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Cross-section of small student group argumentative and metacognitive discussion

Marko Telenius

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University of Turku

Faculty of Education
Department of Teacher Education and Centre for Learning Research
Educational Sciences
Doctoral programme on Learning, Teaching, and Learning Environments Research

Supervised by

Professor Emerita Marja Vauras
Department of Teacher Education
Centre for Learning Research
University of Turku
Finland

University Lecturer Veli-Matti Vesterinen
Department of Chemistry
University of Turku, Finland
Department of Education
University of Helsinki
Finland

Docent Eija Yli-Panula
Department of Teacher Education
Centre for Learning Research
University of Turku
Finland

Reviewed by

Professor Emerita, Maria Pilar Jimenéz-Aleixandre
Faculty of Education
University of Santiago de Compostela
Spain

Professor Emerita, Anastasia Efklides
School of Psychology
Aristotle University of Thessaloniki
Greece

Opponent

Professor Emerita, Maria Pilar Jimenéz-Aleixandre
Faculty of Education
University of Santiago de Compostela
Spain

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ABSTRACT

Research on scientific argumentation in collaborative learning has recently emphasized written argumentation in a very structured context. This dissertation aims to widen the perspective by viewing spoken argumentation in a spontaneous setting supported by a virtual learning environment. The purpose of the dissertation is also to study socially shared metacognitive regulation in a virtually enhanced setting where students spontaneously argument over topics prompted by the virtual environment. There is quite a few research delving into this interconnectedness of spontaneous scientific argumentation and regulation. Participants were 120 students in six high schools and their 19 small groups (56 students). A mixed-method approach was used consisting of analyses of small group outcomes, pre- and posttest results, systematic video observations and statistical analyses and case studies.

In Study I, the aim was to prepare ground for the virtual environment developed by our own research team. At the same time this preliminary study highlighted the characteristics of spontaneous spoken argumentation in the context of virtual collaborative learning. In Study II, the aim was to establish and justify the coding category for spontaneous spoken argumentation while using the virtual learning environment developed by the research team. In study III, the main goal was to observe spontaneous argumentation in relation to socially shared metacognitive regulation both in time and in contents. Study IV continued further on reviewing the different definitions and categories used for argumentation but in relation to geography. The results showed that high performing groups managed to argue and regulate their collaborative work at a higher level than the low performing groups. The virtual learning environment and assignments were demonstrated to promote students' awareness of their argumentation skill, metacognitive regulation and science learning.

KEYWORDS: Collaborative learning, virtual learning environment, argumentation metacognition, computer-supported learning, inquiry learning

TURUN YLIOPISTO
Kasvatustieteiden tiedekunta
Opettajankoulutuslaitos ja Oppimistutkimuksen keskus
Oppimisen, opetuksen ja oppimisympäristöjen tutkimuksen tohtoriohjelma
MARKO TELENIUS: Argumentaatio virtuaalisessa yhteistoiminnallisessa oppimisessa: Läpileikkaus pienryhmien argumentatiivisesta ja metakognitiviisesta keskustelusta
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TIIVISTELMÄ

Tieteellisen argumentaation tutkimus yhteistoiminnallisessa oppimisessa on viime aikoina painottanut kirjoitettua argumentaatiota hyvin jäsennellyssä kontekstissa. Tämä väitöskirja tähtää näköalan laajentamiseen tarkastelemalla puhuttua argumentaatiota spontaanissa asetelmassa, jota tukee virtuaalinen oppimisympäristö. Väitöskirjan tavoite on myös tutkia sosiaalisesti jaettua metakognitiivista regulaatiota virtuaalisesti tehostetussa asetelmassa, jossa opiskelijat spontaanisti argumentoivat virtuaalisen ympäristön syöttämistä aiheista. On melko vähän tutkimusta, joka kaivautuu spontaanin tieteellisen argumentaation ja regulaation väliseen yhteyteen. Osallistujia oli 120 opiskelijaa kuudesta lukiosta ja heidän 19 pienryhmäänsä (56 opiskelijaa). Tutkimuksessa käytettiin monimenetelmällistä lähestymistapaa, joka koostui pienryhmien lopputuotoksista, alku- ja lopputesteistä, systemaattisista video-observaatioista ja tilastollisista analyyseistä sekä tapaustutkimuksista.

Tutkimuksen I tavoitteena oli pohjustaa tutkimusryhmämme oman virtuaalisen ympäristön kehittämistä. Samaan aikaan tämä alustava tutkimus alleviivasi spontaanin puhutun argumentaation erityispiirteitä virtuaalisen yhteistoiminnallisen oppimisen kontekstissa. Tutkimuksessa II tavoite oli puolestaan vakiinnuttaa ja perustella spontaanin puhutun argumentaation koodauskategoria samalla, kun käytettiin tutkimusryhmän kehittämää virtuaalista oppimisympäristöä. Tutkimuksen III päätavoite oli havainnoida spontaania argumentaatiota suhteessa sosiaalisesti jaettuun metakognitiiviseen säätelyyn sekä ajallisesti että sisällöllisesti. Tutkimus IV jatkoi edelleen erilaisten argumentaation määritelmien ja kategorioiden arviointia, mutta suhteessa maantieteeseen. Tulokset osoittivat, että hyvin suoriutuvat ryhmät kykenivät argumentoimaan ja säätelemään yhteistoiminnallista työskentelyään korkeammalla tasolla kuin heikosti suoriutuvat ryhmät. Virtuaalisen oppimisympäristön ja tehtävien osoitettiin edistävän opiskelijoiden tietoisuutta argumentaatiotaidostaan, metakognitiivisesta säätelystä ja luonnontiedeoppimisesta.

ASIASANAT: Yhteistoiminnallinen oppiminen, virtuaalinen oppimisympäristö, argumentaatio, metakognitio, tietokoneavusteinen oppiminen, tutkiva oppiminen

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In Lieto, May 2025

Marko Telenius

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List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Telenius, M., Yli-Panula E., Ahtineva, A. & Vauras, M. (2019). Collaborative science lessons—Learning and argumentation in an interdisciplinary virtual laboratory. *Tutkimuksesta Luokkahuoneisiin. Suomen Ainedidaktisen Tutkimusseuran Julkaisuja; Rautiainen, M., Tarnanen, M., Eds,* 15, 35-56. http://hdl.handle.net/10138/298542

II Telenius, M., Yli-Panula, E., Vesterinen, V.-M., & Vauras, M. (2020). Argumentation within Upper Secondary School Student Groups during Virtual Science Learning: Quality and Quantity of Spoken Argumentation. *Education Sciences,* 10(12), 393. https://www.mdpi.com/2227-7102/10/12/393

III Telenius, M., Iiskala, T., Laakkonen, E. & Vauras, M. (2025) The interconnectedness of spontaneous scientific argumentation and socially shared metacognitive regulation between high-outcome and low-outcome small groups in virtual collaborative science learning process. *The Journal of Research in Science Teaching*, 0:1-19. http://doi.org/10.1002/tea.70004

IV Yli-Panula E., Jeronen E. & Telenius M. (2021). Argumentaatiotaitojen harjoittaminen ekosysteemiopetuksessa: aiheena yhteiskunnallis-luonnontieteelliset ilmiöt. [Practicing argumentation skills in ecosystemic teaching: socio-scientific issues as a topic] E. Luukka, A. Palomäki, L. Pihkala-Posti & J. Hanska (Eds.), *Opetuksen ja oppimisen ytimessä*, 222-251. Suomen ainedidaktinen tutkimusseura. http://hdl.handle.net/10138/333969

1 Introduction

The foundation of all scientific inquiry is the assumption that scientific ideas must be approved and are thus subject to change. Therefore argumentation between scientists is necessary in advancing scientific knowledge and enabling other scientists to examine the same evidence and data, repeat experiments previously conducted, and reproduce research results to confirm or reject possible explanations. Scientific argument is defined as arguments over scientific explanations (i.e. claims), using empirical data (i.e. evidence). A scientific argument is thus a process that scientists follow in their activities. To support the argument, evidence must be presented, and this evidence is then thoroughly tested (Belland, et al., 2015). Therefore in science education, argumentation involves understanding texts, analysing and evaluating critical material, and generating hypotheses (Norris & Phillips, 2003). Argumentation also plays an important role in the natural sciences because it presents, supports, refines, and evaluates scientific knowledge. Argumentation is about making decisions and conclusions by means of logical reasoning (Belland, et al., 2016). It also emphasizes the ability to discuss educational and scientific topics (Sampson & Clark, 2008). Argumentation is at the heart of all science, it is important to integrate scientific argumentation into science teaching. Over the past three decades the number of publications around argumentation has rapidly increased (Henderson, et al., 2018). The foci of the studies have been on supporting students in argumentation through developing argumentation curriculum (McNeill, 2009), instructional strategies (Osborne, et al., 2004), and technology tools (Sampson & Clark, 2008). Other foci have been on supporting pre-service (Erduran, et al., 2006) and in-service teachers (Knight, et al., 2013) with the main weight in integrating argumentation into teachers' instruction. There are also studies on assessment, especially in student engagement in argumentation (Osborne, et al., 2013) and teachers' beliefs and knowledge for scientific argumentation (Sampson & Blachard, 2012).

These trends in science education also reflect the grander paradigm change that places the student, collaborative learning, constructing knowledge together and deep learning with the help of digital tools at the core of the curriculum (Giri & Paily, 2020). This orientation is nearly an exact opposite of the previous trend of emphasising transmission of knowledge, which made science in students' minds a subject in which there are right and wrong answers and where data lead to clear conclusions that do not allow for student discussion or argumentation. This point of view can mislead students to regard science and science knowledge as completed products that can only be learned by heart and that are not prone to questioning (Driver, et al., 2000). Traditional science education thus has not enabled students to develop the ability to argue scientifically. With the new trend the ability to formulate arguments and have discussions based on evidence and results is seen as central for science education. This paradigm change has led scientific argumentation to become a concept as a pedagogical practice and core competency (Faize, et al., 2017) that has globally attained emphasis in school science. As argumentation has many advantages in the context of science education and learning, the new emphasis is on integrating and teaching argumentation to the students. Thus, the interest in argumentation for science teaching and learning has been steadily growing.

However, there are few to no studies in the previous science education literature on spoken spontaneous argumentation or the interconnectedness of argumentation and socially shared metacognitive regulation (SSMR). Hence, the aim of this dissertation is to broaden the understanding of spontaneous argumentation in the context of virtual collaborative learning, to develop an argumentation framework for analysis of spoken spontaneous argumentation, and to provide ways to implement argumentation fostering learning conditions. Simultaneously, the dissertation scrutinises the manifestation of SSMR in relation to science learning and spontaneous spoken argumentation. However, the leitmotif is scientific spontaneous argumentation and its various instances from different perspectives. This dissertation therefore aims to elucidate these aspects of this broad field of research as well as bring new knowledge to the body of literature around argumentation.

1.1 Framing spontaneous spoken argumentation in science education

Scientific argumentation is defined as the attempt to establish or prove a conclusion on the basis of reasons and the scientific community's values and criteria (Norris, et al., 2007). Scientific argumentation is also a method and process of reasoning in which the arguments are gatekeepers for the correctness of the final conclusions (Duschl & Osborne, 2002) and a way to draw conclusions based on their conceptual understanding of the topic and generate statements in support of scientific knowledge claims (Driver, et al., 2000). Therefore scientific argumentation follows a strict structure and can typically be analysed using a formal framework. Spontaneous argumentation by contrast, refers to the natural form of argumentation in which case students are not given explicit instruction about relying on argumentation (Telenius et al., 2020; Vienrot, 1979). Thus, in the context of spontaneous argumentation, the focus is on the arguments that require the knowledge of content to be understandable and involve the use of subject matter (i.e. chemistry and biology in the case of this dissertation). Spontaneous argumentation like this is not common in the classroom because students are not given many occasions to discuss scientific issues, relate data or generate hypotheses. In learning aspects of science and the way scientists work, spontaneous argumentation plays an important role. When combining these two sides of argumentation – scientific and spontaneous – a platform of great potential for promoting students' science learning can be achieved.

Argumentation is typically understood to contain both written and spoken products. The spoken products are often transferred to transcriptions which once again puts them in a written form (Jiménez-Aleixandre, et al., 2000). That is, an argumentative product is a reasoned piece of discourse in which a claim has been justified (Berland & McNeill, 2010). Since Driver, Newton and Osborne (Driver, et al., 2000) introduced argumentation as an important discursive practice, however, written scientific argumentation has received more focus in recent papers. Thus, spoken argumentation is defined as a sole interdisciplinary and discursive piece of discussion that contains a claim and an evidence - a possible explanation or a connection to the theory of the subject matter being discussed (Kuhn, 2010).

Because the argumentative process focuses on the social interactions between participants (Berland & McNeill, 2010), it is natural to observe students' argumentation in its spoken form. The recent focus on the role argumentation supports this definition as the recent orientation strives to recognise the importance of social meaning construction with the use of language (Mortimer & Scott, 2003). The demand is for studying students' participation in debates and argumentation including other forms of communication and communicative resources (Erduran & Jiménez-Aleixandre & Erduran, 2007). Against this background, several studies have focused on the analysis of argumentation in various educational contexts (Driver, et al., 2000; Duschl, et al., 1999; Forman, 1992; Kelly & Takao, 2002). In these earlier studies, students were typically given instructions for argumentation and prompts to argue.

Much of the earlier research on argumentation has focused on written arguments or arguments constructed by a single speaker (Toulmin, 1958). Therefore, the focus has been on the evidence and reasons with which writers or speakers support their claims (Chinn & Clark, 2013) rather than on the collaborative nature of argumentation. This so-called collaborative argumentation refers to an interchange of statements, questions, and replies in a dialogue involving two or more participants (van Eemeren, et al., 2004). Participants in this kind of dialogue typically make claims and support them with reasons. The participants may or may not disagree and try to resolve the disagreement. It is also more appropriate to discuss collaborative argumentation dialogue in which the participants do not disagree with each other (Toulmin, 1958). For example, students may collaboratively develop reasons to support a scientific explanation that all can agree with or use evidence to develop and refine their scientific explanation. Evidence is also naturally used in this situation to support their developing ideas. There is thus collaborative argumentation as the students jointly participate in the construction of arguments.

In the studies in this dissertation, argumentation is observed mainly in its spoken form benefitting from the findings of previous literature and to support a spontaneous, more natural style of argumentation. The studies in this dissertation analyse argumentation based on students' spontaneous interdisciplinary discussion in the context of a collaborative virtual learning environment. Therefore, the spoken argumentation in this dissertation is not seen as a continuation to earlier studies (e.g. Lemke, 1990) in which spoken argumentation was seen as students talking about science or students' rhetorical dialogue to persuade other listeners by using a form of argumentation. This dissertation focuses on students' spontaneous discourse in learning, presenting an original view on the nature of students' argumentation in real-life collaborative learning, where it naturally departs from the features of the virtual learning environment, the adopted researcher role of students, and the need to produce a common product and agreement on the topic. To the best of my knowledge, no studies have addressed these issues. Preliminary studies have found that students' argumentative interdisciplinary discussions occurred spontaneously in the context of collaboratively generating hypotheses and study plans and that students were able to integrate biological and chemical concepts when studying a complicated virtual environment, which was a new learning environment for them (Telenius, et al., 2020). They were also able to independently transfer their knowledge from the virtual environment (Yli-Panula, et al., 2015) which is a driving force of collaborative discussion and argumentation in education. In this study, students' argumentation was analysed using video data. Therefore, in this dissertation, scientific argumentation is framed as spontaneous spoken argumentation to set it apart from earlier literature by emphasising the spoken nature of student argumentation and the fact that the learning situation was not structured specifically to encourage students to argue.

1.2 The effects of scientific argumentation on learning

As student participation in scientific argumentation enhances students' conceptual, epistemological, and methodological understanding about science, it is an important factor in the process of scientific inquiry (Sampson & Blanchard, 2012) and in engaging in science as an argumentative practice, which can promote students' critical and higher-order thinking skills, reflection, and evaluation of evidence (Jiménez-Aleixandre & Erduran, 2007). The pedagogy of scientific argumentation can therefore promote higher-order thinking skills such as critical thinking, but yet it is perceived as challenging by science educators (Simon, et al., 2006).

Hence, argumentation is part of the critical discourse intertwining natural science's process of producing and refining new knowledge (Lakatos, 2015). Students' ability to participate in argumentation is a crucial component of understanding scientific topics and one of the key goals of science education (Sadler, 2004; Jiménez-Aleixandre & Puig, 2012). Argumentation in science education supports adopting research patterns in scientific culture and engagement in science learning in addition to learning contents of science (Driver, et al., 2000; Duschl & Osborne, 2002).

Accordingly, argumentation is a basic skill in scientific literacy (Sadler, 2004). Furthermore, if students are given an active role to build knowledge based on their observations and ideas (Engle, 2012), they demonstrate scientifically orientated productive disciplinary engagement (PDE) instead of classroom-like PDE (Meyer, 2014, see also Koretsky, et al. 2019).

