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Examining Deliberative Interactions for Socially Shared Regulation in Collaborative

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Abstract

Socially shared regulation in learning (SSRL) is essential for collaborative problem-solving and innovation that are required in today's intricated and interconnected world. Recent advancements in learning analytics (LA) and artificial intelligence (AI) have shown promising potential for delivering a more comprehensive understanding of the temporal and cyclical processes of SSRL. It remains lacking, however, a validated standard for integrating theoretical constructs, methodological assumptions, and data structure in the field, which leads to a misalignment between the theoretical and technical aspects. This thus sparks a pressing need for interdisciplinary efforts to revise and devise theoretical and methodological frameworks that take these factors into consideration. In line with this call, the thesis presents a novel approach to applying AI to advance the field of SSRL. It comprises two empirical studies that employed AI-enabled techniques to (1) record and retain qualitative information from video data of group collaboration and (2) analyse their interaction. In particular, the studies examined the sequences of group-level interactions from the theoretical perspective of SSRL and a more micro-lens of deliberative negotiation. The theoretical framework of these studies is based on the recent conceptualisation of regulation triggering events as specific events (often negative incidents or obstacles) that stimulate regulatory responses and aid in locating them. The pattern of group interactions in response to different triggering events was then examined using processing mining and unsupervised AI machine learning clustering, agglomerative hierarchical clustering (AHC).

The findings suggest that regulation triggering events prompt an immediate shift in group interaction responses, in which they engage in more metacognitive and socioemotional interaction. Two types of deliberation sequences were identified through AHC analysis, with differing regulation and collaboration practices: the plan and implementation approach (PIA) and the trials and failures approach (TFA). A key observation of this study is that the shift in group interaction sequence in response to the regulatory trigger is only temporary. The majority of groups soon revert to or maintain the initial type of deliberation sequence they developed at the beginning and do not adopt it in response to regulatory demands.

Theoretically, the thesis makes contributions to understanding SSRL in collaborative learning, particularly the role played by regulation triggering events and deliberation processes in finding, capturing, and modelling SSRL traces. Methodologically, this thesis demonstrates a novel human-AI collaboration approach to examine regulatory responses to triggering events through group-level deliberation to study SSRL in collaboration. Practically, the findings of this thesis suggest that educators, facilitators, and AIED tool designers need to evaluate the regulatory needs of learners and offer appropriate guidance and support in order to ensure effective collaboration.

Keywords: socially shared regulation, deliberation, agglomerative hierarchical structuring, artificial intelligence, collaborative learning, trigger

The secret of life, though, is to fall seven times and to get up eight times.

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17th April 2023   Belle Dang

List of abbreviations and symbols

AI	Artificial Intelligence
COPES.	Conditions, operations, products, evaluations, and standards
CoRL	Co-regulation in learning
LA	Learning analytics
ML	Machine learning
OECD	Organisation for Economic Co-operation and Development
SRL	Self-regulated learning
SSRL	Socially shared regulation of learning

List of original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

I   Dang, B., Vitiello, R., Nguyen, A., Rosé, C., & Järvelä, S. (2023). How Do Students Deliberate for Socially Shared Regulation in Collaborative Learning? A Process-Oriented Approach. *Proceedings of the International Conference on Computer Supported Collaborative Learning* [Manuscript accepted].

II Dang, B., Nguyen, A., & Järvelä, S. (2023). Clustering Deliberation Sequences through Regulation Triggering Events in Collaborative Learning. *Proceedings of IEEE International Conference on Advanced Learning Technologies*. [Manuscript accepted].

Contents

1 Introduction

In today's rapidly changing world, collaboration has become an integral component of modern society and the workplace, as it allows the pooling of resources and expertise needed to solve complex problems. Based on a survey by Deloitte (2014), 80% of respondents believed that teamwork and collaboration were essential to an organisation's success. The global response to the COVID-19 pandemic is a shred of immediate evidence that highlights the essential role of collaborative efforts across industries to address unprecedented challenges (Bernardo et al., 2021), such as the development of vaccines, healthcare delivery, and remote work. It is emphasised in both the Finnish National Curriculum (Finnish National Board of Education, 2016) and the OECD (Organisation for Economic Co-operation and Development, 2018) that collaboration is a key skill of future workers as businesses and industries require employees who can work effectively in multidisciplinary teams to meet the challenges of today's highly interconnected and globalised economy. As a result, educational institutions are increasingly emphasising collaboration in their curricula as a means of preparing students for the modern workplace. The ability to collaborate with others is therefore crucial both for individual success as well as for the success of organisations and society at large. However, complex and multifaceted issues often pose many challenges for collaborative efforts, including cognitive and emotional obstacles stemming from the conflict in background, knowledge, and interests. To address these challenges within groups, a growing body of research has identified and highlighted the role of regulation and, socially shared regulation of learning (SSRL) in collaborative learning (Järvelä et al., 2018).

Several researchers have identified and established SSRL as a critical means of surmounting these challenges and achieving successful outcomes in collaboration (Panadero & Järvelä, 2015). SSRL is built on the theory and concept of self-regulated learning (SRL), which describes learners' ability to be aware of and guide their own learning process. While SRL focuses primarily on the

individual aspect, SSRL expands it to the social domain and highlights the joint nature of learning. SSRL refers to the process which involves the joint negotiating, realigning, and adapting of group regulation processes, strategies, beliefs, and goals (Järvelä et al., 2016). As a result, SSRL recognises that learning is not solely an individual process but a social one, and its success depends upon the ability of group members to interact and regulate their collaborative process. SSRL theory posits that in collaborative learning, the individual and social forms of regulation interact and influence each other through negotiation and social interactions, with negotiation as a core mechanism of adaptation (Järvelä et al., 2018). Yet, despite this crucial role of negotiation, especially deliberative negotiation, there is a dearth of published research examining SSRL through this lens of the deliberative negotiation process, which from this point onward is referred to as "deliberation". The term "deliberation" is selected on account of the term's emphasis on convergent interests and shared nature, making it applicable in a wider range of collaborative learning contexts (Ihnen, 2014). Through deliberation, SSRL allows for the exchanges of expertise and ideas, fostering shared knowledge-construction, of social and cognitive skills that are essential for overcoming challenges and achieving collaboration success. Although decades of research have helped unravel different aspects and facets of learning regulation in collaboration contexts, understanding and measuring the holistic manifestation of SSRL remain challenges due to its multidimensional, dynamic, and intertwined nature (Järvelä et al., 2019).

