthaliakirana et al., 2022).

The qualitative examples of student small-group discussions were vital for understanding the differences in the ways the students engaged in scientific argumentation and metacognitive regulation between the high- and low-performing groups. Since the same components were present in both performance-level groups, the statistical analyses could not differentiate between co-occurrence and relationship in the form of providing statistically significant results. This finding was supported by previous literature (Vuopala et al., 2016).

Therefore, the present study revealed that the spontaneous argumentation type question is statistically significantly related to all forms of metacognitive regulation, in both the high- and low-performing groups. One thing that requires discussion is that when asking questions related to the task, the students also need to regulate their learning. The questions, as presented in the previous study (Telenius et al., 2021) offer an outstanding basis for spontaneous scientific argumentation, which is proven to be prolific for metacognitive regulation as well. Moreover, when taking account of the groups' performance levels and the different phases of the virtual inquiry task, it was demonstrated that the students in the high-performing groups could engage in deeper scientific argumentation and SSMR. Nevertheless, there is a clear difference between the frequencies when mapping out the patterns of argumentation and metacognitive regulation, and these are not merely statistically significant. Despite the statistically insignificant result, it is obvious that the high- and low-performing groups are different when it comes to the metacognitive regulation of learning and practicing spontaneous argumentation. This difference was impactfully revealed in the qualitative examples of student discussions, as both the group levels share the same features; however, in the high-performing group, the quality of argumentation and metacognitive regulation is much higher as is the duration of argumentative and metacognitively regulative chains. Moreover, while asking questions and selecting a hypothesis, the students revealed their thoughts about the question and topic, which enabled metacognitive regulation, as supported by the results of previous literature (Hoffstein et al., 2008).

In terms of practical implications, the learning environment should be designed to scaffold not only scientific argumentation but also SSMR. For example, students could be supported in asking topic- and task-related questions as they were related to metacognitive regulation, which is adequate for science learning. In contrast, as the qualitative examples demonstrated, metacognitive regulation does not guarantee practical procedures without content knowledge that introduces the significance of scientific argumentation into the equation. The current setting of not explicitly structuring it appeared to still arouse instances of spontaneous argumentation and metacognitive regulation; thus, with subtle hints and structures, the scientific process of knowledge acquisition and development could be made visible to students.

6. Conclusion and implications

The spoken, spontaneous argumentation combined with SSMR should be more thoroughly studied, particularly in the context of science education. The present study is one of its kind in terms of integrating scientific argumentation and metacognitive regulation while the discussion naturally unfolds during a virtual inquiry task. Therefore, the present study manages to extend the understanding of the interrelation of scientific argumentation and metacognitive regulation in science education. This has a great potential to benefit science teaching and scientific education, as it has been rarely studied before. In particular, argumentation is rarely combined with metacognitive regulation (Hoffstein et al., 2008), and that status is still unchanged especially when it comes to a social context instead of individual learners and different forms of metacognitive regulation like presented in the current study. The present study clearly shows that high-performing groups can regulate their learning in a situation in which they spontaneously need to argue over a topic they are not already familiar with. Therefore, the setting in which the students needed to study the topic and begin discussing and working on it subsequently was suitable for promoting spontaneous argumentation and SSMR. While studying a convoluted ensemble that collaborative learning is, it is inadequate to scrutinize a phenomenon, like argumentation by itself, but their interaction and co-occurrence.

Thus, the joint scaffolding of spoken spontaneous argumentation and SSMR is crucial for achieving the goals set for science education. This promotion could be further strengthened by inserting intermediate stops where students would need to discuss the following steps of the task, what they have collectively learned and how to augment their learning. These short breaks could be implemented in the virtual learning environment without breaking the flow of the collaborative work. Through these intermediates, the learning process and goals would again be pronounced for the learners. The other way to achieve this same effect would include the teacher checking on students' learning and steering the discussion towards students regulating their own learning and thus promoting their argumentation. Along with these implementations, the combination of argumentation and SSMR within ambivalent and multidisciplinary topics potentially provides students with training of scientific reasoning skills and preparedness to participate in socio scientific discussions (Bruckermann et al., 2023). In all, the present study sets an intriguing basis for following studies and developing the joint observation of argumentation and metacognitive regulation further.

Further studies should focus on the role of metacognitive regulation, particularly SSMR, in science education as implementing metacognitive regulation could improve the learning outcomes of science courses. Students could for example set their learning goals, strategies to achieve that goal and assess their outcomes mirroring their initial goals. Science teachers on the other hand could for example model their own thought and explain their own thinking processes alongside promoting metacognitive talk related to learning objectives. Especially, including the behavioral instances in addition to spoken ones in further argumentation and metacognitive regulation analyses would be ponderable, and provide valuable information for science education.

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