Collectively, argumentation in science education (Erduran, et al., 2005) can have a positive impact on at least five educational areas: motivation, content learning, general argument skills, specific argumentation skills, and knowledge-building practises. In general, the benefits of argumentation are classified as cognitive, situated (Nolen, et al. 2015), or sociocultural (Jiménez-Aleixandre, et al., 2000; Schwarz, 2009). The situative view of spoken argumentation is fitting, as engagement is naturally embedded in social contexts transpiring from the goals and practises of the scientific discipline (Nolen, et al., 2015). A cognitive category of the benefits focuses on individual learning especially in terms of improved representations. Situative and sociocultural categories embrace social practises of learning that take the form of argumentation. In this dissertation, the situative nature arises from the conjugation of focus on groups as main activity units resorting to spontaneous argumentation and examination of individuals and their attributes. Its sociocultural nature, by contrast, arises from the setting of students interacting with each other, as well as with the resources and information in the virtual learning environment.

More explicitly, the benefits of argumentation demonstrated in earlier studies include following five ensembles. Argumentation can enhance motivation. This positive effect may occur if students have more autonomy over what they say in discussions based on argumentation than in traditional classroom situations where teachers lead the discussion and thus limit the possibilities for students to ask questions (Andriessen, et al., 2009). Argumentation as a social practice naturally offers more interaction possibilities with other students. This positive effect blends with the effect of enhancing motivation, which can have the same impact on students (Weinberger, et al., 2007). While having an argumentative discussion, students become aware of their peers' ideas and explanations. In this manner, students become interested in which of the others' ideas are the most defensible ones (Schwarz & Baker, 2017). Argumentation can support science content learning in several ways, such as engaging in an explicit explanation, which is known to promote learning and working of ideas. Argumentation fosters students' engagement in a variety of elaborative processes (Schwarz, 2009). It encourages students to give and receive learning support from others. In the process of argumentation, students learn from others or give them reasons to accept certain scientific explanations. This enhanced learning is because the process of providing evidence for claims can give learners a better understanding of the ideas they are learning and more reason to believe the claims they are developing (Chinn, 2006). Argumentation in education naturally improves general argumentation skills and topic-specific argumentation skills. The explanation for this benefit is that students learn to argue and evaluate arguments while they engage in argumentation (Walker & Sampson, 2013).

Moreover, argumentation is a fundamental aspect of PDE. PDE is a key concept in this dissertation, and its definition in the context of this work is as follows: "PDE is assumed to occur when learners use the language, concepts, and practices of the discipline in authentic tasks to 'get somewhere' (e.g. develop a product or improve a process) over time" (Koretsky, et al., 2021). The part of this definition concerning language related to discipline or resort to reasoning to accomplish a task connects the argumentation tightly to the structure of PDE. Engle and Conant (2002) defined the term PDE by seeing that students' engagement is productive until they make intellectual progress. This finding was identified by demonstrating that the students' arguments for their claims improved as time passed, and their discussions aroused new questions, which again led to more discussions and questions. Furthermore, scientific arguments help students to learn the basics of any of the natural sciences and accumulate knowledge that can help to solve problems in society (Lundqvist & Sund, 2018).

1.3 Categorizations and analysis frameworks for scientific argumentation in general and in the context of socio scientific issues

There are several ways to categorise the diverse nature of scientific argumentation. The most influential cornerstones in the argumentation framework research are the following six theoretical frameworks which focus on the general structure of argumentation rather than on the contents of the arguments. It is possible to apply any of these frameworks to analyse, categorise and evaluate argumentation in which students are engaged, independent of the subject matter. The main principles, focus and evaluated components of the theoretical frameworks are briefly described in the next paragraph.

Toulmin's argument framework (Toulmin, 1958) is the most substantially effective framework in science education and the basis for most of the other, considerably newer categorisations and frameworks. The ground-breaking work of Toulmin distinguished logical-formal arguments and linguistic arguments, which has made this framework versatile in evaluating the quality of reasoning behind the argumentation. In his framework, Toulmin classified the statements that form an argument into six categories: claims, data, warrants, backings, qualifiers and rebuttals. Claims are assertions supported by data that either conclude the argumentation chain or lead to the acceptance of the claim. Claims are statements that address four areas: the existence of the phenomenon, the nature of the phenomenon, the value of the phenomenon, and the follow-up with the claim. Claims are based on data, which can take the form of material, fact, or opinion. These forms of data are referred to as evidence, and they are important in starting the discussion. Warrants are comments used to justify the relevance of the data to the claim that act as links from a claim to data and from data to conclusions. The strength of the warrant is measured by the use of a modal qualifier, and the accessibility of the warrant is strengthened by comments defined as backings. A rebuttal consists of the conditions under which the warrant is set aside and the other evidence is contradicted.

Schwarz's framework (Schwarz, 2009) can be seen as a direct competitor of Toulmin's framework. This framework is applied especially in the context of natural sciences and in situations where students are producing written argumentation within certain intervals or in essays. This framework puts emphasis on the complexity of structure in the evaluation of the quality of an argument. According to this framework, an argument consists of an argumentation type, firmness of the argument, total number of justifications, number of justifications backing counterarguments and types of justifications. The contents are not a decisive factor in evaluating the quality of the argument. In sum, this framework can be used side-by-side with Toulmin's framework when studying students' argumentation practises. Likewise, it does not use area-specific criteria in its evaluation of justifications in a similar way to Toulmin's framework. Therefore, the argument of the highest level – according to this framework – is abstract that is, built upon student's previous knowledge of the topic, experiences and others' claims. At the same time, this is the weakness of this framework from the viewpoint of argument analysis as in the scientific context, the claim should be backed by empirical results.

The other similar argumentation framework is Zohar' and Nemet's framework (2002) which was designed to evaluate the quality of written arguments on the basis of the contents of the justification. Zohar and Nemet define an argument as a whole that consists of conclusions and their justifications. According to them, argumentation is an informal form of reasoning, and students must learn the meaning of reliable knowledge behind their decisions. Based on this framework, a strong argument consists of several justifications backing their conclusions that contain accurate scientific data. The main notion of the framework relates to how students implement scientific knowledge in their arguments, and therefore the framework records the occurrence of scientific data.

In the framework by Kelly and Takao (Kelly & Takao, 2002; Takao & Kelly, 2003), longer, more complicated written arguments, than in the other frameworks, are evaluated. The mark of Kelly' and Takao's framework is in relative, epistemic, and explanatory conclusions and in the links between arguments. This framework offers a way to evaluate the structure of long chains of argumentation and thus expands Toulmin's framework. It does not give much weight to scientific knowledge, which makes it difficult to evaluate whether the students understand the theories or how well the data supports conclusions.

In Lawson's framework (Lawson, 2003) the students are required to formulate arguments that are compatible with the frameworks used by nature scientists. The attention is thereby not on the general structure of the argument. From Lawson's perspective, argumentation is about choosing between competing, natural phenomenon explaining frameworks. According to Lawson, an argument consisting of validations of alternative explanations is stronger than the argument proposed by Toulmin because the argument by Lawson offers the explanation and evidence against other explanations. Therefore, Lawson's framework focuses on reasoning and traditional empirical testing of hypotheses, which limits the generalisability of the framework. However, in the appropriate disciplines, it is a powerful structural framework.

In Sandoval's framework (Sandoval, 2003), students' arguments are evaluated by criteria based on the discipline and conceptual and epistemic quality. This framework is discipline-limited because the conceptual quality of an argument is measured by how well students have articulated their claim within the subject specific theoretical framework and supported their claims with the data available to them. Epistemological quality covers how the student has referred to data while supporting their claim, written a coherent causal connectional explanation to a phenomenon, and incorporated required scientific knowledge. Thus, Sandoval's framework focuses on reasoning and contents, which are seen as the comprehensive explanatory force of arguments, instead of the structure.

Moreover, the general framework of the argumentation is not necessarily sufficient, but the frameworks must be modified to suit the needs of the learning situation. Students developing an understanding of the interdependency of science and society is a goal of science education (Gayford, 2002; Sadler, 2004; Sadler & Zeidler, 2004; Zeidler, et al., 2002). Therefore, socio scientific issues (SSI) have been introduced as a way to treat social problems with the knowledge from the scientific field. The issues are often controversial and uncertain in nature and often arise in the fields of biology and the environment. However, this poses challenges from the viewpoint of improving students' argumentation. As controversial issues, SSI offers different views for students to choose and thus engage in argumentation. The interdisciplinary nature of SSI, by contrast, requires students to bring together different domains (Jiménez-Aleixandre & Erduran, 2007) which challenges the way argumentation is taught in schools. This interdisciplinarity is also crucial aspect of the learning environment on the basis of this dissertation.

The most commonly stated argumentation frameworks in the context of socio scientific issues are as follows: Toulmin's original framework, Toulmin's modified framework, the five principles, the framework of the ESNaS project, the ESD-framework, the five-step framework, descriptive analysis of the effects of teaching, the four-part evaluation table for the quality of argumentation, Gauthier's framework, the evaluation ability of the argument, and the qualitative description of the thinking process.

Toulmin's framework modified by Kuhn (Kuhn, 1991; Kuhn, et al., 2013) and Jiménez-Aleixandre and Puig (2012) mostly aligns with the original framework but highlights the development of argumentative competence within social context. According to Kuhn, by formulating the claim, the student follows the norms dictated by social circumstances, of which some are epistemic and some are behavioural. An epistemic norm based on beliefs and values steers the student towards the direction that the student and the group are expected to take. A behaviouristic norm means adaptation to to these norms in interactive relations.

The five dimensions of argumentative interaction are a framework presented by Baker (Baker, 1999 (April); Baker, 1999) in which the argumentative interaction is seen as fundamental in nature science learning and in establishing interaction between frameworks and empirical observations. Baker adapted the framework to analyse interactive learning situations (Baker, 2002; Baker, 2009). The essential dimensions of the framework are cognitive, epistemic, and linguistic. The cognitive dimension addresses reasoning and argument production and phrasing. Therefore, argumentation can be seen as a process to rebuild knowledge. The epistemic dimension of the argumentative interaction is about the internal nature of the topic being discussed. It is also part of the diversity of knowledge types. This dimension emphasises the ability to initiate changes in epistemic states and that some types of knowledge are more resistant to change than others. The linguistic dimension of argumentative interaction covers the linguistic discourse directed by certain aspects. The argumentative interaction plays a crucial role in framework learning since it helps the learner to understand the topic being discussed and creates potential situations for conceptual learning. It cannot be seen as an actual cooperative mechanism, however.

A German Evaluation of the National Educational Standards for Natural Sciences at the Lower Secondary Level (ESNaS) project (Kauertz, et al., 2010; Kremer, et al., 2012) studied a framework that includes argumentation. The framework is composed of cognitive processes, complexity and competence readiness. Argumentation is categorised under competence readiness belonging to communication with knowledge explanation and knowledge transfer. Argumentation in nature science is seen to be in interaction with verbal reasoning, graphical reasoning, numeric reasoning, and learning a first language.

Education for sustainable development (ESD) framework (Eggert & Bögeholz, 2006) considers socio-scientific reasoning and decision-making in the context of sustainable development. In this framework, the key aspects are understanding and reflecting norms and values, finding and reflecting solutions, qualitative evaluation and reflection of solutions, and quantitative economic evaluation and reflection of solutions. In this framework, socio-scientific argumentation, deduction, and decision-making form the basis for socio-scientific problem solving, more precisely divided into ethical decision-making sub-framework.

Deane and Song (2014) have developed a framework for analysing argumentation. In this framework, skills needed at each stage in the process of understanding, building, and presenting arguments are identified for typical argumentation scenarios. In this way, argumentative discourse is divided into five phases: (1) understanding the stakes, (2) exploring the subject, (3) considering positions, (4) creating and evaluating arguments, and (5) organising and presenting arguments. According to this framework, the first phase is about considering the context and audience, including the audience's beliefs and values. The second phase emphasises the requirement for the participant to have a strong understanding of the topic which shifts the focus onto research and inquiry. The third phase of the framework brings the ability to examine other's perspectives into the centre, meaning that an effective argumentator can position oneself in the mindset of the other participants. The fourth phase of the framework deals with arguments being logically valid and evidentially sound, supported with reasons and evidence. The fifth and last phase of the framework focuses on knowing how to reconstruct other's arguments and how to structure and present one's own argument in an effective way.

Lee and Grace (2010) study the effects of teaching in dealing with socio-scientific problems. In this framework, the simulation of practical conflicts and encouraging students to participate in these conflicts while being neutral is in the focus. Depending on the learning goal, certain values can be considered. Moreover, the essentials of this framework propose several possibilities as well as sharing ideas versus decisions.

Sadler and Fowler (2006) propose an argumentation's quality evaluation structure as part of their threshold framework of content knowledge transfer. In this framework, a situation where a student does not give claims or reasons and therefore little to no knowledge is transferred is evaluated as earning 0 points. A situation is worth 1 point if the claim is not justified or it is justified wrongly in a scientific way corresponding to "rules-of-the-game" knowledge. When the claim is justified in a simple way, it is worth 2 points, which means that the student has advanced knowledge. When the claim contains several detailed justifications and counterarguments, it is worth 3 points, corresponding to the knowledge expected of a professional or expert.

In Gauthier's framework (Gauthier, 2005) four argumentative operations are observed: strategic, normatively regulated, dramaturgy, and communicative. In these strategic operations, the student builds one's operations on evidence and the validity claims refer to the objective world – logic of proposition or empiric efficiency. Narratively regulated operations are based on the values of a social group, whereas dramaturgy operations are about appealing to other's feelings. The communicative operations consist of validity claims that refer to the objective world, social world, and subjective world and orient student's operations based on criteria. Simonneaux and Chouchane (2011) have applied this framework with slight modifications in their study of reasoned arguments around human gene therapy.

Belland, Glazewski and Richardson (Belland, et al., 2008) composed a framework that focuses on how the student convinces one's audience rather than analysing the strict structure of arguments. In this framework, the claim, premises, subclaims, and evidence play a key role. For the argument to be convincing, it must consist of several premises and be based on evidence because, ultimately, argumentation is about proposing one's claim in the most convincing way. Belland continued to study argumentation and thinking related to argumentation (Belland, et al., 2016) and concluded that in the beginning of the thinking chain, the most important feature is to propose the problem in one's own words. This phase is followed by analysing the audience, as the characteristics of the audience have to be taken into consideration. The third phase is the recognition and collection of required knowledge. The fourth phase is generating the claim, collecting additional evidence, and creating links between evidence and claims. This linking is the main component and focus of this revised framework. The main principles of each of these frameworks along with their contribution to the analysis framework of this dissertation are presented in Table 1.

Table 1. The argumentation frameworks in the background for this dissertation.