The integration of AI techniques into education and the learning science field offers a promising solution to the challenges faced in SSRL research (Järvelä et al., 2020; Molenaar, 2022). Recent advancements in AI technology have enabled sophisticated analysis of the learning process and SSRL, as well as personalized pedagogical support for human learning regulation. However, several challenges have been observed in integrating AI and multimodal data to capture and analyse different processes and facets of SSRL (Azevedo & Gašević, 2019; Luckin & Cukurova, 2019). Algorithms employed in AI, especially those of a multimodal approach (e.g., log files, eye tracking, screen recordings of human−machine

interactions, etc.), may depend upon different assumptions regarding the manner in which data should be structured, analysed, or designed in comparison with traditional datasets. These differences result in a lack of engagement between theoretical concepts, data structure, and methodological assumptions, leading to a lack of validity and reliability in research (Järvelä et al., 2023). Therefore, interdisciplinary efforts must be brought forward to align these components with AI techniques. This will enable the utilization of AI to measure SSRL during learning, design learning activities that support SSRL, and advance theories on learning and regulation (Järvelä et al., 2023; Luckin & Cukurova, 2019). Despite this, the majority of these recent SSRL studies relied on macro-perspective data (i.e., at the 30-second segment or meaningful episode level). This is in part due to the resource-intensive nature of capturing and analysing data at a more granular level while still preserving the necessary qualitative information for in-depth analysis. Although these studies have contributed valuable insight into the temporal aspects of the phenomenon, this approach 1) causes challenges to fully integrate with data in different modalities, 2) is insufficient for machine learning, and 3) falls short to provide holistic insights into how these complex processes unfold over time.

Our approach to addressing these gaps is by employing AI techniques and a theoretical framework that considers the alignment between SSRL with advanced methods. It seeks to examine group-level interactions from the perspective of SSRL and a more micro-lens of deliberation to investigate how they manifest in response to cognitive and emotional regulation triggering events in collaborative learning. The structure of this thesis is summarised in Fig. 1.
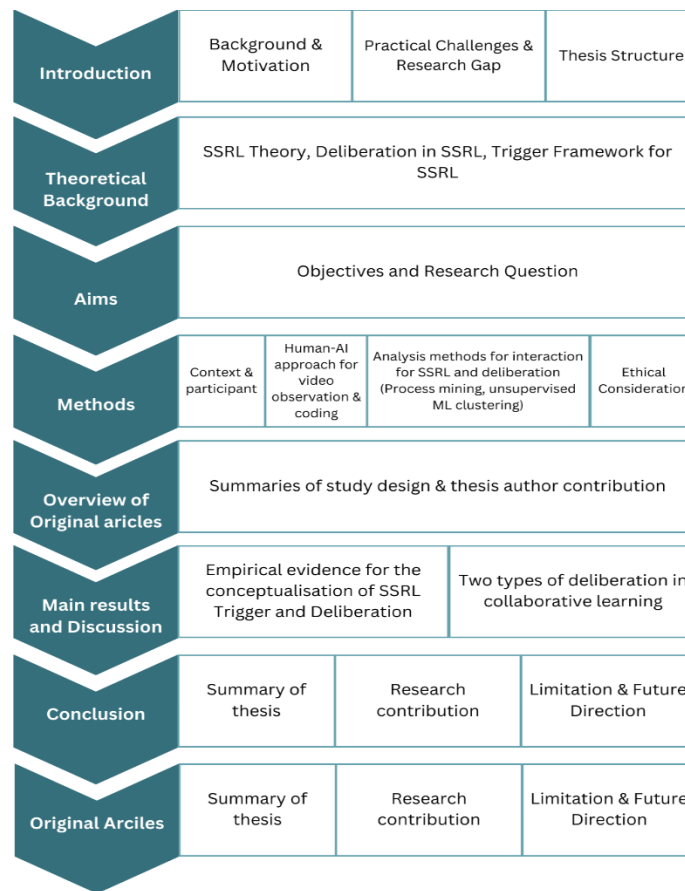
Fig. 1 Structure of the thesis.

Having presented an overview of background, motivation as well as identified practical challenges and research gaps, the following section sets the theoretical background for the thesis, drawing from socio-cognitive learning theory and a body of literature on SSRL. In particular, the theoretical framework guiding this thesis is grounded in Järvelä & Hadwin's (2013) SSRL model and Järvelä et al.'s (2023) framework for the trigger concept in SSRL. The overarching aim and research questions are then stated in the next section. The thesis then continues with a methods section to describe the procedures and analysis techniques used in conducting the two studies, including the experiment data collection, the

instruments and tools used to measure variables, and the methods for data analysis. In this section, brief summaries of each study's aims, methods, and results are included. Following the methodology section, the thesis provides an overview of the two original research articles, summarising the study design and the author's contribution. A collective summary of the two articles' main findings and discussion are presented in the subsequent section. The thesis will be then concluded by discussing the studies' implications, limitations, and future research directions. At the end of the thesis introduction, two original articles are also attached to provide a comprehensive understanding of the research topic. These articles offer additional context and support for the main arguments and findings presented in this thesis introduction.

2 Theoretical foundations and framework

The theoretical framework underpinning this thesis is centred around the concept of Socially Shared Regulation in Learning (SSRL) and its relationship with group-level deliberation patterns in response to different regulation triggering events. The theoretical foundations are based on the SRL theory, which asserts that individuals can achieve their educational goals by constantly monitoring and adjusting their own thoughts, behaviours, and emotions. In particular, this study first draws from the SSRL model developed by Järvelä & Hadwin (2013), which builds on Winne & Hadwin's (1998) COPES model. It extends the SRL framework to include the role of social interaction in examining social forms of regulation in learning, highlighting the importance of social support and collaboration in regulating learning processes. This framework draws attention to the crucial role that deliberation plays in regulation adaptation. Second is the concept of triggering events (Järvelä et al., 2023), which is based on the idea that regulation is triggered by events or actions that require learners to adjust their learning processes. This concept is particularly relevant to the study, as it provides a useful framework for understanding how regulation triggering events affect deliberation patterns in groups that can serve as a trigger signal to identify regulation opportunities, SSRL

traces, sequences, patterns, and models. The integration of these perspectives enables a more detailed analysis that takes into account the complexity and interdependence of these factors. As a result, a comprehensive and nuanced understanding of the relationship between deliberation patterns, regulation triggering events, and SSRL can also be achieved. By providing evidence for the theoretical conceptualization of SSRL triggers and shedding light on the pattern underlying group deliberation in response to varied regulation triggering events, the study will contribute to the advancement of SSRL theory.

2.1 Socially shared regulation in learning (SSRL)

According to Järvelä et al. (2016), collaborative groups can be seen as social systems composed of multiple individuals. To optimise collaboration and effectively overcome complex challenges, it is not sufficient for the individuals to be able to direct their own learning and cooperate in joint tasks; they must also regulate together as a social entity. It is a process known as SSRL, in which members of a group regulate their collective activities, including shared beliefs, processes, and knowledge, all of which aim to achieve a co-constructed or shared outcome (Winne et al., 2013). SSRL has emerged as a natural extension of research on SRL.

SRL theory, which emphasises the individual capabilities in managing their own learning success, emerged in the 1980s as a response to traditional views of education and learning that gave too much weight to external factors like teachers and classroom materials (Zimmerman, 2013). According to this theory, individuals develop and employ metacognitive, motivational, and behavioural strategies to monitor, control, direct, and regulate their learning process (Zimmerman, 2002). Through these self-regulation processes, improved learning outcomes are achieved as more effective and efficient learning approaches are developed over time. SRL has been studied extensively in the field of education and psychology, and several models have been proposed to study various elements, the central mechanism and

processes of SRL. Despite differences, these models in general agree that SRL is cyclical, comprised of different phases (e.g., forethought, performance, reflection) and subprocesses (e.g., planning, monitoring, control) (Puustinen & Pulkkinen, 2001). Many also recognised that SRL is dynamic, and multifaceted, encompassing cognitive, motivational, emotional, and behavioural factors.