Viewpoints of this dissertation's analysis framework: collaborative virtual learning and spontaneous argumentation

AUTHORS / COMPLEMENTERS	PROPERTIES / ARGUMENTATION	ARGUMENT STRUCTURE	IMPLEMENTATION IN THE DISSERTATION'S ANALYSIS FRAMEWORK
Toulmin (1958)	the quality measurement of an argument	claims, data , warrants, backings, qualifiers and rebuttals	the basis for the analysis framework
Lawson (2003)	the generation of arguments in line with ones used by scientists, heavy focus on reasoning and traditional empirical hypothesis testing	arguments offer the explanation and evidence against competing explanations	the refining structural categorization of reasoning
Schwarz, et al. (2003, 2009)	the structural complexity in the quality evaluation of argumentation	strength of the argumentation, the number of reasoning, the number of counter-argument justifications, reasoning types, the higher level argument being abstract	argumentation practices and the examination of argumentation on different levels
Kuhn (1991, 2013), Jimenez-Aleixandre & Puig (2012)	the emphasis on argumentation abilities developing in social contexts	the epistemic, behavioristic and social norms in generating the claim	the impact of social and situational aspect as well the spoken nature of arguments
Baker (1999, 2002, 2009)	the argumentative interaction in science learning and the connection between frameworks and empirical findings	cognitive dimension: reasoning, generating arguments, epistemic and intrinsic nature of the topic, linguistic choices	the general idea of combining findings of the virtual task and the interaction between students through argumentation
Zohar & Nemet (2002)	the content evaluation of written arguments	the argument is seen as a whole consisting of conclusions and their justifications with specific scientific reasoning	the notion of a student implementing scientific knowledge into one's argumentation
Kelly & Takao (2002, 2003)	the evaluation of longer and more complex frameworks than the other frameworks; the main emphasis is on relative, epistemic and explanatory conclusions and links between arguments	long and complicated arguments	the evaluation of argumentation chains and their structures

Eggert & Bögeholz (2006) ESD	the socio scientific reasoning and decision making in the sustainable development with arguments having values and principles	scientific descriptions and arguments	-
Sandoval (2003)	the discipline specific and criteria based evaluation of argumenta with emphasis on conceptual and epistemic quality	the quality of an argument depends on how well it is articulated within the theoretical framework of the discipline; reasoning and contents instead of the structure of an argument are seen as the explanatory force	the causal connection of explanation and phenomenon, and incorporation of scientific knowledge
Kauertz, et al. (2010) ESNaS	the competence readiness, unwrapping knowledge, transferring knowledge, argumentation in relation to verbal, pictorial and numeric reasoning	not mentioned	applicable for problem-solving situation
Lee & Grace (2010)	cultural, socio scientific issue, scientific orientation and socially oriented evidence, argumentation and decision making	scientific and opposing views	simulation conflicts
Közer-Keskin, et al. (2013)	argumentation is based on bioethics	arguments are evaluated on a four-part scale: no claim and no reasoning, claim is not justified, claim and simple reasoning and claim and several justifications and counter-arguments	applicable in several situations and the clear division between four components bears resemblance to the analysis framework
Belland (2007, 2015)	argumentation related thinking, presenting the problem with students' own words and how arguments can bring the others to one's side	claim, premises, sub claims, evidence, arguments consisting of several premises and being founded on evidence	fostering epistemic cognitions and developing epistemic beliefs
Deane & Song (2014)	the argument analysis based on five phases for typical argumentation scenarios	argumentative discourse is divided into five phases: understanding the stakes, exploring the subject, considering positions, creating arguments and organizing arguments	the clear structure of an argumentative process

Sadler & Fowler (2006)	quality evaluation of argumentation in relation to content knowledge transfer split into four levels	four levels of argumentation are no claims or reasons, claim without justifications, claim justified in a simple way and claim containing several justifications and counter-arguments	the division of arguments on different levels
Gauthier (2005); Simonneaux & Chouchane (2011)	argumentation comprised of four operations	argumentative operations are categorized as strategic, normatively regulated, dramaturgy and communicative	different aspects of argumentation being taken in to consideration

1.4 Scientific argumentation and socially shared metacognitive regulation in collaborative learning

Scientific argumentation in its spoken and spontaneous form is a social way of learning that highlights the importance of students not only regulating their claims, evidence, and conclusions but also the way they regulate their own learning. It has a prominent potential of making observable one of the greatest positive effect of argumentation, namely, learning the way scientists construct knowledge and learning content matters. The interconnectedness of argumentation and metacognition has been studied previously in science education (Hofstein, et al., 2008). Metacognition is a framework for explaining individual students' strategies to regulate their learning (De Backer, et al., 2015). However, metacognition at the individual level does not fully explain a dynamic learning process of an individual placed in a social cognitive system (Iiskala, et al., 2004; Volet, et al., 2009). Since this early empirical and theoretical work, the pattern of how an individual's metacognition expands to the social level has been of great interest to researchers (Iiskala, et al., 2011, 2021; Isohätälä, et al., 2017; Isohätälä, et al., 2018; de Backer, et al., 2020; Panadero & Järvelä, 2015; Kim & Lim, 2018).

As a result of previous studies, a strong connection 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 knowledge construction procedures, and awareness of changes in one's own conceptual structure. In addition, the most demanding phases of an argument were connected to higher-level metacognitive strategies. Metacognitive regulation accomplished (Schraw, 1998) if the student regulates their cognition by observing, planning and evaluating the learning task, and as the product of this process, forms an argument that contains proper evidence and scientific principles. Moreover, it is suggested (Flavell, 2005; Flavell, et al., 2001) that in presenting an argument, one has to know about the peer's knowledge on which the argument is constructed. This knowledge is defined as a metacognitive awareness component. Therefore, complex scientific tasks are of utmost importance when supporting students to engage in argumentation and regulate their learning.

As an expansion and adaptation of this learning setting, Jin and Kim (2021) showed that students continuously refine their knowledge of argumentation through discussing and negotiating with group members. This development could continue as the students kept engaging in reflective argumentation by establishing their argumentative norms through social interactions with the teacher and the other students. Metacognitive regulation was the integrative momentum in this reflective change of ideas, propositions and conclusions. This deep connection comes to its full potential in complex problem-solving situations in the science classroom, which develop students' argumentative practice and metacognitive regulation. Science education provides a natural foundation for incorporating metacognitive strategies that are integrated with additional instructional interventions such as collaborative learning, problem-solving, and inquiry learning. However, this combination of learning approaches makes the isolation of specific contributions of metacognition difficult (Zohar & Barzilai, 2013). A recent example of this kind of study setting is a metacognitive argument-driven inquiry approach in developing students' conceptual understanding (Antonio, et al., 2021). An inquiry approach such as this developed students' conceptual understanding and argumentation skills. Thereby, students' development of conceptual understanding, argumentation and metacognitive regulation was significant.

In addition, employing experiments and integrating argumentation and metacognitive regulation can improve students' science process skills (Kalemkus, et al., 2021). At the same time, students' metacognitive awareness levels and attitudes towards science developed the most in the groups in which science teaching was based on experiments and argumentation. Moreover, considering that the argumentation process is a crucial component of critical thinking (Marthaliakirana, et al., 2022), argumentation about scientific issues can contribute to developing students' critical thinking skills that relate to metacognitive strategies and thus contribute to the development of metacognition.

Critical thinking can therefore be seen as a metacognitive awareness, consisting of several subskills such as analysis, evaluation, and interference, which are important for producing an argument or solution to a scientific problem (Hogan, et al., 2015). Analysis as part of critical thinking and metacognitive awareness helps the student to identify the role statements play in an argument, the connections between statements, the source evaluation of the information included in an argument, and the balance of information. Evaluation is a critical thinking skill that is used in the assessment of the strengths or weaknesses of information resulting from different sources. These sources can be the credibility of information, the relevance of information, the logical strength of relationships among propositions within an argument, and the potential for bias.

In this dissertation the main focus is on the social level of metacognitive regulation, namely SSMR, which is the nature of students' social process in collaborative learning (Brocos, et al., 2022). It is a useful framework in explaining how group members align the current task of the collaboration with a desired goal. SSMR is especially crucial in regulating joint learning and coordinating versatile group tasks. (De Backer, et al., 2015; Iiskala, et al., 2011; DiDonato 2011; Järvelä, et al., 2016). Hence, SSMR refers to a process in which multiple group members regulate their collective activity (Vauras, et al., 2003). The process involves regulation of joint cognitive processes in collaborative problem-solving contexts (Iiskala, et al., 2011). As such, SSMR is closely tied to the regulatory processes of group members. Within the SSMR framework, a group is conceptualised as a social system within which team members influence and regulate each other's learning (Järvelä, et al., 2016; Khosa & Volet, 2014). The regulation of teamwork is orientated toward the shared responsibilities and joint goals of the team (De Backer, et al., 2015; Vauras, et al., 2003).

SSMR affects students' participation in teamwork and team effectiveness (De Backer, et al., 2015; DiDonato, 2013). The dynamic interplay of social and individual elements influences effective collaboration in group learning (Volet, et al., 2009). Interaction facilitated by SSMR makes team problem-solving easy and productive (Hurme, et al., 2009). Embedding metacognitive skills practice in the learning setting can result in stronger student metacognitive skills relative to sections that did not include a metacognition intervention (Santangelo, et al., 2021). In this dissertation, SSMR is observed in accordance with argumentation, as the novel analysis scheme for spontaneous spoken argumentation has been established.

1.5 Collaborative learning in virtual learning environments

In this dissertation, students' learning occurs in a collaborative setting within a virtual learning environment that promotes and fosters spontaneous spoken argumentation and SSMR. Succeeding in this promotion, collaboration between students plays a key factor. Collaborative learning indeed represents a shift away from the typical teacher-centred classrooms. In collaborative classrooms, listening to the teacher talk and note-taking may not disappear entirely, but they live alongside other processes that are based on students' discussion 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 (Goodsell, 1992; Gorgônio, et al., 2017; Schoor & Bannert, 2012).

Collaborative learning covers a broad territory of approaches with variability in the amount of in-class or out-of-class time built around group work. Collaborative activities range from classroom discussions with short teacher lectures to entire class periods, and the goals and processes of collaborative activities vary widely. Activities can be small-group work around specific steps or a more spontaneous agenda developing from student interests or questions. In some 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, respond to each other's work, or engage in analysis. (Vuopala, et al., 2016; Perry, et al., 2021).

Collaborative learning in its carefully structured form is based on the social interdependence theories of Kurt Lewin and Morton Deutsch (Deutsch, 1949; Lewin, 1935). These theories and associated later 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, et al., 1989). In this dissertation, the approach to collaborative learning is that it involves students working together on specified activities or learning tasks in a group small enough to ensure that everyone participates. The learning environment comprises a virtual research vessel, an interactive laboratory, and tasks to be completed within the limits of the environment. Hence, it is differentiated from unstructured group work.

Earlier research (Muijs & Bockhove, 2020; Perry, et al., 2021; Jørgensen, et al., 2023; Jørgensen, et al., 2024; Khosa & Volet, 2014; Molenaar & Chiu, 2014; Vuopala, et al., 2016) shows 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 understanding of diverse perspectives and preparation for real life social and employment situations are advantages of collaborative learning (Adinda, 2021). The carefully built virtual science learning environment in the present study aimed to guide and strengthen collaborative activities and learning of science content.

Collaboration helps students to learn from and about scientific argumentation and to make their own thinking visible. Using appropriate evidence and reasoning helps students to complete inquiry practices. As evaluating scientific arguments has proved difficult for students, they should be encouraged to collaborate with each other on tasks requiring the generation of a scientific explanation (Sampson & Clark, 2008). To strengthen the requirement for collaboration and scientific argumentation, and because the conditions for science learning improve through integration across different disciplines (Duschl, 2008), the virtual laboratory environments are interdisciplinary in nature. As it is difficult to develop a curriculum that reconciles the requirements of context-based education with the reality of the classroom (Knutsson, et al., 2012; Pilot & Bulte, 2006), collaboration and virtual laboratories may serve to address this issue.

In this dissertation, collaborative learning is viewed in the context of virtual learning environments. A virtual learning environment was originally developed to facilitate student group learning enabling a large amount of study data to be shared and used (Gibbs, 1999). In more modern literature, a virtual learning environment can be seen as a system for delivering learning materials to students over the web. These systems include assessment and student tracking features and collaboration and communication tools (Phungsuk, et al., 2017). Technologically, these systems are thus rooted in the web, which expands the term to cover all software that runs on the internet. Students believe that the use of technology in education benefits learning, but are aware that technology enhanced learning cannot replace a human educator. Virtual learning environments usually replace and foster traditional learning, and in addition education relies on students being able to use online learning software efficiently (O'Donnell, et al., 2012).

The advantages of virtual learning include exposure to new forms of learning, having extra time for self-study, and easy access to online resources (Dung, 2020). By contrast, the disadvantages of virtual learning are extensive time at digital screens, lack of conditions for developing social interaction skills, fear of online assessment, suffering from concentration loss, potential lack of peer interaction, potential lack of time and condition to speak with peers and teachers, difficulties in acquiring the lesson contents, potential lack of interaction with instructors, and lack of self-discipline. In sum, virtual learning environments can support students' construction of arguments by providing them access to real data, incorporating tools to increase groups members' awareness of their participation within the group, co-creating and sharing intellectual compositions, and distributing roles and activities. The common synchronous mode of the learning environment not only demands but also develops student's argumentation skills (Jiménez-Aleixandre & Erduran, 2007). Thus, virtual learning environments support scientific argumentation, collaborative learning, metacognitive regulation, and addressing topic-specific issues, such as socio-scientific issues. More so, virtual learning environments are designed to individually study issues in one discipline. However, in this dissertation, the virtual environment was designed for collaborative working to enhance students´ learning (e.g. collaborative thinking and multi-perspective taking in small groups across two disciplines). According to Taber (2008), to be able to connect new material to existing knowledge and to evaluate new theories, it is essential that students are able to integrate knowledge across disciplines. To see how two disciplines' contents (biology and chemistry) are integrated, students must understand how key concepts of the disciplines are interrelated and how they are built on in other disciplines among science (Simon, 2008). Additionally, reasoning skills are required to understand interrelated scientific concepts and theories (Lawson, 2004). Learning key topics and concepts from the perspectives of different disciplines is more inspiring and highlights science' s conceptual integration (Taber, 2015; Taber, 2017). This is something for which a virtual learning environment is suitable. The concepts are summarised in Figure 1.

Figure 1. Concepts of the four studies in this dissertation.

2 Aims and structure of the dissertation

The dissertation has theoretical, methodological and empirical aims to extend the understanding of spontaneous argumentation during small group collaborative learning in science as described in the previous introduction to concepts and phenomena. The theoretical aim is to broaden the understanding of spontaneous argumentation in collaborative learning and, more specifically, in the virtual learning context. The methodological aim is to develop an argumentation framework for analysis of spontaneous spoken argumentation in the context of collaborative science learning utilising a virtual learning environment. Ultimately, the empirical aim is to provide educational artefacts for implementing learning conditions that foster spontaneous scientific argumentation either in the form of learning environments or assignments. To understand spontaneous spoken argumentation in collaborative science learning, a multimethod approach was reconstructed step by step from preliminary results through the use of a crafted virtual learning environment and the creation of a novel analysis framework to bring argumentation and SSMR together and to reflect upon possible assignments to support the use of scientific argumentation and implementations in teacher education. These intertwining aspects of spontaneous argumentation fabricate an intact general view that elucidates a complex whole.

Therefore, the four studies in this dissertation fluently complement each other (see Table 2). Study I was a qualitative case study describing the phenomenon of spontaneous argumentation in a collaboratively supported virtual interdisciplinary environment using mixed methods (Cohen, et al., 2017). The data consisted of content knowledge, scientific reasoning, and common products as well as videotaped discussions. This study aimed to examine how upper secondary school students integrate knowledge from two separate disciplines, namely biology and chemistry, and spontaneously argue over content issues through collaborative interdisciplinary learning. In this thesis it was epochal that the virtual learning environment was designed to enhance students´ collaborative learning in small groups across two disciplines rather than one, as is the case with most virtual learning environments.

Studies II and III demonstrated that despite the argumentation frameworks diverging regarding the numbers and types of structural components, many of them agree on the structure of an argument as a pair of claims and justification. Thus, in this dissertation, argumentation is also seen as a chain from a claim through observation and evidence to the interpretation of the claim. As the data for analysis consisted of spoken argumentation rather than written arguments, a balance between the different approaches, depth, and nature of argumentation was eventually struck. Therefore, argumentation was defined as a way for students to reach a common understanding about certain scientific interdisciplinary topics. The aim of Study II was to compare small student groups of various performance levels and demonstrate the differences in the quantity and quality of argumentation. This comparison was strengthened with the use of statistical methods to elucidate the statistically significant relations and differences.

Study III added to this whole the important layer of SSMR, which naturally knits together with collaborative learning and argumentation. Thus the scope is on the grander view of the interdisciplinary discursive discussion and its nuances. The data consisted of mainly the same small student group discussions, which made drawing parallels with argumentation and regulation between the different performing-level groups natural and able to emphasise the aspects of the complex learning situation.

Study IV focused on student teachers' ability to construct tasks and assignments that promote argumentation over socio-scientific issues. Therefore, the data consisted of the written assignments compiled by student teachers as opposed to the spoken argumentation analysed in the other three studies. This study discloses the importance of a task setting as a way to implement spontaneous argumentation. Similarly to the studies with the virtual learning environment, the task settings did not explicitly ask for argumentation but hinted at using it. In this way, the scope changes from upper secondary students to student teachers and from collaborative small group work to an individual task. Moreover, this study brings into discussion the socio-scientific issues that have been proven to be fertile ground for fostering argumentation.

Table 2. Aims of the four studies in this dissertation.

General aims:

Theoretical aim: to broaden the understanding of spontaneous argumentation in collaborative virtual learning, and more specifically in the context

Methodological aim: to develop an argumentation framework for analysis of spoken spontaneous argumentation in the context of science learning and education

Empirical aim: to provide educational artefacts for implementing learning conditions that foster spontaneous scientific argumentation either in the form of learning environments or assignments

STUDY I	STUDY II	STUDY III	STUDY IV
Small student groups collaboratively working on a virtual learning environment developed by an outside research team	Small student groups collaboratively working on a virtual learning environment developed by an inside research team	Small student groups collaboratively working on a virtual learning environment developed by an inside research team	Student teachers individually creating an assignment and framework answer
Qualitative, mixed-method case-study **Specific aims:**	Quantitative study **Specific aims:**	Semi-quantitative with addition of case-study **Specific aims:**	Mixed-method study **Specific aims:**
To investigate upper secondary school students' spontaneous spoken argumentation	To relate the quality of spoken argumentation to groups' learning achievement during a collaborative inquiry task.	To relate the quality of spoken argumentation to group members' SSMR during a collaborative inquiry task	To examine tasks constructed by student teachers of biology and geography that aim to teach high school students argumentation skills
To investigate interdisciplinary integration of biology and chemistry	To compare the argumentation patterns in three phases of the virtual environment	To constitute a perception of ways to regulate learning during argumentation and across different phases of the virtual environment and group levels	To analyse the products using the common argumentation frameworks
To achieve preliminary results based on which a new virtual learning environment and a framework specifically for spontaneous argumentation were drafted and completed	To form and present a novel framework for analysis of spoken spontaneous argumentation	To build a whole view of the argumentative small group discussion	To investigate what phenomena and views the student teachers chose for their assignments

3 Methods

Of the four studies of this dissertation, the first one is a qualitative study following a mixed-method approach, while the second one leans on the quantitative methods. The third one is a semi-quantitative study with additions of case-studies. The fourth one is a mixed-method study. The methods are thoroughly explained in the following chapters.