Among these models, Winne & Hadwin's (1998)'s COPES model, which stems from information process theory, control theory, and metacognition research, provides a powerful metacognitive perspective on regulation in learning. The acronym "COPES" stands for Conditions, Operations, Products, Evaluations, and Standards. These are five essential components of SRL, which include the situational and personal conditions under which learning occurs, the learner's cognitive and metacognitive operations, the learning product, performance evaluation, and personal standards for achievement. According to the theory, the interplay between individual cognitive processes and external factors leads to a dynamic, adaptive process that allows individuals to control their own learning.

The SSRL theoretical framework that this thesis is based on is the SSRL model developed by Järvelä & Hadwin (2013), as depicted in Fig 2. This model builds on the individual-oriented COPES framework but expands it by incorporating the
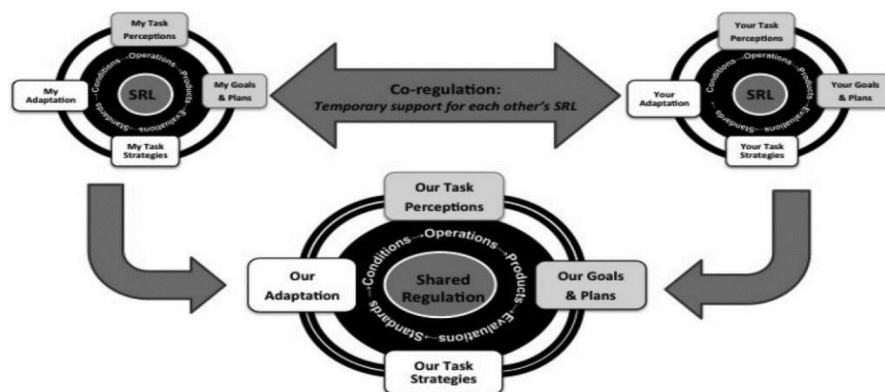

Fig. 2 Socially shared regulated learning model. Adapted from Järvelä and Hadwin (2013)

social process that occurs when learners collaborate. This SSRL model explains how learners in collaborative settings regulate their learning through interacting, negotiating, and sharing to establish common ground, a shared understanding of the task, and the strategies necessary to complete it. In doing so, it recognises the situated and contextual nature of regulation processes and also takes into account the ways that different types of regulation (self-, co-, and shared-) interact with each other. According to this theory, collaboration involves all three forms of regulation: SRL, CoRL, and SSRL. SRL refers to the individual's (meta)cognitive, motivational, emotional and behavioural adjustment in response to the interaction with the group members. CoRL refers to the process by which a more competent individual or tool is utilised to facilitate or hinder self- and shared regulation of an individual or group. SSRL refers to the collective process in which group members engage in deliberate and strategic planning, task enactment, reflection, and adaptation through negotiating (deliberating), realigning and adjusting their shared regulatory processes, belief, and knowledge (Järvelä & Hadwin, 2013). These forms of regulation do not occur in isolation but rather interact and influence one another dynamically.

Overall, by considering the dynamic interplay between SRL, CoRL and SSRL, the model offers a more comprehensive framework for understanding how learners regulate their own learning and group collaboration in the collaborative setting. Nonetheless, by broadening the foci from individual to group level, the number of potential interactions and the complexity between different entities and elements have increased significantly compared to individual SRL systems. Several empirical findings have provided evidence to support the SSRL model, including the identified social forms of regulation (Järvelä et al., 2013, 2016), their dynamic interplay (Bakhtiar & Hadwin, 2020), as well as evidence that SSRL might promote learning and performance (Castellanos & Onrubia, 2018). However, this also presents new challenges that evoke the development of more sophisticated methodologies and measurement instruments to capture and study the phenomenon. Deliberative negotiation, an important mechanism for regulation adaptation in

SSRL, can potentially address this need as it allows for a more fine-grained analysis of what group members do in response to challenging situations. This focus on the micro-level interaction and decision-making processes of groups can offer a new promising instrument lens for SSRL research.

2.2 Deliberation in SSRL

Successful regulation in collaborative learning is marked by the ability to adaptively respond to challenges and optimise personal and collective goals (Järvelä et al., 2023). This does not refer to spontaneous adaptations but to strategic and purposeful ones that emerge as learners engage in active and deliberative negotiation to align goals, motivations, and beliefs. Deliberative negotiation is thus, as SSRL theories have argued, one of the key mechanisms for regulation adaptation, since it involves the active, transactive consideration of different perspectives and ideas by group participants in order to reach a mutually beneficial understanding (Hadwin et al., 2018). By doing so, the group will be able to manage collaborative challenges strategically and adapt accordingly.

To describe such processes, the thesis uses the term "deliberation" rather than "negotiation" for a specific reason. As opposed to negotiation, which is centred on resolving conflicts through compromise, deliberation focuses on the process of discussing and considering various perspectives to arrive at a well-informed and thoughtful decision (Ihnen, 2014). This indicates a convergence of interest and shared nature that is better in line with SSRL's goal and fits in the broader collaboration contexts. Studies have shown that facilitating purposeful deliberation during collaborative challenges may have beneficial effects. Less successful collaboration is often characterised by parallel working and ignorance of other group members' contributions (Haataja et al., 2022).

Deliberation involves the exchange of ideas, the evaluation of evidence and argument, and the negotiation of differences in viewpoints or opinions, which shares similarities with the collaborative problem-solving (CPS) process (OECD,

2017). However, deliberation is not synonymous with CPS. CPS focuses on solving problems, and research in this area has concentrated on identifying the collaborative processes that lead to successful problem-solving (Meier et al., 2007). Deliberation, on the other hand, focuses on the characteristics and nature of interactions exchanged by group members and how they shape a shared understanding or co-constructed adaptation. The process of deliberation is a complex one but possible to capture and analyse through micro-data points of discourse at every turn of a group member's speech. In collaborative learning, different deliberation patterns can be triggered in response to a variety of conditions, including conflicting viewpoints or the necessity of making a shared decision. This means that interactions for deliberation have the potential to serve as signals for trigger events, a lens to SSRL trace, patterns, sequences, and model, thereby allowing researchers to examine the factors that contribute to effective or ineffective regulation during collaborative learning (Järvelä et al., 2023).

2.3 Triggers Concept Framework for SSRL

To capture the complexity and dynamics of SSRL, advanced learning analytics and methodologies are needed (Järvelä et al., 2021). Nonetheless, the alignments of these new techniques with traditional datasets are questionable as the existing SRL and SSRL theories may not offer the most optimal frameworks to guide this integration. As a result, there is a lack of integration between the rich multimodal data and the theoretical underpinnings requires for its analysis (Chen et al., 2020). To address this gap, Järvelä et al. (2023) have proposed a theoretical framework that combines the triggering events of regulation with multimodal data analysis in SSRL. The foundation of productive collaborative learning is a complex, multifaceted interaction process that encompasses cognitive, motivational, and emotional components (Borge et al., 2018). To overcome challenges and succeed in collaborative learning, students must engage actively and iteratively in co- and socially shared- regulation in learning (Hadwin et al., 2018). This has led to a

considerable effort in examining the different layers and processes of metacognitive, cognitive, motivational, and emotional interactions that underlie CoRL and SSRL (Isohätälä et al., 2017; Nguyen et al., 2023; Winne, 2019) in collaborative learning, referred to as interactions for regulation. However, the existing body of research on SSRL has suggested that regulation rarely occurs in normal learning contexts and often is triggered by certain incidents. The trigger framework developed by Järvelä et al. (2023) is thus, crucial to addressing these challenges, as it integrated multimodal data with a human-AI collaborative approach to propose the operationalisation of capturing and analysing the phenomenon of SSRL through these triggering incidents. In collaborative learning, regulation triggering events are specific types of events that invite regulatory responses, such as the emergence of conflict or disagreement among group members. Data collected from a multimodal approach, such as audio, video, physiological, behavioural, or discourse data, can provide signals of cognitive, emotional, motivational, or social sources for these events. Examples of recent studies for these include Haataja et al. (2018), who have employed multimodal data as a means of investigating SSRL. The study has found that physiological synchrony among students collaborating was identified as a predictor of cognitive regulation trigger events. Or Sobocinski et al. (2020), who utilised coded video data of collaborative interaction and state transitions in heart rate to distinguish adaptive from maladaptive behaviour in collaborative learning. Dang, Nguyen, Hong, et al. (2023) utilised data from facial emotion expression captured with AI techniques, to show how the transition of latent affective states is related to emotion regulation in a synchronous learning environment. These signals serve as empirical identification of SSRL traces, sequences, patterns, and models where regulation occurs or does not occur, and whether it is adaptive more maladaptive adaptation.

In summary, SSRL and deliberation are complex processes that are crucial to collaborative learning that can be detected through signals of triggering events using multimodal data analysis. An array of multimodal data sources, including audio, video, behavioural, and discourse data, can be used as a means of identifying

cognitive, emotional, motivational, or social sources of triggering events in SSRL, as well as empirically identifying SRL traces, sequences, patterns, and models where regulation occurs. They serve as metacognitive markers of the invisible mental process underlying regulation in learning. Taken together, these frameworks provide a conceptual foundation for integrating multimodal data and advanced methodologies with SSRL and SRL theories.

3 Aim

This thesis aims to examine how group-level interactions, through the broader theoretical perspective of SSRL and the micro-lens of deliberation, manifest in response to cognitive and emotional regulation triggering events in collaboration contexts. As part of this study, cognitive and emotional triggering events were introduced to observe their effect on the regulatory and deliberative characteristics of group interactions, as well as examine the relationship between them. The thesis also pursues a methodological objective by exploring the potential of a developed coding scheme for deliberative characteristics and the use of AI techniques to gain a more nuanced understanding of the group collaboration process, as well as to detect, capture, and model traces and sequences of SSRL.

The empirical aim of this thesis is to address the following research questions:

1. Is there a relationship between regulatory and deliberative characteristics of interactions in response to cognitive and emotional regulation triggering events? (see Study I)

2. What patterns of group deliberative characteristics are manifested in response to different regulation triggering events? (see Study I and II)

3. How do the patterns of group deliberative characteristics change in response to regulation triggering events? (see Study II)

4 Methods

4.1 Participants and context

This thesis examines a subset of the existing data from an experimental research design set in order to explore the trigger concept of SSRL during collaborative learning. A sample of 30 first-year high school students in Finland participated in this part of the study in a laboratory environment. Students were randomly divided into small groups of three learners, who then worked collaboratively on a Google document shared by all the groups. Participants were asked to develop a nutritious breakfast smoothie based on the nutritional needs described in the document. In addition, they were also provided with information concerning the nutritional value of different foods that could be used in their smoothie recipes. In the course of their collaboration, each group received a manipulated cognitive triggering event in which a customer sent a voice message stating an allergy to a certain product. Three emotional triggering events followed, each involving the customer expressing his or her impatience at intervals of three minutes (see Fig 3). Each trigger increased the intensity of the customer's emotional valance, leading from mild impatience to increased urgency, and finally to annoyance.
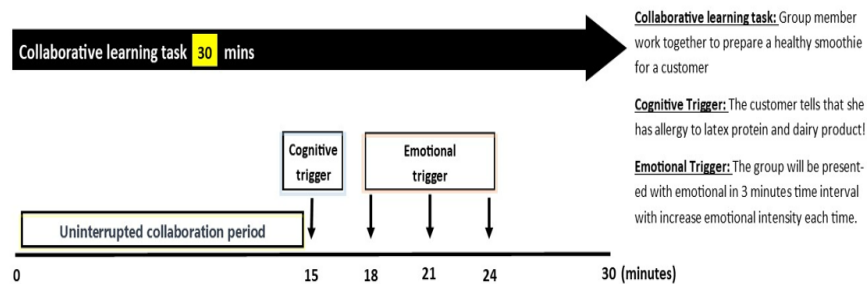
Fig. 3 Overview of the research design for the experiment group.

4.2 Data collection and analysis

High-quality audio and video data were collected from each group using individual microphones and Insta360 Pro video cameras placed in the centre of the group. Insta360 Pro is a 360-degree camera that has six camera spots, allowing for the complete capture of the 360-degree learning environment (see Fig 4).

The data and methods used in each empirical article are outlined in Table 1. Detailed information about the data and analysis procedures is provided in the original publications.
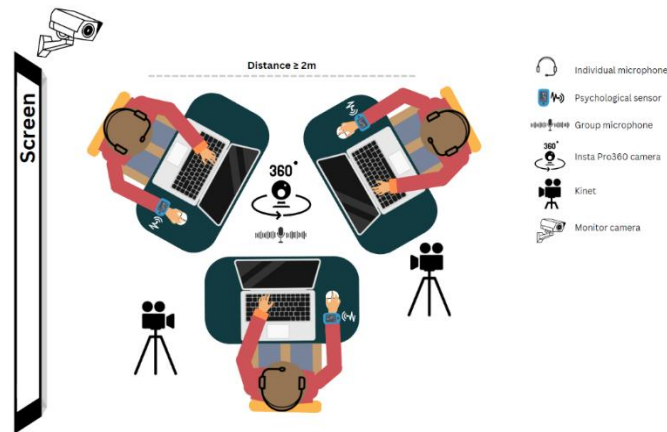
Fig. 4 Illustration of the experiment arrangement and configuration.