3.1 Participants

Of the four studies, the first one was conducted in two upper secondary schools in southwest Finland during the spring semester of 2014, whereas the two following studies were carried out in six high schools in southwest Finland during the spring and autumn semesters of 2015 and 2016 (see Figure 2). The fourth study was conducted at the university within student teachers' subject-specific pedagogical studies. The reason for the distinct participant sets was that the first study dug preliminary results of a possible argumentation framework in the condition of spoken spontaneous small group discussions; Studies II and III focused on the same participants with the newly developed virtual learning environment; and Study IV gave insight into establishing argumentation-supporting assignments for upper secondary students in the context of teacher education and socio-scientific issues. All four studies emphasised upper secondary students since they are at the crossroads in relation to their future studies, and they had adequate background knowledge to realistically engage in interdisciplinary argumentation. In addition, teachers were in a minor participating role for Study I, as their interactions and instructions were observed to provide data for the settings of the following studies. One high school in Study I was urban and one was rural; of the six high schools in Studies II and III, two were rural and four were urban. Participating students in Study I (N = 35) were between 16 and 17 years old (M = 16.42, SD = 0.38) and gender distribution was even (46% were male and 54 % female). Moreover, four science teachers (two biology and two chemistry teachers) participated in Study I. Participating students in Studies II and III (N = 120) were between 16 and 19 years old (M = 17.27, SD = 0.68) and most were female (65%), of whom six small groups (N=18) were chosen for the further analyses. Participants in Study IV (N = 39) were between 23 and 26 years old. Participants in the four studies included both the individual students in small groups and student teachers that gave a research permit. The research permit was gathered from the students and their legal guardians as written consent before the study began.

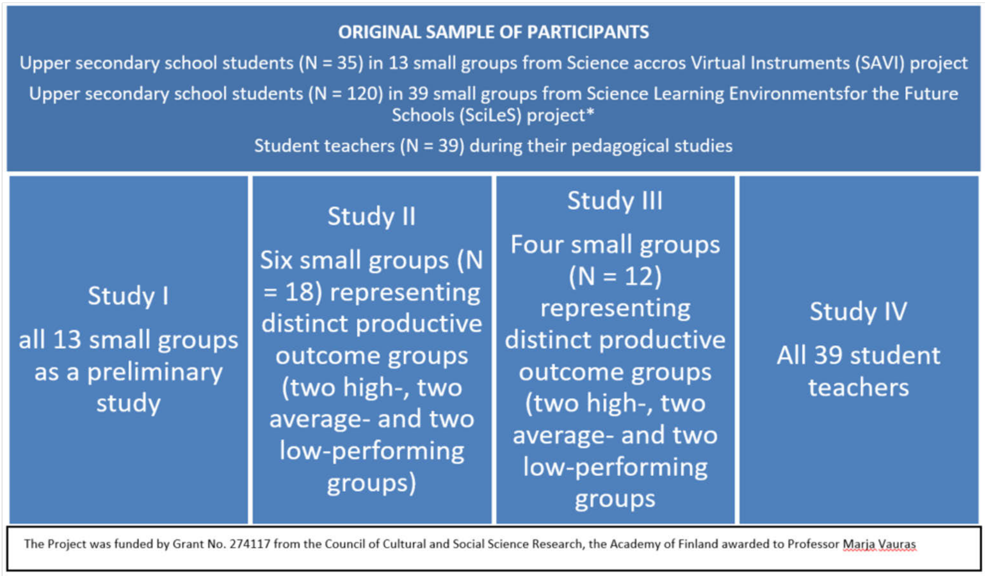

Figure 2. Participants in the four studies in this dissertation. The original sample of participants in the SciLes project was the data pool for studies II and III in the dissertation, and a smaller sample was used for the further analyses.

Study I

Participants were the 35 upper secondary school students and four science teachers who participated in the Science across Virtual Institutes (SAVI) research project. Teachers' subject specificity was evenly distributed, as two taught biology and two taught chemistry. To ensure congruence of the research, teachers from both schools received the same instructions, information and guidelines separately. The students' tasks were constituted in accordance with the National School Curriculum for upper secondary schools (FNBE, 2003) in both the schools, and participants were students of either an optional biology or chemistry course. The students used laptops during their normal lessons and were experienced in using web-based learning software. Regarding the study, it was important that they had neither studied in a virtual laboratory environment nor used the scientific approach or integrated biology and chemistry in their courses. Participation was voluntary, and a signed consent containing permission to videotape all small group discussions was fulfilled by the students and their legal guardians and by the teachers. The students naturally received course credits for their participation as this was an integral part of their optional course. The teachers divided students into pairs (N = 4) or threes (N = 9), and each pair or small group worked on a shared laptop on which the virtual laboratory was pre-installed. The teachers formed the 13 groups to ensure functioning group dynamics, sufficient disciplinary knowledge in biology and chemistry and satisfactory English language skills.

Study II

Six intact groups with a total of 18 students (four male and 14 female) were eventually chosen out of 36 three-student groups for systematic, in-depth analysis of the six groups in relation to spontaneous spoken argumentation and collaborative learning outcomes. The science teachers were excluded from this study, as the focus was solely on student discursive interactions during collaborative virtual inquiry tasks. The selection criteria for the groups were differing science outcomes (two high, two average, and two low performing groups), integrity of the groups over the whole research period, which spanned three lessons, and the sufficiently high quality of the video data to ensure the reliability of the analyses. Participants were from biology and chemistry lessons of diverse courses that are of a biology specialisation, biology compulsory, and chemistry compulsory course. All tasks were arranged according to the Finnish national core curriculum. In the small groups, learners were mixed in collaboration with the teachers to diminish the individual differences in relation to disciplinary knowledge in biology and chemistry and English language skills and group dynamics. The students studied in small groups of three in the virtual laboratory Virtual Baltic Sea Explorer (ViBSE) on a shared laptop (Kinnunen, et al., 2018).

Study III

The participants were the same as in Study II, with the exception of average-performing groups not being included. This decision was made to ensure differences in argumentation and SSMR patterns, as average groups differed in the level of argumentation but not in the level of metacognitive regulation.

Study IV

Participants were 39 subject student teachers in biology and geography, biology in many cases as a major, and some of them had chemistry as a minor. They all gave a research permit and were having their pedagogical studies during 2018–2020 semesters. The total number of participants was 42 but of them three refused to be part of the study. The total number referred to the totality of student teachers participating in the pedagogical studies during the research period. Therefore, unlike the upper secondary school students, they were selected based on their subject-specific teacher studies, and no other exclusion principles were applied. The student teachers needed to formulate an assignment for upper secondary students containing a topic related to ecosystems and socio-scientific issues and to complete their assignment in the form of a framework answer. The length of the answer was defined as be two–three pages. To complete the assignment, all kinds of material were allowed (e.g. text, figures, maps, and tables). Formulating the assignment and answering to it was part of student teachers' pedagogical studies, which denoted that they were familiar with this kind of procedure. As adult students having studied these specific subject matters they proved to have deep content knowledge both in relation to the disciplinary topics and the task design.

3.2 Virtual learning environment

This dissertation utilises two topic-specific and interdisciplinary virtual learning environments, of which the first one covers Study I and the second one covers Studies II and III. Study IV did not benefit from the use of a virtual learning environment.

In Study I, the virtual learning environment was the Virtual Marine Scientist (VMS; https://www.gu.se/en/research/virtual-marine-scientist) (Fauville, 2013) that represented the laboratory-like end of the virtual environment spectrum. This web-based software was designed to foster collaborative learning and problem solving and to follow the way scientists conduct research. The virtual studies students needed to carry out in the environment focused on the impact of ocean acidification on mussels' and sea stars' vitality and growth speed. Moreover, that provided an excellent basis for interdisciplinary discussion and decision-making. The VMS included short videos of the scientific principles in the background of the studies, of real researchers explaining phases of the virtual experiment and giving tasks to do next, as well as written material for students to familiarise themselves with at their own pace. The laboratory experiments were interactive to give students freedom to try out study settings and see how certain initial values affect the phenomenon.

In Studies II and III, the virtual learning environment was ViBSE (Kinnunen, et al., 2018). This environment was built in the dominant science language (i.e. English) and pre-installed on a shared laptop the small student group needed to use. Students were tasked with executing a virtual experiment on the effects of pH on copepods in the Baltic Sea's food chain. ViBSE is an open-ended, multifaceted learning platform that consist of a library explaining the structure of the research and a scientific background of the phenomena, photographs, interviews with the crew and researchers of the real research vessel Aranda, laboratory tasks, and links to external web pages providing real-time data of the Baltic Sea. Therefore, the virtual environment offered multiple tools to the students to approach the open task they needed to formulate first on the basis of the introduction. In a similar way to the VMS, this virtual learning environment aimed to acquaint the students with the way real scientists conduct research. The learning environment emphasised hypothesis formation, the experimental phase, and interpreting the results while being far more open to students' trial and error. All the experiments were based on studies by real marine biologists (Bonaglia, et al., 2013; Engeström-Öst, et al., 2014) which challenged the students to formulate their own research problem.

In the beginning of the virtual learning phase, the students chose their topic, set their hypotheses and study designs, and then advanced to the virtual laboratory part of the environment. Initially, the teachers were encouraged to promote student groups' scientific argumentation, but no explicit guidelines were given to the teachers. In the laboratory, students were allowed to choose between the number of seawater bottles, eggs, pH, and time, after which they were able to collect data and conduct analyses that contained, for example, the number of eggs and basic statistics. Ultimately, the students were able to draw conclusions and interpret results.

After completing the virtual laboratory part of the study, the students were asked to prepare a PowerPoint presentation - including the research plan, results, and conclusions - that was considered the outcome of collaborative learning. Therefore, the collaborative virtual learning had three phases: planning, experimenting and drawing conclusions that were reported as the results. These phases naturally acted as partitions for the argumentation and metacognitive analyses.

To supplement the goal of the thesis, 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 prior the lessons as well as decide on several key points of the experiment. The teachers intervened and provided help only if the project was not progressing properly and the group was having difficulty in a certain phase of the virtual study. In addition, the virtual learning environment was designed to support collaborative problem-solving and complex thinking through scientific reasoning. These aspects made the environment metacognitively and socially demanding for the students, as did the environment being in a second language and having to integrate knowledge from two separate disciplines. Table 3 details the structure of the study steps and tasks with the virtual learning environment.

In Study III, the same environment was used, whereas in Study IV there was no virtual learning environment.

Table 3. Structure of the virtual learning environment study steps and tasks.

STEP	TASKS	ALOTTED TIME	DATA
Pre-tests	online biology and chemistry content tests and test of scientific reasoning	no time limit	content and scientific reasoning test results
Lessons in the virtual learning environment	background knowledge, key theories and logic of the experiments studied, generation of study plans and virtual experiments, results analysed and PowerPoint presentations created	approximately 3 lessons (45 – 75 minutes depending on the school)	videotaped student group discussion and collaborative learning
Presentations	finalized presentations according to the blueprint of a scientific article presented to the class	1 lesson (45-75 minutes depending on the school)	collaborative outcome to evaluate and rank the student groups
Post-tests	online biology and chemistry tests	no time limit	content test results

3.3 Student and student group performance assessment

To provide information on the spontaneous argumentation during collaborative virtual learning and comparison of different small group students' collaborative products were graded in addition to measuring students' science content and scientific reasoning. The science competence measures were conducted before and after the virtual learning intervention during the three lessons. These measurements were only used in Study I, as the other studies examined aspects of the collaborative inquiry work, to which this information was not directly relevant. Intrinsically, the level of the collaborative outcome was evaluated separately for each group at the end of the virtual learning phase. These collaborative outcomes were used to categorise small student groups into three different performing levels (high, average, and low), which in turn formed the fundamental categorisation for the in-depth analyses of argumentation and SSMR.

Science content and scientific reasoning measurements

The science competence measurements were only utilised in the first preliminary study to give a diverse understanding of the principles of the appropriate virtual learning environment and a satisfactory analysis framework for spontaneous spoken argumentation. However, this background knowledge was collected from all the participants excluding the student teachers in Study IV. Therefore, Study I applied three separate tests consisting of pre-tests in Finnish, biology content knowledge test, chemistry content knowledge tests and scientific reasoning. The students were gathered in a classroom, where they completed the tests under the surveillance of the teacher and the researchers. At the end of the collaborative virtual learning phase, after their PowerPoint presentations, students were asked to complete the post-tests, which involved biology and chemistry content tests and scientific reasoning. The students in Study I did not answer the scientific reasoning test due to a lack of time. Otherwise, students completed the tests without time limits.

The biology content knowledge test consisted of seven multiple-choice questions, in which the student needed to choose the correct answer of the three given ones, and nine open questions. The chemistry content knowledge test consisted of 14 multiple-choice and no open questions. Students' scientific reasoning was, by contrast, assessed prior to Study I and after group work using an existing questionnaire, Lawson's Classroom Test of Scientific Reasoning (previously validated: Lawson, 2000). This classroom test was used for categorisation purposes.

The pre- and post-tests in content knowledge assessed students' understanding of basic biology and chemistry concepts with differing questions between pre- and post-test but with similar question setting. The contents of questions related closely to the themes of the virtual laboratory (i.e. pH, ocean acidification, climate change, and population dynamics). Both content knowledge tests measured recall and interpretation of graphically presented data, were designed by two biology and two chemistry university teachers and accepted by the research team. The content knowledge tests were piloted (Yli-Panula, et al., 2015) in one school by International Baccalaureate (IB) students prior to the study. Based on the findings of that pilot study, some items were modified to suit the needs of Study I. For easy and secure data access, all test results were converted for each student into electronic format using the ViLLE learning platform.

Collaborative outcome grading

The measure of each group's collaborative outcome was based on their PowerPoint presentation. A six-level scale was introduced to generate the categories for student groups' conclusive presentations. The scale adopted the five categories of the Structure of Observed Learning Outcomes (SOLO) taxonomy (Biggs & Collins, 1982; Chan, et al., 2002), with the addition of one further category for unstructured presentations. To ensure reliability and quality of outcome assessment, established assessment criteria (Peeters, et al., 2010) were integrated into the grading framework to categorise presentations into six levels (graded from 1 to 6). After establishing the grading system, two qualified science professionals in biology and chemistry evaluated the overall quality of the groups' PowerPoint presentations. The emphasis was on 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. Based on the assessments, the student groups were divided into high-, average-, and low-performing (1 = low -, 2 = low +, 3 = average -, 4 = average +, 5 = high - and 6 = high +). From each level of performance, videos of two groups were selected for closer analysis in this dissertation. All selected small groups consisted of three students. In Studies II and III the number of distinctive collaborative outcome groups was six high (13 female, 3 male), 14 average (28 female, 14 male) and 19 low (34 female, 22 male) groups of the large original sample.

In Study I, the same scale was used to assess the accepted hypotheses and study plans, confined to the four upper end levels due to the preliminary nature of the study and the differences in the way the virtual learning environment worked. In grading hypotheses and study plans, integration of biology and chemistry was considered a crucial element in relation to performing level. A direct comparison to the collaborative outcome is difficult, but when considering the grade for the hypothesis, study plan and presentation, the number of distinctive general performance groups was one high group and 12 average groups. This demonstrated the more structured nature of the virtual environment in Study I as opposed to the one applied Studies II and III. The grading flow of content and collaborative outcomes is expressed in Table 4.

In Study IV, the participants were student teachers and therefore they were not measured in the same way as the upper secondary students in the first three studies. Their assignments and framework answers were analysed in relation to the three phases of the framework presented by Eggert and Bögeholz (2006).

Table 4. Flow of the grading of outcomes and selection of data for analysis.

STEP	TASKS
Marking the pre- and post-tests	tests were graded based on commonly established criteria by the researchers and literature, the scores were parallel verified, the connections between scientific reasoning and content knowledge and pre- and post-results were analyzed
Grading the PowerPoint presentations	the grading scale was based on inductive content-based analysis and SOLO taxonomy and parallel verified, hypotheses, experimental plans, experiments, results and interpretations were considered
The group selection for analyses	high-, average- and low performing groups were selected for in-depth analyses based on level of the presentations and the quality of videotaped data

3.4 Video-based observations

All teachers' and students' interdisciplinary discussion was videotaped and audio recorded during the virtual learning interventions with digital cameras and microphones. There was one camera for each group positioned in front of the group, and depending on the size of the classroom, one to two cameras for the whole classroom were positioned in one corner of a classroom to give a general view of the classroom. To provide additional information on the students' work with the learning environment, the student activity at the laptop was recorded with Snagit, a screen capturing software. Video segments for each group were subsequently selected so that they featured the three working phases of the virtual learning environment that followed the steps of scientific research: planning, experimentation and conclusions (Tsovaltzi, et al., 2013). Moreover, video segment selection was based on the general principles of video research for science learning, with an emphasis on data selection, pattern-finding, interrater reliability and protecting the human subjects (Derry, et al., 2010).

After the initial selection of the segments, six intact small groups were chosen for the analyses. Then, verbal turns of each student in every selected small group were stamped with a precision of seconds, after which the videotaped sessions went through the thorough and in-depth analyses. This was the video analysis procedure for studies II and III.

Unlike in Studies II and III, which followed the general procedure of video segment selection and processing for analysis, only two groups' discussions were analysed from the videotaped lessons in study I. For these analyses, two videotaped excerpts were independently selected from both small groups on the basis of the group's general performance. In these excerpts, the groups discussed their study plans and results regarding the virtual experiments, which could be seen as an analogy to the planning and conclusion phases of the more sophisticated learning environment utilised in the later studies. In Study IV, no video-based observation was conducted due to it being a different type of study.

3.5 Analysis

To understand spontaneous spoken argumentation in a collaborative virtual learning setting in the context of science education versatile and mutually complementary analysis methods are crucial. Therefore, the analyses in the studies differed from each other depending on the focus and the nature of the concerned study. In Study I, data-sets for analyses were compiled from two sources: assessments of three distinctive data-sets (i.e. written virtual study plans and hypotheses and PowerPoint presentations explaining groups' procedures through the virtual inquiry) and videotaped group work segments. In Studies II and III, the main analyses were conducted on the basis of student groups' collaborative outcomes and selected video segments of students' collaborative spontaneous argumentation and metacognitive regulation. In Study II, one of the main focuses was on establishing a novel framework for spontaneous spoken argumentation, which was achieved using all six small groups. By contrast, the main goal of Study III was to connect argumentation to metacognitive regulation, which was possible only by using a more condensed amount of videotaped material due to the complex nature of integrating these two aspects of collaborative learning. Table 5 summarises the general steps of the analyses.

Table 5. The structure of the analyses of the virtual learning environment studies.

STEP	TASKS
Selection and editing of three student group interaction segments for four small student groups	approximately 10 – 16 minutes long and from each of the six groups (two high-, two average- and two low-performing groups)
Transfer to Observer XT software	videotaped data transferred to the analysis software and initial settings and coding
Differentiating the verbal communication from the non-verbal communication	only verbal communication was analysed in the context of spoken spontaneous argumentation and metacognitive regulation
Separate coding of argumentation and metacognitive regulation	only the parts of the videos containing verbal communication were analysed, distinguishing argumentation and metacognitive regulation from other verbal communication and cognitive activity and SSMR from other forms of metacognitive regulation, analysing on-task argumentative and metacognitive regulatory verbal communication
Merging of the coding and analysis schemes of argumentation and metacognitive regulation	the different schemes were combined with each other with the analysis software for the general view

In-depth video analysis

In Studies II and III, qualitative-level video analysis of group interaction enabled shifting to deep moment-to-moment observation and thus revealed the nature of spoken spontaneous scientific argumentation and the dynamic between argumentation and SSMR.

Study II was the foundation for vivid video analysis since the same video segments acted as the data for Study III. The video analysis proceeded in that manner, so that three distinct, meaningful, and self-contained interaction segments (approximately 10–16 min) were selected from each of the six groups. Criteria for the selection were that the chosen segments were crucial for task performance and completion, demanded student collaboration, and were representative for 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. Videos were first edited using MovieMaker software. Videos were subsequently added into the Observer XT 12 software programme as new observations. As the analysis was focused on verbal communication between 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 video was coded this way from beginning to end. After this categorisation, the parts of the video with verbal communication were analysed further. Thus, one verbal comment is regarded as one turn, which is then coded according to the code scheme.

The second stage of analysis involved distinguishing argumentation from other verbal communication. Each instance of communication was categorised as “off-task”, “on-task non-argumentative”, or “on-task argumentative”. The “off-task” category contained student discussions of issues that were 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 consisted of students’ dialogues that concentrated on scientific content and the task but without scientific argumentation. For example, students talked about how to prepare a presentation, how to cut and paste a picture, or where to save their materials. The instances of verbal communication categorised as “on-task argumentative” were chosen for closer analysis. All codes were mutually exclusive, meaning that they could not occur at the same time. In practice, inserting a new code automatically ended the previous one. The third stage involved analysing on-task argumentative verbal communication with the use of the introduced framework.

Inter-coding agreement

In Study I, only two videotaped excerpts were used as evidence for spontaneous argumentation. The selection was made by an outside researcher, and the analysis by the three authors of the study I. Due to the study I being a preliminary case study, no inter-coder agreement was required for the video analyses. Nevertheless, the three researchers analysed the collaborative outcomes independently, which led to the common agreement rate being as high as 98%, and disagreements were resolved through discussion.

However, an inter-coder agreement was established in Study II to ensure the reliability of the coding. In the first phase, episodes of argumentation were identified in the video data manually using two independent coders, and inter-coder agreement was calculated using percentage agreement. In the second phase, video segments for in-depth analyses were randomly selected from the episodes of argumentation using two coders who viewed selected video segments independently. The inter-coder agreement at the last phase was calculated using percentage agreement and Cohen's kappa (Landis & Koch, 1977). Minor disagreements were resolved with discussions. Using this final framework of analysis, the videos were coded by the first author of Study I, and parallel coding was done by another science teacher with pedagogical competence. The percentage agreement of the coding was 81%, and the Cohen's kappa was 0.713. Thus, the inter-rater agreement is substantial (Landis & Koch, 1977). The reliability across researchers (i.e. inter-rater reliability) was good in Study II since the coding category was created and discussed together and the coding agreement was relatively high (Landis & Koch, 1977; Anastasi, 1997). Inter-coder reliability and agreement were therefore good as well. The definitions of codes and components of argumentation were also consistent in Study II, and attention was given to ensure that they were consistent and understandable for both the readers and researchers. Differences in analysis were discussed until a common agreement was achieved. Inter-coding for metacognitive regulation was conducted in the same way in accordance with other studies not included in this dissertation. Thus, it was not repeated for this study or dissertation. However, after the principal coder had finished the coding of two phases from two groups (i.e. one high- and one low-outcome group) the inter-rater coded 26% of that data. Inter-rated agreement was 86.2% and Cohen's kappa .75 (see ref. Iiskala, et al., 2021), indicating the substantial strength of agreement (Landis & Koch, 1977). The principal coder coded two last groups on the same principle as the first two groups.

Argumentation analysis

In Study I, argumentation was analysed using excerpts of student discussion during collaborative virtual learning and was therefore a preliminary case study rather than an in-depth analysis of students' spontaneous argumentation. Study I demonstrated that in the high-performing group all students' contributions to achieving the task were meaningful and accepted after spontaneous argumentation and reasoning with interdisciplinary connections to other domains of nature science and even socio-scientific topics, whereas in the average group the finalized product was one student's output and the absence of interdisciplinary connections to other fields of science was apparent. For this preliminary analysis, the quality of each group's spontaneous argumentation was rated as either high or low. Argumentative discussion was rated as high if the students combined their knowledge of biology and chemistry in their argumentation and provided clear evidence in support of their claims, and as low if no interdisciplinary discussion occurred and no evidence or only weak evidence to support their claims was provided. However, Study I laid the groundwork for the argumentation analysis framework presented in Study II.

In Study II, the on-task argumentative discussion was thoroughly analysed, and as a product, a novel framework for spontaneous spoken argumentation was introduced. The analysis scheme took advantage of Toulmin's argumentation theory modifying its categories in the direction of the framework illustrating the components of a scientific argument presented by Sampson and Schleigh (2013). The final presented framework placed emphasis on the nature of the evidence and the claim strengthening it with the interpretation of the data and the analysis method. The depth of this framework was adjusted to meet the requirements for analysing spontaneous, spoken argumentation. More importantly, these categories were in line with the three phases of the task the students conducted in the virtual learning environment. As a result, 6,768 instances of verbal communication were analysed with respect to argumentation. Of these instances, 1,348 (19.9%) were categorised as "on-task argumentative". The proportion of argumentative instances of verbal communication was lowest for the low-outcome groups.

During the initial analysis of the students' spontaneous on-task argumentation presented in Study I, it was noteworthy that the chains of argumentation usually began with a question. That question often included the claim, which was expected from a spontaneous discussion where the participants are unsure how to proceed. After the question, the argumentation continued with one or more observations, which provided evidence or offered an interpretation linking the claim or evidence to the theory. Therefore, in line with previous literature, three data- and theory-driven components of spontaneous verbal argumentation were recognized according to Table 6: questions (Q), observations (O), and interpretations (I). In regard to the frequencies of on-task argumentative instances categorized as "questions", "observations", and "interpretations", the low-performing groups had a significantly lower proportion of instances categorised as questions compared to the average- and high-outcome groups.

The quality of argumentation in each of these components was evaluated based on the nature and function of the argumentation. The quality of argumentation was evaluated based on how well the claim included in the question fit the theory, as well as on whether or not it led to the continuation of the argumentative chain. Instances of communication categorised as observations were evaluated based on how strong and relevant the evidence was, as well as whether or not it led to the continuation of the argumentative chain. Interpretations were analysed based on how strong and relevant the link to theory was, as well as on whether or not it led to the continuation of the argumentative chain.

Table 6. Argumentative analysis framework.

ARGUMENTATIVE COMPONENT	QUALITY LEVEL AND ABBREVIATION FOR ANALYSES	DEFINITION
Question (Claim)	1: Qlv1: no claims is given, doesn't start an argumentative chain 2: Qlv2: claim fits poorly with the theory, leads to the continuation of the argumentative chain 3: Qlv3: claim fits well with theory, leads to the continuation of the argumentative chain	A given claim that fits with the scientific theory of the specific topic and contributes to the continuation of the argumentative chain
Observation (Evidence)	1: Olv1: no evidence is provided, doesn't start nor continue an argumentative chain 2: Olv2: weak evidence is provided, can lead to the continuation of the argumentative chain 3: Olv3: evidence is relevant and strong, leads to the continuation of the argumentative chain	A provided piece of evidence brings relevant information to the process and begins or supports the continuation of the argumentative chain
Interpretation (Link to theory)	1: Ilv1: no link to theory is given, doesn't start nor continue and argumentative chain 2: Ilv2: link to theory is weak and factious, can lead to the continuation of the argumentative chain 3: Ilv3: link to theory is relevant and strong, can lead to the continuation of the argumentative chain	A link to the scientific theory relevant for the specific task is given which can lead to the continuation of the argumentative chain

Socially shared metacognitive learning analysis

Metacognitive regulation was based on the scheme developed by Iiskala et al. (2021) and was coded from students' verbal communication based on the same video recordings of the small groups' learning processes as in the argumentation coding. However, metacognitive regulation was coded independently from the argumentation coding, so in metacognitive coding, the argumentation coding was not visible. The coder did not know which one of the groups was a high- or low-outcome group. In metacognitive coding, off-task behaviour was omitted from analysis (see argumentation coding) and each instance of verbal communication (i.e. a student's spoken turn) was categorised according to Table 7 as no metacognitive regulation, verbalised metacognitive self-regulation (VMSR), ignored metacognitive regulation (IMR), metacognitive other regulation (MOR), or SSMR.

For 'no metacognitive regulation', the group verbally expressed cognitive functions. No metacognitive regulation category was included, for example, reading, counting or conducting the task without observable metacognitive regulation. In VMSR, a student regulated and referred to their own thinking. In IMR, a student tried 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 regulation was goal-directed, shared and complementary. In SSMR coding, at least two turns had to be coded as such (see in detail Iiskala, et al., 2021).

Table 7. Metacognitive regulation analysis framework (see ref. Iiskala, et al., 2021).

FORMS OF METACOGNITIVE REGULATION	ABBREVIATION FOR ANALYSES	DEFINITION
No metacognitive regulation	-	Purely cognitive functions are expressed without metacognitive regulation to be observed
Verbalised metacognitive regulation	VMSR	Students regulate only their own thinking processes
Ignored metacognitive regulation	IMR	Students try to regulate the groups' common thinking processes but the other group members ignore these attempts
Metacognitive other regulation	MOR	Students regulate other students' or the group's common thinking processes
Socially shared metacognitive regulation	SSMR	Students' goal-directed, shared and complementary regulation of the group's common thinking processes, and in addition at least two students must be involved in the regulation

Descriptive statistics

With respect to argumentation and SSMR, descriptive statistics were used in Studies II and III to provide detailed information of argumentation chains and their correlation with regulation. Frequencies were computed using IBM SPSS Statistics version 28 or newer software.

In Study II, cross-tabulations and chi-square tests were performed to investigate the significance of the differences between groups with different outcomes and between the phases of the task. Statistical significance and effect size were reported using p-values as well as the phi coefficient for 2x2 cross tables and Cramer's V coefficient for larger tables. In the study, it was noted that the effect size was context-dependent and external criteria for effect size values should be interpreted more as guidelines than firmly established rules (Engle, 2012). For example, in the context of the data scrutinised in Studies II and III, small differences in the instances of communication might be statistically significant as opposed to the general rules in treating datasets statistically.

In Study III, cross tabulations were performed as a descriptive examination for relations between argumentation and regulation and expressed as two-way frequency tables and percentages. A chi-square test of independence was conducted as a test for the statistical significance of the association. However, in cases of small-expected frequencies in cross tabulations, the chi-square test was substituted with the Fisher exact test. When the result of the chi-square test was significant, Z-tests for differences between percentages were conducted as a follow-up study. The strength of the association (i.e. the effect size assessment) was conducted using Cramer's V and odds ratios with 95 % confidence intervals. Analyses for associations between argumentation and regulation were first conducted at certain time points as both argumentation and regulation were examined at the same moment in time. Then the same analysis was conducted for the association of the argumentation at a certain time, T, in relation to regulation at a time window spanning over three turns, T+1 – T+3. Studies I and IV were different in their aims and settings, and therefore they did not contain any statistical analyses.

Data-driven and theory-directing content analysis

In Study IV, the assignments and framework answers by student teachers were observed in relation to the three phases of the framework by Eggert and Bögeholz (2006): prequalification (I), selection of evaluation and decision-making (II, III), and post-selection ergo implementation phase (IV). If there were traces of a certain phase, the whole product was defined to contain characteristics of that phase. Accordingly, if there were expressed values and hopes regarding the solution to the phenomenon, the product was categorised as the selection phase of evaluation and decision-making. The post phase contained the assignments and framework answers in which applications or actions regarding the ecosystem were introduced and which were about data search and developing decision-making processes.

In the beginning of the analysis, all the ecosystems that were located on Earth and phenomena connected to them were selected and listed. The named eco systems represented both forest and water eco systems. The assignments on socio-scientific issues were divided into assignments starting with different interrogatives (e.g. what, what kind), pondering assignments, assignments based on statements, and assignments containing a claim to support argumentation observation.

According to the argumentation literature, the answers were further analysed on the following four criteria: (1) making the phenomenon understandable (Berland &

Reiser, 2009; Kuhn & Reiser, 2005.; Sampson & Clark, 2008; Sandoval, 2003), (2) creating a sufficient and useful explanation (Lawson, 2003; Sandoval, 2003), (3) justifying the explanation with appropriate evidence and reasoning (Erduran, et al., 2004; Kuhn & Reiser, 2005; Sandoval, 2003), and (4) validating the explanation and evaluating the acceptance of the explanation (Kuhn & Reiser, 2005) to ensure the sustainability of the explanation or action with everything said before. Based on the previous literature, these approaches manifested issues in which the students struggle with scientific argumentation and thus need support. Therefore the assignment's argumentative support was further condensed into three categories: preselection, selection, and post-selection (see Table 8). When analysed, if there were traces of a certain phase, the whole product was defined to contain characteristics of that phase. For example, if values and hopes regarding the solution to the phenomenon were expressed, the product was categorised as the selection phase of evaluation and decision-making.

Table 8. The framework for the argumentative support of student teachers' assignments.

PHASE	META MODEL OF DECISION MAKING
Preselection	identifying decision-making situations, data search, evaluation process, and forming intentions as procedures
Selection	evaluation and decision-making, developing decision making processes, evaluation processes, reflection, comparing factual knowledge, attitudes and norms
Post selection	implementation of the selected process

4 Overview of empirical studies

This dissertation includes four studies that examine and extend the understanding of scientific argumentation that spontaneously emerges during collaborative virtual science learning. Each study applied diverse methods and supplements the others by proceeding from a preliminary study with a virtual laboratory developed by an external research group to a study combining scientific argumentation with SSMR in the condition of using the virtual learning environment developed by our own research team. Study I was a preliminary study focusing on the principles of student interaction and spontaneous spoken argumentation in line with group outcomes in the context of virtual collaborative science learning. Therefore, it established the basis for a thorough argumentation analysis scheme, which came to realisation in Study II. Study II introduced and examined the argumentation analysis scheme for spontaneous spoken scientific argumentation as well as the virtual learning environment that had been developed as a part of this project. Study III merged the analysis of spoken scientific argumentation with the analysis of socially shared metacognitive learning to provide an insight into the complicated and multi-layered nature of student group discussion while the students were executing a complex task in the virtual learning environment.