Table 1. Data sources and analysis methods in the empirical studies

Data	Analysis method	I	II
Video	Video observation analysis	·	
	Constant comparison analysis	·	
	Qualitative coding	·	·
	Statistical analysis	·	
	Agglomerative hierarchical clustering		·
	Process Mining	·	

In this thesis, both studies utilized video data, and a video observation analysis was carried out to analyse group interactions for regulatory and deliberative characteristics. In real-life settings, this method enables researchers to capture and study specific human behaviours, interactions, and events that are difficult to quantify. To examine the complex and abstract phenomenon of SSRL that is suitable for AI analysis, two coding schemes were used: one for high-level SSRL characteristics and another for easier-to-capture low-level deliberative characteristics. This allows for modelling high-level SSRL on low-level deliberation activities, providing a comprehensive and multi-level understanding of SSRL. First, the coding scheme for different types of regulatory characteristics was adopted from prior studies (Näykki et al., 2021; Nguyen et al., 2022), with four categories including metacognitive interaction, cognitive interaction, socio-emotional interaction, and task execution interaction (see Table 2). These categories corresponded to the facets of regulation in learning that are adopted in research examining the interaction processes that underlie CoRL and SSRL in collaborative learning (Isohätälä et al., 2017; Nguyen et al., 2023; Winne, 2019).

Table 2. Coding scheme for video quantitative analysis

Categories	Description	Example
Regulatory characteristics of interactions		
Metacognitive interaction	Meta-level mental processes toward the control and monitoring of cognitive and emotional activities (orienting, planning, monitoring, evaluating, and regulating). The connection and reflection are aimed at task-related strategies, group processes or dynamics.	*S1: By the way, I don't use this ingredient page at all, I just put it in there and see what happens.* *S2: If we just keep the ingredients the same, but increase their number in the same ratio, so then those percentages go absolutely nowhere.*
Cognitive interaction	Interactions focus on higher learning-related thinking skills such as understanding, analysing, reasoning and	*S2: Well, here are the others, here are all the chia seeds, hazelnut spread, whey protein powder.*

	evaluating at the object level related to task content.	S1: But here would be pineapple or blueberry, then they would be the kind where there would be very little of everything.
Socio-emotional interaction	Actions and interactions relevant to the expression of one's emotion in a social context with clear negative/positive affect nature (e.g., showing gratitude, joking, disputing)	S1: Oh, good time, this guy first orders a smoothie, and then tells us to make it again and then complains that it's taking us a long time to make it this. [Express annoyance with group shows shared feeling]
Task execution interaction	Actions and interactions that primarily focus on carrying out task requirements, completing the task: i.e., typing on the computer, reading instruction	S1: Yeah, I'll change them to one hundred and twenty-five. [Inform current process] S2: One hundred and twenty-five. OK that should be twenty-five then.

For deliberative characteristics, as there is no existing coding scheme deemed suitable given that this is the first attempt to granularity examine deliberation in SSRL, the constant comparison method (Onwuegbuzie et al., 2009) was applied. Altogether, we identified 18 different categories for deliberative characteristics of interactions (see Table 3).

Table 3. Types of deliberative interactions - results of constant comparison analysis

Categories	Description	Example
Deliberative characteristics of interactions		
Define the problem	Share understanding of the problem, defining the present situation and the desired future, to make the current issues problem clearer to group members.	S1: So, what couldn't be there? S2: Natural rubber and milk protein allergy. S1: Well, should the natural rubber be that low or… S2: Yes, all of them should be low. [..]It's not good when hazelnut spread has natural rubber so high…
Establish strategy	Suggestion and implementation of process steps (how to	S1: […] we need another 250 kilocalories, half of it.

	approach the tasks, ways of executing certain aspects of the task)	*S2: Yes, [...] And then we'll get increased protein and fat if we only put these [...] Let's raise everyone a little, so it won't change these ratios.* *S1 & S3: Yeah. (Okay).*
Specify information needs	Identify technical background information that is pertinent to the issue; identify information that is available and information that is needed.	*S1: Where does it say natural rubber?* *S2: It reads over there, on the other side.* *S3: That last one of those nutrients.*
Educate each other	For back-and-forth discussions of group members trying to work on disagreement and align shared understanding by identifying and sharing understanding, interests -- reasons, needs, motivations; etc.	*S1: Well, but you mustn't bring a lot of fat at once.* *S2: We already have a package.* *S3: Let's put something in it.* *S2: We don't have that [...] You can't put anything left.*
Generate options	Brainstorm and generate a solution for task-related problem-solving and offer alternatives.	*S1: Where can I get more energy?* *S2: Shall we put that oatmeal in there?*
Evaluate options	Make a judgement about the generated options	*S1: Shall we put kale in there when?* *S2: It sounds a bit strange.*
Reach agreement	Confirm shared agreement on the options, ideas, and opinions.	*S1 & S2: Oat or almond, is it either?* *S3: Oat drink* *S1: Okay, let's make an oat drink.*
Implement the agreement	Carry out the selected options to attempt ideas.	*S1: Yeah, I'll change them to one hundred and twenty-five. [Inform current process from previous agreement]*

Attempt ideas	Apply for testing out alternatives/solutions without forethought & discussion between group members.	*S1: I'm going to try a bit of randomness here now, there's a moderate one, so not really.*
Monitor the time	Keep track and check on the time	*S1: There are now four hundred and ninety-eight calories. Isn't it about time?* *S2: I don't think it's the time.*
Monitor group operation	Observe and check on the group's focus and shared agreement, current progress within the task, and quality of the procedure.	*S1: It's time we think about how we can produce protein.* *S2: So here…*
Monitor environmental context	Observe and check on other conditions around the task, i.e., technical and resources; social conditions.	*S1: Oh yeah, isn't it, and it's just a visual glitch of ours that the fat is half of what it should be?*
Monitor the result	Check on task requirements and how the current result is meeting those.	*S1: Now we have a little too many calories.* *S2: Isn't the maximum - about 500 didn't read here?*
Evaluate group operation	Make a judgement about group focus, shared agreement, current progress, and procedure quality	*S1: Now it's good. Wise one about 500 [Complement group's strategy]*
Evaluate the result	Make a judgement about the current result in accordance with the task requirement.	*S1: If we score it 15 g, then five hundred and five, pretty much those. I guess there is nothing to complain.*
Regulate group emo-mo	Interaction with the intention of regulating group focus or emotional - motivation about the situation	*S1: Well, it's probably right for us.* *S2: If it's the same for you, then we'll trust it.*

Positive socioemotional interaction	Positive socio-emo interaction without the intention of regulation.	*S1: Well, it's not- (It's my own fault when I forgot my allergy.)* *S2 & S3: synchronous laughing and agreeing to*
Negative socioemotional interaction	Negative/ neutral socio-emo interaction without the intention of regulation.	*S1: Well, if only we scored something. [all group members non-verbal show a lack of motivation]*

The unit of analysis was each turn of utterance by a student, but the coding decision was made in the broader context of the team discussion to capture the group-level interaction. The context window ranged up to 7-10 turns but was not limited to it. Each utterance turn was coded for both regulatory characteristics (e.g., metacognitive, cognitive, etc.) and deliberative characteristics (e.g., generate options, or educate each other, etc.) simultaneously. It is important to note that the context window for regulatory characteristics may differ from that of deliberative characteristics.