4.1 Study I

Telenius, M., Yli-Panula, E., Ahtineva, A., & Vauras, M. (2019). Collaborative science lessons—Learning and argumentation in an interdisciplinary virtual laboratory. *Tutkimuksesta Luokkahuoneisiin. Suomen Ainedidaktisen Tutkimusseuran Julkaisuja; Rautiainen, M., Tarnanen, M., Eds*, 15, 35-56.

The aim of this study was to investigate upper secondary school students' spontaneous argumentation and interdisciplinary integration of biology and chemistry in a virtual learning environment during science lessons. The aim was also to elaborate on the connection between students' content knowledge and scientific reasoning and spontaneous argumentation during a virtual science inquiry. Content knowledge and scientific reasoning were measured before and after the virtual inquiry intervention, and it was collected in two upper secondary schools. Students

(N = 35) collaborated in small groups (N = 13) to generate hypotheses, study plans and presentations, which were analysed by SOLO taxonomy, and this data was supported by videotaped spoken products. The results of this qualitative study showed that the students were able to generate hypotheses despite the non-supportive curriculum and were able to integrate biological and chemical concepts and spontaneously argue in a virtual environment. Therefore, the results demonstrated the occurrence of collaborative argumentation and interdisciplinary integration during a virtual inquiry. The outcomes of the group performance reflected students' ability to integrate their knowledge in biology and chemistry and engage in spontaneous argumentation. However, the results hinted that a well-structured hypothesis did not guarantee a high-grade final presentation, and the number of declined hypotheses was not associated with the level of final outcomes in presentation.

In conclusion, Study I showed the importance of scientific argumentation in understanding complex interdisciplinary concepts and the need to implement socio scientific issues in science learning to promote argumentation and integration of separate science domains. This study validated the presence of spontaneous spoken argumentation in small group discussions, although use of argumentation was not instructed. That validation was promising with the development of our own virtual learning environment and the basis of Study II in mind.

4.2 Study II

Telenius, M., Yli-Panula, E., Vesterinen, V. M., & Vauras, M. (2020). Argumentation within upper secondary school student groups during virtual science learning: Quality and quantity of spoken argumentation. *Education Sciences*, *10*(12), 393.

The aim of this study was to relate the quality of spoken argumentation to groups' learning achievement during a collaborative inquiry task. The data included video recordings of six groups of three upper secondary students performing a collaborative inquiry task in a virtual learning environment. These target groups were selected from a larger sample of 39 groups based on their group outcome: two low-, two average-, and two high-outcome groups. After the selection of the video segments and tagging of the verbal turns of students, analysis focused on argumentation chains during the students' discussions in the planning, experimentation, and conclusion phases of the inquiry task. The core of the coding scheme was based on Toulmin's levels of argumentation, which was modified to suit the context of spoken spontaneous argumentation with emphasis on interdisciplinarity and usability. This novel analysis framework was one of the most prominent aspects of Study II. The results revealed differences between the groups of students, with high-performing groups engaging in more argumentation than average- and low-performing groups. In high-performing groups, the students asked topic-related questions more frequently, which started the argumentative discussion. Meanwhile, there were fewer questions in the low-performing groups, most of which did not lead to discussion. An evaluation scheme for the quality of the arguments was created and the spoken argumentation was analysed using a computer-based programme. The results may be used to benefit subject teacher education and to raise teachers' awareness of their students' scientific, topic-related discussions.

In sum, the results of this study align with the previous literature, indicating the significance of spontaneous scientific argumentation and an appropriate learning environment while teaching complex interdisciplinary topics. Consequently, Study II extended the understanding of spontaneous spoken argumentation in science lessons and added a framework to analyse spoken argumentation into the current argumentation literature.

4.3 Study III

Telenius, M., Iiskala, T., Laakkonen, E. & Vauras, M. (2025). Spontaneous scientific argumentation and socially shared metacognitive regulation of high- and low-performing small groups in virtual collaborative science learning. *The Journal of Research in Science Teaching, 0:1-19.*

The aim of this study was to relate the quality of spoken argumentation to groups' members' level of SSMR during a collaborative task in the form of a virtual learning environment. The data included video recordings of four groups of three upper secondary students performing a collaborative task in a virtual learning environment. The groups for this study were selected from a larger sample of 39 groups based on their groups' outcomes: two low-, and two high-outcome groups. The coding scheme presented in Study II was used to code these video samples along with a coding scheme for socially shared metacognitive learning. The results showed that high-performing groups had more SSMR within their chains of argumentation when compared to their lower-performing counterparts. The low-performing groups had still their share of metacognitive regulation, but that did not lead to true regulation of their group's work, nor did it lead to a higher level of argumentation over the topic being the task of the group.

To conclude, Study III was among the few studies considering both argumentation and metacognitive regulation. Connecting these two phenomena is especially prominent, as the previous literature has identified that metacognitive regulation and argumentation are deeply intertwined during collaborative learning.

Understanding the nature of this interconnectedness has a major potential to advance science education and teacher education as well.

4.4 Study IV

Yli-Panula, E., Jeronen, E., & Telenius, M. (2021). Argumentaatiotaitojen harjoittaminen ekosysteemiopetuksessa: aiheena yhteiskunnallis-luonnontieteelliset ilmiöt. [Practicing argumentation skills in ecosystemic teaching: socio-scientific issues as a topic]. *Opetuksen ja oppimisen ytimessä*. Suomen ainedidaktinen tutkimusseura.

Study IV examined assignments and tasks constructed by student teachers of biology and geography that aimed to teach high school students argumentation skills. The participants (n=39) drafted and answered their own SSI - themed task. In addition, the kinds of perceptions of ecosystems, their phenomena, and related SSI transmitted through these assignments were considered. Assignments and answers were analysed using content analysis. Tasks created by the student teachers focused on forests, aquatic ecosystems, and Australian nature. Tasks supporting the practice of argumentation were mainly in the form of 'discussion'. They contained little decision-making or implementation typical of argumentation. Four of the 39 responses defined the SSI. The study results exhibited that the biology and geography student teachers did not have a clear understanding of SSI regarding ecosystems and their phenomena.

In conclusion, teaching should therefore explicitly include socio-scientific problems that require reasoning based on scientific evidence. As the previous literature and studies included in this dissertation have demonstrated socio scientific topics provide a fostering medium for spontaneous scientific argumentation and deeper learning of science topics. Thus, by bringing student teachers into focus, this study continued the research branch started in Study III and closed the circle.

5 Main findings and discussion

5.1 Main findings of the studies

The main purpose of this dissertation was to examine the spontaneous spoken argumentation within collaborative science lessons that utilised a virtual learning environment directed at fostering inquiry learning about certain topic-specific issues in the same way as the researchers carry out their studies. This overall aim was constituted on the accomplishments of previous literature regarding general argumentation in educational contexts and specifically scientific argumentation on the ground of written or spoken products and ways to promote students' skills in scientific argumentation and metacognitive regulation. Thereby, this dissertation endeavours to deepen the apprehension of spoken scientific argumentation as it unfolds naturally and spontaneously while students collaboratively work on a complex interdisciplinary task over a virtual learning environment by emphasising students' spontaneous argumentation and regulation over strict instructional and explicit settings. In addition, a significant purpose was to introduce an argumentation framework for the purpose of analysing students' spontaneous spoken argumentation and, moreover, a way that that enables integration of other aspects of learning (e.g. metacognitive regulation). Lastly, the purpose was to study how the learning setting in the form of a virtual environment and assignments can be structured to be beneficial for students and which features are the most prominent for promoting argumentation and regulation and thus learning itself.

To complete these purposes, four studies were conducted of which the three first were empirical and the fourth focused on theory-driven, literature-based classification of data. In Study I, the features of spoken scientific argumentation in the context of a virtual learning environment were perceived jointly with the level of collaborative outcome. Study II built upon this by establishing a novel analysis scheme for spoken argumentation in a specifically constructed virtual learning environment emphasising the connection to the quality of the co-products. Study III then effortlessly united the aspect of spoken argumentation to metacognitive regulation as they both manifested in the setting without explicit prompts. Lastly, Study IV knitted this investigative arch together by bringing focus on student teachers, teacher education, and assignment drafting in the context of socio-scientific issues which again are naturally favourable to spontaneous argumentation.

The main findings of this dissertation can be summarised as follows. First, scientific argumentation arises spontaneously in students' collaborative small groups when the task is open-ended in regard to the goals, approaches to the goal, and how results are discussed and presented. Second, the results demonstrate a connection between high-quality collaborative outcomes and profound spontaneous argumentation. Third, the findings confirm that the quality of the collaborative outcome and argumentation is connected to stronger metacognitive regulation when compared to lower-performing small groups. Fourth, student teachers tend to implement argumentation spontaneously when asked to draft assignments about socio-scientific issues, which in turn has the potential of promoting students' argumentation in science lessons. Below, the key outcomes of the four studies are briefly captured before the discussion of the contributions.

Study I found that scientific argumentation appeared spontaneously when students were discussing and collaboratively generating hypotheses and study plans. In group discussions, spontaneous interdisciplinary argumentation arose, although it was neither instructed nor encouraged before the inquiry activity. The argumentative discussion demanding content knowledge helped students to better understand complex environmental issues, which was noted in the correlation of high-level hypotheses, study plans, and final outcomes with the level of students' spontaneous argumentation. Therefore, argumentation offered a means of social interaction and engaging in collaborative science learning, which was observed among students in the small groups and therefore assisted students to achieve their goal (Celik & Kihc, 2013). The socio-scientific topics of the virtual studies including (e.g. climate change and ocean acidification) promoted spontaneous spoken argumentation expanding over more than one discipline, as they cannot be properly addressed by one discipline (Osborne, 2010). This allowed students with different assets to participate in the discussion and thus contribute their part to the common product. In that sense, spontaneous argumentation highlighted the interdisciplinary nature of the virtual laboratory context, as the students had to justify their study methods and study plans using integrative reasoning. Accordingly, when spontaneous argumentation arose in written presentations, biology and chemistry were integrated into the hypotheses and study plans. The students justified their arguments using biological and chemical concepts (e.g. using the concepts of population, chemical and physical environmental factors).

More commonly, students enacted interdisciplinary integration, implying that they discussed the given topics using concepts from the disciplines of chemistry and biology. Thus, in this study, the virtual learning environment fostered interdisciplinary reasoning and learning. These findings were encouraging as success in science studies does not guarantee availing of interdisciplinary learning. In addition, it was demonstrated that students with high reasoning skills performed better on the chemistry and biology content tests than those with low reasoning skills, which was evident across all groups and highlighted the meaning of argumentation in collaborative learning. In addition, a professionally structured hypothesis or study plan did not guarantee a high-grade final presentation, and the number of declined hypotheses was not associated with the level of final outcomes in the presentation. In that sense, the virtual learning environment accurately reproduced a real-life laboratory situation, where a thorough study plan does not ensure the success of the experiment. However, no uniform score changes between pre- and post-tests were observed. The two student groups selected for the argumentation analysis demonstrated remarkable abilities to integrate biology and chemistry in their hypotheses, study plans and argumentative discussion but differed significantly in how they collaboratively contribute towards a common goal. The difference was most striking in that the better-performing group's argumentation was led by one student but all students' contributions were implemented, collaboratively constructed knowledge was identified, and the teacher encouraged the students to move on with their reasoning regardless. By contrast, the lower-performing group was restrained by one student leaving no possibilities for the others to participate in discussion, which weakened the incorporation of individual students' ideas, and the teacher did not contribute to the results. The preliminary results highlighted the importance of a challenging collaborative task on interdisciplinary issues in the context of a virtual learning environment.

Study II proved that better argumentative discussion led to better qualitative outcomes (Sampson & Clark, 2009). Most significantly, Study II introduced its own way to code spontaneous spoken argumentation in the context of collaborative group work as an outcome of this study. In addition, the virtual learning environment prompted students to argue, although this was not instructed nor structured in an explicit way, which demonstrated that a socio-scientific topic in science education fosters argumentation if it is implemented in a lesson in a way that promotes collaborative discussion (Khifste, 2022). It therefore has the potential to engage all students in the discussion. Finally, this study showed new findings about scientific argumentation with its sole focus on spontaneous spoken argumentation during a collaborative inquiry task, including the notion that students were able to achieve the highest quality components of argumentation in the top performing groups; questions containing a vessel for a claim were crucial for the beginning of spontaneous argumentation chains, as well as the ability to advance the argumentation with links to theory and interpretations of the results.

Distinct connections were demonstrated to exist between the differences in argumentation within each phase and the outcomes of the groups. The working phase in the virtual learning environment was also decisive for spontaneous argumentation, which was demonstrated by the planning phase being the most prominent environment for rich argumentative and topic centred discussion. Insurmountably, it contained the highest proportion of on-task argumentation across all performance level groups. During the conclusion phase, the argumentation focused on interpretations, and the proportion of questions promoting argumentation was the lowest of all the phases. In low-performing groups, discussion was non-argumentative in nature for the most part. In contrast, the high-performing groups engaged more in argumentation during the collaborative group work than the average- and low-performing groups. Although the average quantity of verbal communication differed across the groups, the average- and high-performing groups engaged considerably more in argumentation than the low performing groups. Interestingly, all these argumentative components were present in the average-performing groups but in lesser numbers when compared to the high-performing groups. Particularly, the most qualified components were missing in the discussion of average-performing groups. The low-performing groups were most commonly in the non-argumentative zone. Only a small portion of the low-performing groups' topic-relevant discussion was argumentative, and these groups engaged the least in argumentation. Complementary, the low-performing groups were not able to ask questions and promote argumentation within their group.

Study III found that spontaneous spoken argumentation was connected to SSMR both in the low-performing groups and in high-performing groups across all working phases in the virtual learning environment. Thus, it was found that metacognitive regulation and spontaneous spoken argumentation co-occur when students are executing their task (Jin & Kim, 2021). Interestingly, the high- and low-performing groups differed somewhat qualitatively and in the proportions of different modes of regulation. The study found that when comparing questions starting argumentation chains to the next steps of spoken argumentation (i.e. observation and interpretation) within metacognitive regulation, SSMR and no metacognitive regulation were related to different steps of argumentation. Most importantly, SSMR was connected to questions supporting the initial hypothesis of this step being the most crucial for deep metacognitive learning, as well as to the questions that have the potential to promote argumentation. Thus, students regulated their learning when they asked questions on how to proceed with the task and the topic. Secondly, SSMR was significantly more likely to occur during the early steps of argumentation chains when considering all the small groups of low- and high-performing levels or taking account of the group level, which emphasised this finding more so. Thirdly, it was demonstrated that there was no statistical difference between steps of spontaneous spoken argumentation during a time interval of three turns within SSMR and all other forms of regulation. The patterns were similar in the small groups. Spontaneous argumentation and SSMR were observed to alternate as the students evaluated the data, engaged in argumentation over ways to accomplish the task, and interpreted the results. Moreover, students made spontaneous arguments, demonstrating and arousing metacognitive regulation. However, for the high-performing groups, the frequencies of metacognitive regulation compared to turns was much higher, and the occurrence of SSMR was more likely during the argumentation chains. Despite the statistically insignificant result, it is clear that the high- and low-performing groups are different in regard to regulating learning and spontaneously engaging in argumentation.

Thus, metacognition was a predictor of deeper argumentation and discussion within the student groups. This demonstrated that responsibilities normally handled by the teacher were transferred to students. In turn, this seemed to increase students' pressure to engage in argumentation and strive for success in their collaborative inquiry learning task (Santangelo, et al., 2021). The virtual learning environment fostered students in reflecting their arguments, ideas, and reasons and developing understanding of the content concepts, argumentation and metacognitive regulation. Study III verified that high-performing groups had a distinct orientation towards success in the collaborative task and excelled in the number of unique ideas to proceed and interpret results, responses to these ideas and challenges, criteria used to distinguish between the steps of the task, and use of available data when compared to the low-performing groups (Vuopala, et al., 2016) in the context of a virtual learning environment.

Study IV found that only some student teachers were able to incorporate argumentation-promoting components when drafting assignments and answers in the context of socio-scientific issues, which favor spontaneous argumentation as addressed in Studies I-III. As such, the assignments were shown to be a prominent foundation for the incorporation of spontaneous argumentation in science education. However, the socio-scientific problems were not defined in nearly all assignments, but they appeared as a reference to human action.

The assignments proposed by student teachers were versatile in their topics and contents. In the assignments and framework answers there were also contents enabling argumentation, even though typical characteristics of argumentation (e.g. decision-making and the appliance of knowledge) were only present in a minor part of the results. However, assignments and framework answers requiring pondering on certain topics were common. Still, only a few answers clearly stated the socio-scientific problem.