During the coding process, the coding categories were refined and finalized with the researchers through iterative refinement. An inter-rater reliability test, where 20% of the data was individually coded by two different coders, was used to ensure the validity of the coding scheme, Cohen's $\kappa = 0.76$ for deliberative characteristics and moderate to high value for regulatory characteristics (κTask execution= 0.63; κCogntive = 0.69; κMetacognitive =0.71; κSocio-emo =0.88). Both studies utilized a fine-grain utterance-level coding approach for regulatory and deliberative characteristics, which allowed for further advanced machine learning analysis.

4.2.1 Is there a relationship between regulatory and deliberative characteristics of interactions in response to cognitive and emotional regulation triggering events? (Study I)

The purpose of Study I was to investigate the relationship between the observed regulatory (Table 2) and deliberative characteristics of interactions (Table 3) through different regulation triggering events. As both variables were categorical, Chi-square and Cramer's V tests were applied. Our assumption about the role of regulation triggering events was examined by the significant difference in the distribution of interactions based on their regulatory and deliberative characteristics 3 minutes before and 3 minutes after the regulation triggering events.

4.2.2 What patterns of group deliberative characteristics are manifested in response to different regulation triggering events? (Study I & II)

Through fuzzy mining, a process mining algorithm, the time-related patterns of regulatory and deliberative characteristics were examined. The process analysis was conducted using Fluxicon Disco, a software program commonly used in learning sciences research to describe learning logs and activity processes (Juhaňák et al., 2019). The process maps in Study I illustrate the primary pathway through which regulatory and deliberative characteristics of group interactions shifted in response to the cognitive and emotional regulation triggering events. These provide insight into how group immediate changes in SSRL and deliberative characteristics manifest through these regulation triggering events.

Study II's examination of two types of clustered deliberation sequences through different phases according to the regulation triggering events also contributes to this understanding and is discussed further in Section 6.

4.2.3   How do the patterns of group deliberative characteristics change in response to regulation triggering events? (Study II)

Study II aimed to investigate the main patterns of deliberation for SSRL throughout the regulation triggering events. An unsupervised machine learning method, agglomerative hierarchical clustering, was used. For the current data, this method was promising because it could handle categorical data and did not require assumptions about distribution, as is typical for process data. Furthermore, a Silhouette Coefficient was calculated to measure the goodness of the clustering and to determine the optimal number of clusters. By revisiting qualitative coding and video data, this study analysed not only the distinct characteristics of deliberation sequence within each cluster type but also revealed a longitudinal pattern of how these types manifested over time. Further discussion of these findings is presented in Section 6 of the thesis.

4.3 Ethical Consideration

A careful consideration of ethics was made during the design phase of the studies, so that neither the research aims, nor the methodology could be harmful to the participants. Although not being used in the current thesis, the broader research design was subject to the approval of the Ethics Committee of Human Sciences of the University of Oulu. Following the national guidelines, an ethical statement was applied by the Ethics Committee of Human Sciences at the University of Oulu. To accomplish this, detailed plans were created, describing in detail how participants will be informed, and how the data will be collected, analysed, and stored in a manner compliant with both the Finnish National Board on Research Integrity (2019) and the General Data Protection Regulation[1]. The studies were conducted only after receiving the necessary ethical approvals.

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[1] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) [2016] OJ L 119/1

Throughout the study, informed consent was taken into account as the first and foremost consideration, which entailed providing the participants with information about the study and the use of the data, in a manner suitable to their age. As part of the study, the participants provided their written consent and were free to withdraw from the study at any time without any adverse effects on their learning or additional burdens. Prior to the installation of physiological sensors, participants were informed about the procedure and how it measures cognitive and emotional processes and were given the opportunity to ask any questions they may have. The sensors were attached to participants in a sensitive manner to ensure their comfort. The collected data were then anonymized by replacing names and identifying information with unique ID numbers, except for faces in video data, to which only members of the research team had access. Data from each study was stored on backup network drives managed by the University of Oulu's IT department.

5 Overview of the original articles

A total of two empirical articles are included in this thesis, each produced through collaboration, but with the author of this thesis as the first author. Table 4 presents the contributions of each article, along with how the author contributed to their creation. The following sub-sections briefly introduce each empirical study's design.

Table 4. Overview of the aims and author's role in empirical articles

	Article Aim	Author's participation
I	To explore the potential of using regulation triggering events as treating conditions to stimulate and locate regulatory interaction and in examination with deliberative interaction	First author, video analysis, statistical analysis, reporting
II	To identify the pattern underlying group deliberation in response to different regulation triggering events to inform evidence for the theoretical conceptualization of SSRL triggers.	First author, video analysis, machine learning analysis, reporting

6 Main results, findings and discussion

To accomplish the goals of the thesis, two empirical studies have been conducted and their detailed results have been reported in two separate articles. In this section, the results of these studies are discussed in relation to the thesis' overall objectives and research questions.

6.1 Deliberation as a lens and regulation triggering events as a marker to capture the interaction for regulation in response to them.

The primary objective of this thesis was twofold. First, it sought to examine how regulatory and deliberative characteristics of group interactions manifested in response to different regulation triggering events. This aid to verify our theoretical hypothesis about capturing learners' behaviour and interactions for SSRL in response to them using deliberation as a lens. At the same time, the second is to provide empirical evidence for the conceptualisation of the trigger concept in SSRL. The statistical tests conducted on the regulatory and deliberative characteristics of group interactions before and after different regulation triggering events are all significant with small to large effect sizes (Table 5).

Table 5. Results of Chi-square Tests and Effect Sizes for Regulatory and Deliberative Characteristics of Interactions

Test	χ^2	df	p-value	Cramer's V
Regulatory characteristics of interactions before and after regulation triggering events.	76.7	12	< .001	.12
Deliberative characteristics of interactions before and after regulation triggering events.	503.9	68	< .001	.26
Regulatory characteristics based on deliberative characteristics	3006.2	51	< .001	.75

These have confirmed (1) our theoretical prediction about the role of regulation triggering events and (2) the relationship between SSRL and deliberation. The resulting process maps in Study I revealed that group members changed their collaborative approach to task solving and engaged in more metacognitive and socio-emotional interactions after cognitive and emotional regulation triggering events, respectively (Fig. 5).
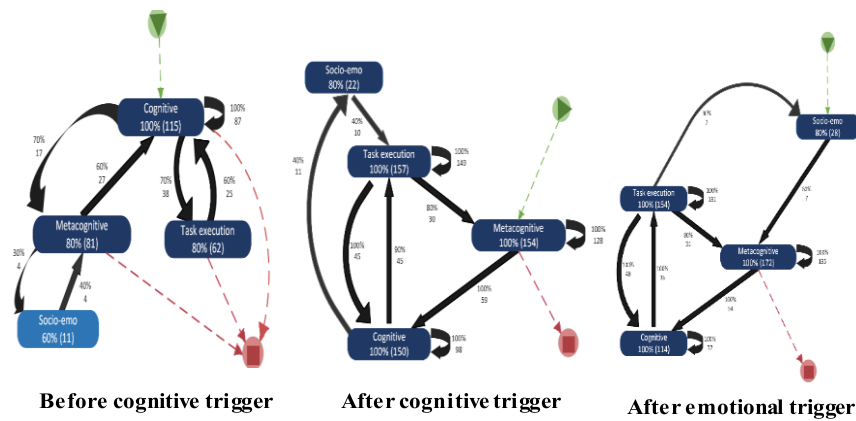

Before cognitive trigger   After cognitive trigger   After emotional trigger

Fig. 5 Process maps for patterns of interactions for regulation through cognitive and emotional regulatory triggers (Dang, Vitiello, et al., 2023)

The process maps revealed the most common path of regulatory characteristics in different phases before and after the regulation triggering events across all group. The maps displayed both the absolute frequency and case coverage percentage (proportion of cases that pass through the process steps). These results are consistent with previous studies that have examined how cognitive and social obstacles may contribute to the emergence of regulation in learning (Näykki et al., 2021). More importantly, Study I also revealed a strong respective correlation between the aforementioned shift and that of deliberative characteristics. Before regulation triggering events are introduced, group deliberation follows a problem-solving-like process that can often be observed in collaborative learning environments. When cognitive and emotional regulation triggering events occur, the group's deliberation patterns change to a more metacognitive one, where group

members are intentionally controlling their behaviour to accomplish the task and providing emotional support to one another. These findings are consistent with those found in research conducted by Bakhtiar et al. (2018), where students utilised similar strategies to coordinate their collaboration and maintain cognitive activities.

Taken together, the findings of these studies suggest that regulation triggering events, such as cognitive and emotional challenges, can facilitate regulatory processes, thereby aiding in the identification of learners' in situ regulatory responses. Further evidence of this phenomenon can be observed in the changes in the deliberation process, as captured in the content of the utterances. SSRL, thus, can be traced, patterned, and modelled using these shifts and changes in deliberation. Ultimately, the findings provide crucial insight into the role of regulation triggering events and deliberation in investigating the adaptive and maladaptive regulatory processes necessary for successful collaborative learning.

6.2 Different types of deliberation sequences in response to regulation triggering events

The primary objective of Study II was to delve deeper into the dynamics of deliberation in collaborative learning when presented with various cognitive and emotional regulation triggering events. Upon clustering the deliberation patterns of groups facing regulation triggering events, two types emerged: Plan and Implementation (PIA) and Trials and Failures (TFA). The PIA type, which involves analysing, discussing, and making joint decisions, might reflect more effective regulation and cooperation practices than the TFA type, which lacks problem-solving strategies and tests ideas at random without sufficient consideration. Both of these types of deliberation provide valuable insight into how groups deliberate and respond to regulation triggering events. Most importantly, our findings suggest that groups tend to adhere to their existing deliberation sequence and do not fully alter it across the collaborative session. These can further be seen in Table 6.

Table 6 Distribution of sequences within two clusters across groups and phases

Type					Group					
	A	B	C	D	E	F	G	H	I	J
1	3		1	1	1	2		1		1
	5		2	2	2			3		
			3		3					
			4		4					
2	1	1	5	3		1	1	2	1	2
	2	2		4		3	2	4	2	5
	4	3		5		4	3	5	3	
		4							4	

[1]The number from 1 to 5 in each row represents the corresponding phases of the sequences.

Each group has undergone five different phases (1 - before the cognitive trigger, 2 - after the cognitive trigger, 3 - after emotional trigger 1, 4 - after emotional trigger 2, and 5 - after emotional trigger 3). Thus, there are five corresponding sequences for each group. The table shows the distribution of these sequences within two clusters, labelled as cluster type 1 and cluster type 2, across all groups labelled as A to K.

In combination with the findings of Study I, this shows that regulation triggering events can facilitate short-term changes toward metacognitive regulatory interactions but do not result in long-term changes in deliberation behaviour patterns. Previous research has suggested that students often overlook or fail to fully recognise and respond to emerging regulatory needs or situations (Nguyen et al., 2023; Törmänen et al., 2022). This behaviour is consistent with the findings of Study II, which showed the pattern of groups eventually reverting to the initial deliberation sequences. Furthermore, this finding is also congruent with literature on regulation in learning, which suggests that regulatory cycles consist of iterative adaptation at different temporal levels (Järvelä et al., 2019; Nguyen & Järvelä, 2023), in which short-interval small-scale adaptation (Järvelä & Bannert, 2021)

embedded within and influences the high-level regulation of longitudinal changes (Caprara et al., 2008).

Together, these findings highlight the importance to support students in recognizing and addressing emerging regulatory needs in collaborative learning environments. Furthermore, these have significant implications for two areas. First, in the analysing of SSRL using AI technique. it suggests moving beyond fix-time intervals as it is inadequate for examining regulation at various levels of granularity and temporal level. Second, in the development of AIED tools, it highlights the need for providing timely and relevant interventions and feedback that support both short-term adaptations as well as long-term development of SSRL skills.

7 Conclusion

The main aim of this thesis is to examine group interactions in response to cognitive and emotional regulation triggering events through the theoretical lenses of SSRL at the macro-level and micro-lens of deliberation. The findings are derived from a variety of methods used to achieve this aim. Overall, these findings provide several conclusions that can be incorporated into scientific discourses in the learning process regarding regulation triggering events, deliberation, and the trigger framework (Järvelä et al., 2023). The conclusions are presented in terms of their theoretical, methodological, and practical implications.

This thesis provides empirical evidence for the trigger concept in SSRL by demonstrating that regulation triggering events, such as cognitive and emotional challenges, can facilitate regulatory processes in collaborative learning and aid in locating learners' in-situ regulatory responses. Our results confirmed a significant relationship between the regulatory and deliberative characteristics manifested in interactions before and after the regulation triggering events. This thus also supports the use of deliberation as a lens to model learner behaviour and potentially trace the sequence of SSRL. Moreover, the study identifies two distinct types of deliberation patterns (i.e., the PIA and TFA) among groups when facing cognitive and emotional regulation triggering events. Taken together, these respond to the

current call for informing the development of theoretical models, in this case, SSRL in collaborative learning, in alignment with advanced methodologies (Chen et al., 2020).

The thesis also has methodological implications. It showcases a human-AI collaborative approach, employing an array of techniques for data processing and analysis to investigate group-level interaction for regulatory and deliberative characteristics. Leveraging AI techniques for auto video transcription enabled more efficient data processing, allowing fine-grained analysis and further application of ML that can be difficult to achieve with a manual approach. Through the integration of multiple analysis approaches in video data and transcription, an in-depth understanding of the interactional patterns that arose in response to different cognitive and emotional regulation triggering events was possible. The approach utilised in this thesis, combining multiple methods in one data stream to gain new insight into complex processes, can serve as a model for future research investigating SSRL.

Additionally, this thesis has practical implications, since the results can be applied to the design of effective AIED interventions and feedback mechanisms for SSRL in collaborative learning. A key finding of this study is that learners need support in recognizing and responding to emerging regulatory needs when working collaboratively. The design of this support also needs to take into consideration the target of regulatory adaptation, whether it is short-term changes or long-term strategic adoption. Together with the identification of two distinct types of deliberation patterns, these findings can assist in designing learning activities and interventions to promote successful regulation and collaboration. Lastly, the study provides insight into the types of regulation triggering events that can be used to trace learners' situational responses, which can be used to inform the development of in-time learning interventions.