Most of the student teachers' answers to their own assignments represented the traditional written answer without an emphasis on argumentation. The answers contained mainly the first steps of argumentation chains. From this perspective, only a few of the assignments by student teachers explicitly supported the development of argumentation skills, even though the original task assignment prompted that. Noting one's viewpoints was only in a couple of answers. The actual formation of a claim and its critical evaluation based on evidence and predicted counterclaims were lacking from most answers. The results showed that student teachers would need support in the argumentation chains to make the phenomenon more understandable, create the explanation, justify and validate the phenomenon, and evaluate the acceptance of the claim. However, the current task assignment offered an excellent basis for the development of argumentation skills and support of critical steps. However, the assignment and the description of the framework answer should have clearly stated how argumentation is used in the socio-scientific decision-making process.

Accordingly, in their answers, the student teachers resorted to the selection phase of argumentation by evaluating source material's reliability and validity. Moreover, they evaluated the topic phenomenon, validity and quality of the product, realisticity of the actions, and their own products and conclusions. The upper secondary students were instructed to assess their own actions in three answers that contained evaluations of explanations and justifications supporting argumentation. The evaluation scale of the student teachers did not focus on argumentation-characteristic justifications. The human actions were mostly considered in the answers to the assignments.

The steps of a decision-making process lacked in half of the answers, and socio-scientific problems' decision-making process was not presented in any answers. Only some single and general mentions fell under this category. The implementation phase typical for argumentation was, however, presented in most answers to the assignments. As a whole, the student teachers do not have a clear perception of eco systems and their phenomena in the context of socio-scientific problems, which can pose challenges to science education and the integration of scientific argumentation.

5.2 Theoretical contributions

The four studies included in this dissertation make theoretical contributions to both collaborative and computer-supported science learning as well as teacher practises in regard to task assignments. The dissertation extends the understanding of spontaneous spoken argumentation and procedures to naturally promote argumentation in the context of virtual learning environments and science education. Scientific argumentation has been observed in its spontaneous spoken form (e.g. Jiménez-Aleixandre, et al., 2000; Baker, 2002; Saddler, 2004) and in the setting of a virtual learning environment (Reiser, et al., 2012) in a limited number of studies. The dissertation completes the findings of the previous literature concerning the important role of argumentation in science learning and the invocation of a socio scientific topic as an argumentation fostering ground by providing new knowledge on the understanding of spontaneous spoken argumentation and the relationship between scientific argumentation, group performance, and metacognitive regulation, as well as the appropriate virtual learning environment and task setting.

A virtual laboratory promotes spontaneous scientific argumentation and the integration of two disciplines, biology and chemistry, which was demonstrated in Study I. In the utilised virtual learning environment students were required to collaborate to frame and eventually select the most appropriate scientific explanations through argumentation and reasoning. The virtual learning environment is therefore approrpiate for sociocultural purposes and makes the steps of conducting scientific research a visible part of classroom learning, which is seldom carried out in this subtle way. The marine biology material around which the virtual environment was implemented proved to be suitable for integrating biology and chemistry, as it contained chemical concepts and students needed chemical reasoning to formulate hypotheses and analyse study results. Thus, the virtual learning environment fostered the integrated use of concepts from the two disciplines and was able to foster interdisciplinary reasoning and learning. The implementation during biology and chemistry courses and the collaboration of the biology and chemistry teachers contributed to the same goal. These findings complement and adeptly align with the study by de Magistris (2005), which examined the integration of mathematics and physics for university students. In that study the course was similarly based on a virtual learning environment, and the students exhibited increased comprehension of theoretical subjects. The integration of biology and chemistry on an upper secondary school level was lacking in the previous literature. Taber (2008) also emphasises that interdisciplinary integration is important in science education and constructing knowledge of comprehensive science concepts and topics. Significantly, the students were able to integrate scientific concepts across biology, chemistry and physics in Study I.

As a continuation, students with high reasoning skills performed better in the chemistry and biology content tests than their counterparts with low reasoning skills, which was evident in all groups. This result of Study I is in harmony with Lawson’s (2000) findings. He found a relationship between hypothesis testing skills and lecture content exams, and based on his findings, emphasised the importance of argumentation in the collaborative learning process. To understand complex scientific concepts and theories, students must develop the necessary reasoning abilities with the support of their teachers (Lawson, 2004; Kuhn, 2010). This dissertation diverged from the established consensus of the teacher support in not necessitating the support but contrariwise instructing the teachers to intervene as few as possible in small group work. Therefore, Study I evinced that the students were still able to form scientifically valid hypotheses and reason over the explanations, which had not been proven in the previous literature.

Once again, the use of a virtual learning environment in a collaborative learning context and the notion that even without distinct instructions, the students argued over the work phases, concepts, and theories, was seminal. Hence, Study I neatly brought its share to the previous findings of students spontaneously resorting to argumentation when learning in an environment that takes advantage of small group discussion, where students are subjected to criticism and resilience for changing views, and teachers act as intellectual authorities rather than mediators of ready-made knowledge (Duschl, 2008; Chinn & Clark, 2013; Osborne, 2010; Ryu & Sandoval, 2015). A similar study(Aydeniz, et al., 2012) examined the impact of argumentation-based education on college students and showed that students in the intervention group performed significantly better than control group students, as argumentation created a social environment for learners to elaborate and receive feedback on pre-existing ideas in chemistry.

A significant difference in the low-, average-, and high-performing group members' engagement in argumentation, while the group performance evaluation was exclusively based on the collaborative outcome was powerfully proven by Study II. This finding complements the previous literature, which has shown that longer and more intense student discussion on a topic leads to a deeper understanding and learning (Zhao, et al., 2018; Sampson & Clark, 2009). More importantly, when classroom activities change toward argumentation practises students can generate better learning outcomes (Chen, et al., 2016), as found in Study II. The other key finding was that the three lessons long engagement in argumentation was subdividing between the high- and low-performing groups and its relation to better outcomes. This result was due to a longer working phase helping students generate more in-depth arguments and interpretations based on scientific data, which was in line with previous research (e.g. Georgiou, et al., 2020). Despite the relatively short duration of the virtual collaborative learning intervention, the results were contradictorily similar to previous studies' outcomes with considerably longer intervention times. This incongruity might indicate that the capitalised setting was more impactful on students' learning and promotion of argumentation skills with a balance with instructions and intellectual freedom. Thus implemented with these unique features, the setting of Study II, where students needed to construct an understanding of the task, discuss the topic, and write a representation together, separates students who engaged in deep discussion and argumentation in relation to deeper learning as opposed to students who did not, which is in line with literature (Van Amelsvoort, et al., 2007). Notably, in the case of Study II, as in Study I, the settings consisted of three phases: construction of a presentation, discussion of the topic, and consolidation which formed strong evidence for the positive correlation between the virtual learning environment structure and learning outcomes. As for the framework to analyse spontaneous spoken argumentation in the context of collaborative science learning, no such scheme has been presented in the previous literature. This intelligible argumentation analysis framework is a prominent contribution to the research field of scientific argumentation and science education as a whole.

Complementing these results, metacognition was demonstrated to be a significant predictor of deeper argumentation and discussion within the student group as students were responsible learners instead of acceptors of new knowledge, which led to a situation where students needed to engage in argumentation. This theoretical contribution of Study III complements the previous literature (e.g. Panahandeh & Asl, 2014) with a new perspective on rooting spontaneous spoken argumentation and metacognitive regulation in science education that has not been implemented as such before. The co-occurrence of metacognitive regulation and spontaneous argumentation was proven to manifest. Although being in line with the previous literature (Jin & Kim, 2021), this interrelation of metacognitive regulation and argumentation has not been shown to occur when there have been no explicitly stated structures for argumentation or metacognitive regulation. As an open-ended task, the virtual environment encouraged students to engage in argumentation and reflect their arguments, ideas, and reasons, simultaneously promoting the development of students' understanding of the task goals and evidence-related norms of argumentation and metacognitive regulation. However, concerning SSMR in science education, there is no prior evidence on which to lean in regard to the findings of Study III. This is a significant research gap and absence of previous data onto which this study brought new knowledge from its part, thus completing the theory of SSMR and argumentation.

On the contrary, it was demonstrated that the high- and low-performing groups in relation to their collaborative outcome and argumentation level do not differ that much in the proportions of different modes of metacognitive regulation (i.e. no metacognitive regulation, verbalised metacognitive self-regulation, ignored metacognitive regulation, metacognitive other regulation, and SSMR) but do differ qualitatively. The finding of weak metacognitive regulation being associated with weaker learning outcomes and argumentation complements the previous literature (Santangelo, et al., 2021; Lobczowski, et al., 2021) in the context of virtual learning environments. In the high-performing group, the orientation towards successful learning task as well as little or no off-task discussion were observed. This aligned with the previous literature (Vuopala, et al., 2016) with the introduction of SSMR in relation to spoken spontaneous argumentation. Therefore, this study reinforced the established comprehension of the low- and high-performing groups differing in the number of unique ideas introduced into the conversation, responses to these ideas, opposition to these ideas, criteria, and available data used to distinguish the ideas with new knowledge. This reinforcement of the previous knowledge was accordingly supported by the literature (Sampson & Clark, 2011), but exclusively in the traditional classroom, unlike in this dissertation.

Spontaneous argumentation and SSMR were observed as students evaluated the data, argued over ways to accomplish the task, and interpreted the results, which were correspondingly in line with the literature (Kalemkus, et al., 2021), and expanded the existing theory to cover virtual learning environments, resorting to tactful instructions. Students engaging in spontaneous argumentation also demonstrated metacognitive regulation, as was speculated by the literature (Marthaliakirana, et al., 2022), and the transposition of metacognitive regulation and argumentation was thus proved.

In regard to the contributions of Study IV, it solidified the theory of student teachers choosing to teach forest ecosystems as was suggested in the previous literature (Nupponen, et al., 2019), according to which student teachers appreciate forests as a learning topic. The concerns expressed by the student teachers regarding eco systems were somewhat similar to the concerns in the study by Nupponen and others (e.g. climate change and decrease in nature diversity), but Study IV widened the previously presented list with various threats and catastrophes to pristine nature and species. These topics (e.g. threats to water systems and ecosystem catastrophes) are especially appropriate for socio-scientific issues because they are current, real-life problems (Sadler, 2009; Sadler, 2011) that do not offend anyone personally or ethnically (Marks & Eilks, 2010). Therefore, the previous general theories were fleshed out with practical examples and elaboration of the ideas in Study IV. However, the socio-scientific problems were not defined nearly in all assignments, which emphasised the need for explicit inclusion of socio scientific issues in the current theories. However, the assignments and problems had been connected as part of global changes and threats in most answers because nature topics offer a natural basis for handling socio-scientific problems as presented in the previous literature (Roy, 2019; Semken & Freeman, 2008; Tal & Kedmi, 2006).

Moreover, the socio-scientific topics from the emphasised viewpoint of human activity would have offered potential conditions for argumentative discussion according to previous studies (e.g. Herman, et al., 2019). Nevertheless the assignments and answers did not support this notion. The formed assignments, on the one hand, represented question, discussion, verification, and statement types, but on the other hand, they did not develop these aspects towards any argumentation demanding assignment. A statement assignment is the most natural assignment type for high-quality argumentation because it prompts the answerer to use arguments rather than questions and supports the argumentative consideration of the contents (Toulmin, 1958), but the answers to these assignments were not written to support argumentation. Therefore, even these assignment types were inconsistent with argumentation theories. Likewise, argumentative roles were mentioned in only one text, and similarly with the argumentation components these roles were not broadened further. According to the previous literature (Agell, et al., 2015), argumentative roles should support the formation of opinions, critical thinking and argumentation skills but this was not demonstrated by Study IV.

Furthermore, argumentation skills are affected by previous knowledge as well (Chang & Chiu, 2008). The student teachers aimed to take ecological knowledge into account in their assignments and framework answers to support argumentation, but instead, societal knowledge was rarely considered. However, societal environmental knowledge is required in discussing socio-scientific issues (ICEE, 1997). Comparing scientific and societal knowledge while studying technology and the effects of its development on climate, or ecosystems, and biodiversity offers excellent possibilities to expand and deepen upper secondary students' perceptions of sustainable development (Wals, 2014), but student teachers failed to grasp and implement this aspect in their assignments. The type of argumentation chosen by the student teachers, who utilised argumentation at least to a certain extent, was written argumentation in accordance with previous studies (e.g. Osborne, et al., 2004). However, during the current era of computer-supported teaching and social media, the meaning of socially spoken-based argumentation arises (Telenius, et al., 2019), and this was not considered in the assignments. Equally important decision-making processes for argumentation were absent from half of the answers, which was not expected based on the previous literature (Eggert & Bögeholz, 2006). Instead, in line with the previous literature, the implementation phase was emphasised in the answers, which was natural and appropriate for addressing socio-scientific problems.

5.3 Methodological contributions

The methodological contributions of this dissertation expand on earlier research into scientific argumentation and metacognitive regulation. As the key aspects of this dissertation, scientific argumentation and metacognitive regulation were observed in their natural educational environment during science lessons. The contributions thus reflected the spontaneous instances of spoken scientific argumentation in the context of a virtual learning environment. Additionally, another important methodological contribution of this dissertation is the social systematic analysis of argumentation by means of a multimethod approach. This approach enabled us to observe argumentation over three lessons spanning period of time, both on a general level and in more detail, implementing a novel analysis framework for spontaneous spoken argumentation. Moreover, this dissertation contributes greatly to metacognitive research in educational psychology by incorporating metacognitive regulation into the same coding system and observing the interrelation of spontaneous argumentation and metacognitive regulation during collaborative inquiry learning. In addition, this dissertation contributes methodologically by examining the features of virtual learning environments and traditional task assignments that promote and foster scientific argumentation. Thus, this dissertation is positioned in science education and touches upon teacher education. All the methods were mutually complementary and reinforcing in their aim at explaining spontaneous spoken argumentation in virtual inquiry learning.

The methodological procedure of a qualitative and case study with a heavy emphasis on several individual performance-explaining assessments of students and student groups was utilised in Study I. The main motivator for this repertoire of methods was the preliminary nature of this study. The combination of pre- and posttests and ready-made tests provided a strong methodological basis for the refinement of the upcoming studies and the development of the virtual learning environment. This eloquent integration process revealed the relation between students' scientific reasoning and content knowledge. The methodological approach was further strengthened by assessments of student groups' PowerPoint presentations, grant applications, hypotheses, and study plans, which were quite ponderous and unique for a preliminary study. Hence, it is noteworthy that with the use of several methods and data sources the importance and multifaceted nature of science education were adequately emphasised. To construct as precise a general view as possible, groups for detailed argumentation analysis were selected based on the assessed outcomes of the groups. This methodological step included the choosing, editing, and analysis of the appropriate videotaped extracts. The combination of several data sources was methodologically inventive and, as such, led to the generation of the term spontaneous spoken argumentation which is the leading premise of this dissertation. In addition to argumentation, the study methods enabled the integration of biology and chemistry with the rich data from content tests and students' hypotheses and experimental plans. The small size of the preliminary data limited the methodological contributions to a certain extent but the combination of several data sources formed an intact overview of the student discussion during collaborative science inquiry learning giving promising findings for subsequent studies.

Study II utilized both quantitative and qualitative methods as the number of selected small groups was relatively small, but the number of separate oral turns and excerpts were significantly myriad, bringing this study close to a quantitative study. Thus, a qualitative video analysis was the primary source of data for this study. As a product of this in-depth qualitative video analysis an argumentation analysis scheme was introduced. The introduced scheme benefitted from several prevalent and commonly accepted argumentation theories, but most notably from Toulmin's traditional scheme (Toulmin, 1958) which has a dominating status in the scientific argumentation research due to its clear, easy-to-analyse structure. Its two distinguishing factors as an argumentation analysis framework were to bring spoken spontaneous argumentation to the forefront and to ground the framework in the context of a virtual collaborative learning situation. This methodological orientation was supported by the findings of the previous literature (e.g. Sandoval, et al., 2019), in which productive argumentation in classroom-type spoken situations was promoted by combining discourse practises specifically with a collective sense-making goal.

The naturally arising scientific aspect of the analysis framework was introduced by ensuring its suitability for science lessons in a virtual learning environment. To avert odds for miscoding, the scheme could not be too complex, but a balance between the depth, complexity, and fluency of the argumentation-coding was achieved. As the results convincingly showed, this framework enabled argumentation analysis in the three distinct argumentative phases – planning, experimenting, and making conclusions – while implemented at the same time in the ViBSE collaborative virtual learning environment. A prominent feature of this framework could be that it supplements ready-existing frameworks with a template for spontaneous, spoken scientific argumentation, which research literature would have otherwise lacked. Since Driver, Newton, and Osborne (2000) introduced argumentation as an important discursive practice, written scientific argumentation has received most of the focus in research papers (e.g., Duschl & Osborne, 2002; Zohar & Nemet, 2002). Few studies on spoken argumentation have been conducted in science (e.g., Telenius, et al., 2019; Sandoval, et al., 2019), which created challenges for the methodology of Study II yet, offered a gap to be filled.

In addition to these methodological contributions, the argumentation analysis framework was conceded reliable over time and content wise since the videotaped sessions spanned several lessons and separate phases and included critical components from argumentation theories. The study was not repeated with the same group after a certain time, which was a drawback but did not diminish the accomplishments of the methodology. The framework's criterion validity was also intact since the argumentation coding gave results in line with the outcomes of the selected groups. Therefore, the argumentation not only in the form of an analysis framework but also actualized in a real outcome. Methodologically notable is that the transferability of the framework to other science lessons is admissible. However, a condition for this is that argumentation is not explicitly required and instructed, and there is a virtual environment to provide students with a common ground for collaborative inquiry. Additionally, the transferability has a minor limitation since, in the strict statistical sense, the framework is valid only for the six groups selected for Study II and not for all 39 groups forming the original data source. Therefore, individual differences between the students affecting the outcome of the whole group may be expected if this framework had been targeted on the whole dataset. However, this methodological weakness was bolstered by mixing different learners into groups in collaboration with the science teachers. Nonetheless, the framework distinguished evidently argumentation from other verbal communication, which was a fundamental generalisation over all the groups. In summary, Study II created an overall view of spontaneous spoken argumentation during small group inquiry in science lessons and therefore formed a favourable basis for Study III with respect to methods.

Argumentation analysis was further strengthened by metacognitive regulation coding in Study III. The same qualitative video analyses as in Study II formed the backbone of Study III, but the methodology was supplemented with the versatile and theoretically confirmed metacognitive regulation framework. As with the argumentation analysis, the number of separate verbal turns was high despite the number of groups being limited to four. It was remarkable that spontaneous scientific argumentation was combined with metacognitive regulation, which has not been studied in the previous literature in this manner.

The analysis framework for metacognitive regulation distinguished confidently SSMR and cognitive action from other forms of metacognitive regulation. This factor was important, as the main methodological aim was to observe phases of argumentation with SSMR in addition to the general view of metacognitive regulation over the small groups' collaborative work. Lastly, the merging of coding schemes and analysis frameworks for argumentation and metacognitive regulation was one of the most impactful methodological contributions of the dissertation.

Thus, the interconnectedness of spontaneous spoken argumentation and SSMR was a novel methodological finding of Study III that was further evidenced with statistics. A statistical significance was found between questions starting argumentation and SSMR within concurrent singular instances and sequential chains of spoken discourse. That was a methodological merit that has not been demonstrated in any previous literature. Similarly with the limitation in Study II, observations about argumentation and metacognitive regulation are, in the strict sense, valid only for the four groups selected for the thorough analysis. However, the metacognitive regulation framework had a good reliability over time since the study spanned over three phases and several lessons as well as content since the framework was founded upon metacognitive theories. Likewise, the metacognitive analysis framework was valid in terms of criterion because it yielded results that were to be expected based on both argumentation and metacognitive regulation theories from the outcomes of the selected groups.

As a continuation of the methodological contributions the integration of these two frameworks enabled us to observe patterns during small group work in relation to argumentation and metacognitive regulation. A statistically significant pattern in the high-performing groups was noted, but the same was not observed in the low-performing groups. Nonetheless, this was an interesting finding not presented in previous literature and upon which follow-up studies could be built. As a whole, Study III illustrated the complex nature of collaborative learning, where scientific argumentation and metacognitive regulation intertwined to form a vessel for transferring science knowledge, practises and culture.

A data-driven and theory-directing content analysis was introduced into the repertoire of methods in Study IV as student teachers' assignments and answers were analysed in relation to utilising biological and geographical theories in the context of socio-scientific issues, and thus the emphasis shifted onto treating qualitative data. The student teachers' assignments and answers were also analysed from the point of argumentation, which suppors expanding the methodological spectrum from student small groups to teacher education but restricting to science education. The argumentative aspect arose naturally because solving socio-scientific problems required justifications and argumentation, as was demonstrated in Studies I-III. Therefore, Study IV focused on studying and analysing complicated socio-scientific issues from the viewpoint of scientific argumentation. The theory-directing analysis took advantage of the known Toulmin's argumentation theory (Toulmin, 1958), including the argumentation analysis framework.

From the perspective of methods, the approach to analyse argumentation fused several theories but principally followed the three phases of Eggert and Bögeholz's framework (2006): prequalification, selection of evaluation and decision-making and post-selection implementation phase. This framework was adjusted to the methodological needs of Study IV and therefore used to an applicable extent to support the analysis of argumentation, which limited the contributions of this framework. Overall, the assignments and framework answers by student teachers were observed in relation to these three phases. The decision to categorise a whole product as belonging to a certain phase of the framework was a fluent and theory-complementing way, although it simplified the situation to a certain extent. Still, methodologically, it was important to focus on student teachers rather than being restricted to student groups and to consider teacher education. In general, Study IV closed the research arch, spanning from a small-scale preliminary study to in-depth video analyses containing qualitative studies leading to an analysis framework for spontaneous spoken argumentation and metacognitive regulation by taking into account the student teachers and socio-scientific issues and their connection to argumentation.

5.4 Educational implications

This dissertation has several educational implications. Though previous research has delved into scientific argumentation in both its written and spoken form, understanding of spontaneous spoken argumentation is limited, especially in the aspect of analysis frameworks. Concurrently, there is limited knowledge of the interconnectedness of scientific argumentation and metacognitive regulation. Both of these limitations in previous literature that this dissertation complements are crucial in the educational context.

Study I relied on a multimethod approach in its effort to lift the veil in the setting of small student groups working on complex tasks that were the same for each group. From an educational perspective, engaging content knowledge through a foreign language can support dialogue and collaboration between students as they check the meanings of terms and their common understanding (Nikula, 2017). In summary, a virtual learning environment can be understood as an inquiry task environment that has great potential to promote spontaneous scientific argumentation, and more importantly, the integration of two disciplines. In a virtual learning environment, students must collaborate to generate explanations, justify these explanations, and collaboratively adjust their reasoning according to scientific practises and content knowledge. The virtual platform has potential for sociocultural purposes, as it gives each student responsibility over their learning and task setting with the help of the teachers' guidance. This dissertation therefore supports the idea of implementing a collaborative interdisciplinary study platform embedded in digital software influencing student group collaboration and scientific argumentation. In addition, supportive material for teachers is needed because the teachers might not have the necessary knowledge to implement these kinds of settings in their lessons or ways to foster spontaneous argumentation. The demand for supportive material for teachers arose also from the analysis of student teachers' socio-scientific assignments with potential prompts for argumentation.

As another important educational implication, the connections between pre- and post-tests, especially the topic-specific epistemic beliefs questionnaire, could be analysed in relation to argumentation coding. The epistemic beliefs questionnaire is of particular interest since the literature (Duschl, 2008) indicates that there should be a strong connection between students' argumentation and epistemic beliefs. These results and argumentation analysis, along with the results from the data of this dissertation but with affect in focus (Pietarinen, et al., 2019; Pietarinen, et al., 2020) can be used to benefit teacher education and to provide teachers with tools to observe and evaluate their students' argumentative discussion, which is crucial for science education. This integration of several diverse aspects of collaborative learning enables the learners and teachers to comprehend the multilateral nature of science learning which then permits the appliance of appropriate learning tasks.

As a natural continuation to the groundwork laid by Study I, the findings of Study II can be implemented in designing science learning situations, collaborative tasks during lessons, and instructions teachers give to their students. Teachers should be aware that certain tasks and virtually enhanced class structures can spontaneously promote thoughtful discussion and spontaneous argumentation. Such tasks and structures can be used to augment science learning and the adoption of the culture in which the science is carried out. The results of this dissertation support putting into practice a new learning culture that values a group's joint learning outcome rather than an individual learner's outcome, thus leading to true collaborative learning. The inclusion of collaborative learning in classrooms, by contrast, can promote and foster skills needed for future work life, social and interpersonal skills and higher-order thinking processes (Larraz, et al., 2017), and thus this dissertation provides ways to integrate collaborative learning enhancing structures that benefit science education through promoting scientific argumentation.

While previous literature has demonstrated that teachers must guide students through the spoken argumentation process (e.g. Sandoval, et al. 2019). This dissertation has proved that spontaneous spoken argumentation can arise without active teacher guidance if the tasks and structures are thoroughly designed. For the upper secondary school students, they need to be active (e.g., generate a question or a claim) stay focused on the key science issues to be resolved, and follow scientific experimental research steps, which clearly begins by framing science activity and creating a collaborative culture in which students must improve the criteria and framework for their learning. The students must do this work in small-group discussions, reflecting the students' PDE. This is a powerful notion in Study II that can be of great use in especially science education, as through the implementation of specific structures it is possible to achieve the learning goals set for secondary education.

The joint scaffolding of spoken spontaneous argumentation and SSMR is crucial for actualising the educational implications of this dissertation. Hence, Study III showed that students in the high-performing groups can regulate their learning in a situation where they spontaneously need to formulate arguments over a topic with which they are not familiar. Therefore, the setting where the students needed to study the topic and start discussing and working on it later was suitable for promoting spontaneous and socially shared metacognitive regulation. This promotion could be further strengthened by inserting intermediate stops where students would need to ponder not only the following steps of the task but what they have collectively learnt and how to boost their learning. These short breaks could be implemented in the virtual learning environment without breaking the flow of the collaborative work or argumentative discussion. 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.

Continuing this train of thought, Study IV demonstrated that tasks requiring the students to commit to discussion, pondering, and argumentation should be favoured in assignments. For example, nature's intrinsic value could be this kind of socio-scientific topic that inspires students (Wilson, 1992). Argumentative practises are in themselves socialise students into scientific ways of thinking and dealing with socio-scientific issues. By incorporating assignments about socio-scientific issues that aim to train argumentation practises, the development of higher-order thinking skills could be supported. In this context, the virtual learning environment has been shown to be a chassis to foster collaborative learning, scientific argumentation, and SSMR through the natural integration of socio-scientific issues. In this manner, the inclusion of socio-scientific issues is subtle, and the need for argumentation and metacognitive regulation arises naturally, which is crucial in achieving the goals set by the national curriculum and in being able to take part in current and future social discussion.

5.5 Future directions

The findings of this dissertation not only significantly expand the understanding of spontaneous spoken argumentation in science education in relation to metacognitive regulation, designing virtual learning environments, and generating assignments, but also raise intriguing questions for future research. In Studies I and II, the focus was on the two ways to implement two distinct virtual learning environments in science lessons. Although the results demonstrated that the virtual learning environment in its current form promoted spontaneous argumentation and metacognitive regulation, virtual learning environments could achieve a major breakthrough in the near future. Virtual learning environments form an educational monolith that could potentially expand into several domains of science. One significant aspect of the potential expansion is the rise of artificial intelligence (AI), and, more importantly, generative AI based on large language models (LLMs), of which the most common are the chatbots. Therefore, the implementation of AI in a virtual learning environment could possibly enable personalised instructional materials, create adaptive assessments and tasks, and automate routine tasks, making the whole learning environment more interactive than the ones utilised in this dissertation. When combined with adaptive learning mechanics, AI can use data analysis to understand an individual student's learning style, strengths and weaknesses in a subject. This information could then be used to provide student with personalised instructions tailored to their needs. In relation to scientific argumentation or metacognitive regulation, the virtual environment could start argumentative discussion with the learner or prompt the student to think of their learning. From teachers' point of view, the AI-enhanced environment could be beneficial, as it could be employed to create and grade assignments. However, as with all new technology, it is important that students and teachers learn to incorporate these technologies into the learning process. This incorporation of technologies, tasks, and structures is at the core of this dissertation, which provides practical ways for integration and several implications for the results to be put into use in the field of science education.

In line with the rapidly growing use of AI for educational purposes is the recent modification of Bloom's taxonomy (Siemens, et al., 2023; Bloom, et al., 1956). In this modification, Bloom's taxonomy has been reconsidered for the age of generative AI to support teachers and students in teaching and learning. Especially the ways students might use AI tools for learning activities and assessments has been emphasised along with the ways the inevitable feedback data collected by the AI could be used to revise learning activities, assessments, and materials. In this framework, AI can suggest alternate approaches, help avoid potential drawbacks, and describe real-world cases that could benefit students' creative skills. In evaluation and analysis, the revised Bloom's taxonomy can offer different courses of action, compare data, compute appropriate themes and trends within the data, and predict results for students. On applying and understanding levels, AI can help students with illustrations and methods to solve an inquiry by framing the situation and providing versatile clarifications of concepts to suit the needs of different learners, providing translations to different language sets, and recognising and thus giving inquiry-related examples to highlight the main components of the task. The revised Bloom's taxonomy could recall factual information on behalf of the student and offer lists of possible answers, thus constructing a scheme of the task with definitions of terms. Considering the findings and contributions of this dissertation, the revised Bloom's taxonomy could be readily unified with the virtual learning environment to form an educational unit for the needs of learners and teachers. This educational unit could then, as cogently noted in this dissertation, scaffold the development of students' argumentative and metacognitive skills, promote collaborative learning, and ultimately lead to deeper learning.

Moreover, in addition to the integration of AI, in future research it will be important to study both students and teacher's collaborative argumentation and metacognitive regulation in virtual environments based on the observations from Studies I, II and III. This dissertation addressed the fact that students spontaneously resort to argumentation and metacognitive regulation during small group work, but the teacher, as an argumentative and cognitive facilitator, could take the social learning situation to a level where instances of argumentation and regulation would be frequently observed. As a practical implication based on the notable findings of this dissertation, the learning environment should be designed to scaffold not only scientific argumentation but also SSMR. The current setting of not structuring it explicitly was proven to arouse instances of spontaneous argumentation and metacognitive regulation. With subtle hints and structures, the scientific process on knowledge acquisition and building could be made visible to the students. A new learning culture is inevitably mounted, and it could profit from being facilitated by a virtual learning environment that allows students to determine and follow the steps from hypotheses to results and conduct research that is carefully crafted on the principles of inquiry learning. This dissertation also acts as an envoy in bringing change in science education by evidencing the effective new practises and introducing the virtual learning environment within which this outcome can be achieved.

Deducing from the findings of Study IV and delving deeper into domain-specific areas, in biology and chemistry teaching, relevant socio-scientific issues based on students' age should be explicitly integrated that require reasoning based on scientific evidence to make conclusions. Furthermore, to engage students in discussion about socio-scientific topics, it is important to advance their argumentation skills in science learning with the use of a virtual learning environment, as demonstrated in this dissertation. This aspect is crucial due to argumentation improving critical thinking and other higher-order thinking skills (Osborne, et al., 2012) that are fundamental skills in science learning. Continuing this orientation towards teacher education, student teachers are aware of local, regional, and global socio-scientific problems, but when working towards a sustainable society, subject student teachers should get practice in all eight key competencies for sustainability (UNESCO, 2017; Yli-Panula, et al., 2022). The role of scientific argumentation and metacognitive regulation would be in promoting the critical discussion and thinking related to these specific topics. The virtual learning environment would then be the mediator for these topics. Thus, this dissertation encourages the idea to develop and implement a new collaborative interdisciplinary study platform embedded in digital software influencing student group collaboration and scientific argumentation, with the addition of supportive material for teachers and the possible incorporation of AI. These aspects have been studied in this dissertation with promising results, and therefore building on the findings of this dissertation could advance science education towards its interdisciplinary, comprehensive learning goals stated in the curriculum.

Accordingly, the National School Curriculum for upper secondary schools (FNBE, 2019) currently in use explicitly states the development of argumentation as part of becoming an active citizen with appropriate professional skills in accordance with pervasive competence in several subjects. These subjects contain all language studies, from the first language to foreign languages, biology, chemistry, philosophy, history, social studies, and ethics, which demonstrate the rising significance of argumentation in the Finnish education system from both the perspective of linguistic and scientific topic-specific domains. This revamp of the curriculum is in line with the findings of all the studies in this dissertation. Due to the lack of studies regarding argumentation in the current curriculum, this dissertation is a pioneer in this domain as well. In terms of this dissertation specifically, it is interesting to examine how the current curriculum defines argumentation in biology and chemistry. The curriculum sees argumentation in biology as part of communication skills through which students learn to evaluate their own and others' view-points by means of biology content knowledge. The curriculum clearly dictates that the teaching is given in different learning environments with diverse working methods that develop students' social and interaction skills, as the findings and implications of this dissertation supplement. In addition, argumentation has been merged as one of the main evaluation principles in biology. By contrast, in chemistry, argumentation is raised to be one of the roles of the subject as part of students learning to draw conclusions, evaluate, and argue over their research results. In chemistry courses, argumentation is viewed as a key feature in writing texts and critically interpreting and analyzing the results. Argumentation in the current curriculum for the upper secondary schools has not been covered in the previous literature, but it has nevertheless been stated that societally driven teaching of socio-scientific issues combined with critical thinking and argumentation are ways to educate students for the future (Härmä & Kärkkäinen, 2022). Additionally, it is important to study thoroughly whether students have equal learning opportunities while utilising an English virtual learning environment and whether the predictor of high-level argumentation is the metacognitive regulation or the differencies in group's performance level. These aspects together are the future-focused message of this dissertation. Virtual learning environments such as the ViBSE are powerful tools to promote students' awareness of their argumentation skills, metacognitive regulation, and specifically science learning required to build sustainable societies for the needs of the future.

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