It is important to acknowledge, however, that this thesis has some limitations. This thesis presents research conducted in a controlled laboratory environment, which may not fully replicate the complexities and variability of real-life

collaborative learning environments. In addition, the sample size was relatively small and therefore may not reflect the views of a wider and more diverse population. Thus, there is potential for future research to address some of these limitations by conducting larger-scale experiments in less controlled and complex settings and by including a broader range of participants in the research. Furthermore, although the focus of this thesis was on group-level interaction for deliberation, future research could explore how other factors, such as individual emotion and motivation, influence group-level deliberation.

Original publications

I   Dang, B., Vitiello, R., Nguyen, A., Rosé, C., & Järvelä, S. (2023). How Do Students Deliberate for Socially Shared Regulation in Collaborative Learning? A Process-Oriented Approach. *Proceedings of the International Conference on Computer Supported Collaborative Learning* [Manuscript accepted].

II   Dang, B., Nguyen, A., & Järvelä, S. (2023). Clustering Deliberation Sequences through Regulation Triggering Events in Collaborative Learning. *Proceedings of IEEE International Conference on Advanced Learning Technologies*. [Manuscript accepted].

How Do Students Deliberate for Socially Shared Regulation in Collaborative Learning? A Process-Oriented Approach

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Abstract: Socially shared regulation (SSRL) has been recognized as a contributing factor to successful collaborative learning. In this paper, we adopted a process-oriented approach to examine how students deliberate for SSRL through different regulatory triggers in a collaborative learning context. More specifically, this study examines the relationship between different types of regulatory and deliberative characteristics of interactions and then explores their sequential patterns through cognitive and emotional triggers. The study involved ten triads of secondary students (N=30) working on a collaborative learning task. The process mining results showed that following regulatory triggers, groups switched to more metacognitive and socio-emotional interactions as they adopted control strategies, such as defining problems, establishing strategies, and providing social support. This study not only contributes to a better understanding of SSRL by exploring learners' deliberative negotiation but also presents a novel fine-grain video analysis approach to examine SSRL in collaborative learning.

Introduction

Driven by the needs of the 21st century, collaboration and self-regulated learning are increasingly important skills for academic success, career progression, and life-long development (Järvelä et al., 2019). Increasing evidence suggests that regulation in learning is critical for achieving collaborative success at both the individual and group levels (Bakhtiar & Hadwin, 2020). This has, thus, offset an evolution of growing bodies of research in self-regulated learning (SRL) and its social forms namely co-regulated learning (CoRL) and socially shared regulated learning (SSRL) (Hadwin et al., 2018) in collaborative contexts such as computer-supported collaborative learning or collaborative problem-solving (Michalsky & Cohen, 2021; Zheng et al., 2019). However, the main challenge faced by many researchers in the field is that it is difficult to capture and study (S)SRL in authentic learning contexts (Järvelä et al., 2019). (S)SRL rarely occurs in normal learning situations and the dynamic cyclical, multidimensional, and intertwined nature makes it difficult to identify, complex to examine and little is known about its emerging mechanism. In collaborative contexts, all three types of regulation exist, interact dynamically, and influence each other (Bakhtiar & Hadwin, 2020; Järvelä et al., 2019). Through constant reflection and negotiation with the self, context, and other(s), learners take control of the learning process and overcome challenges through constant iterative adaptation at different levels of cognitive, behavioral, motivational, and emotional conditions. Collaboration is often inhibited by multiple levels of challenges such as task difficulties, lack of shared understanding, or emotional conflicts (Järvenoja et al., 2019). However, research has reported a relationship between these challenging situations and regulatory activities. Researchers have argued that negative incidents and obstacles can also trigger discussions and negotiation among group members, suggesting its potential for locating situated interactions for regulation in response to them (Järvelä et al., 2019).

In line with this call, our study aims to provide empirical evidence regarding the potential of using regulatory triggers as treating conditions to stimulate and locate regulatory interactions. A regulatory trigger refers to a motivational, cognitive, emotional, or behavioral event that inhibits task progress and requires adaptation of current regulatory practices or strategies (Järvelä et al., 2023). In this study, we particularly examine the cognitive and emotional triggers that target the adaptive process of cognition and emotion correspondingly. We attempt to examine SSRL from a deliberation process-oriented approach, as theories of SSRL have suggested negotiation is one of the core mechanisms for the cyclical adaptation of regulated learning (Hadwin et al., 2018). The focus on deliberative negotiation, i.e., the term "deliberation", is chosen for its distinctive emphasis on convergent interests and a shared nature (Ihnen, 2014). We examined the types and patterns of interactions throughout regulatory triggers from both regulation and deliberation perspectives. Specifically, our research questions are as follows:

RQ1: Is there a relationship between regulatory and deliberative characteristics of interactions in response to cognitive and emotional regulatory triggers?

RQ2: What are the patterns of the regulatory and deliberative characteristics of interactions through different types of regulatory triggers?

Theoretical Background

Socially Shared Regulation in Collaborative learning

Three types of regulation emerge as necessary for success in the context of collaboration: (a) self-regulated learning in which individuals systematically adapt their own regulation processes, beliefs, and goals; (b) co-regulated learning in which individuals support or influence another team member's regulation processes, beliefs, and goals; and (c) socially shared regulation of learning in which team members collectively negotiate, realign, or adapt group regulation process, strategies, beliefs, and goals (Järvelä et al., 2016). In this model, phases of collaborative solving are defined as task understanding, planning, task enactment, and reflection and adaptation (Hadwin et al., 2018). Thus, group regulation is a cyclical and social phenomenon requiring both regulations of cognitive and relational states of collaboration.

Research has shown many learners lack regulatory skills and struggle to enact them when working on complex collaborative tasks (Järvelä et al., 2019). This inability to regulate cognitive and relational states may explain why learners often struggle to collaboratively problem-solve and co-construct knowledge. In this paper, we aim to study the nature of group regulation during problem-solving in the presence of cognitive and emotional triggers to better understand how to support learners during these collaborative challenges.

Challenges and Negotiation in SSRL

A critical marker of successful regulation is a learner's ability to adaptively respond to challenges during collaboration to optimize both personal and group goal progress. This adaptation is not spontaneous but rather emerges only when strategically and purposefully enacted during moments that the task, situation, or social domain requires it (Hadwin et al., 2018). It is well established that this complex, multifaceted phenomenon is difficult to observe and rarely occurs naturally in collaborative contexts (Nguyen et al., 2022). Consequently, experimentally studied data collection must be carefully designed to introduce these challenges to effectively and timely capture these situated responses and interactions (Järvelä et al., 2019). Accordingly, this study presents a systematic introduction of treatments comprising cognitive and emotional triggers to better collect and analyze interactions during critically situated regulatory phases.

While these challenges introduce difficulty in regulation on both the individual and group levels, they also provide opportunities for learners to engage in active and purposeful negotiation to align goals, motivations, and beliefs. Deliberative negotiation is described as one important mechanism by which productive groups can strategically take control of collaborative challenges and adapt to them as they arise. Prior research supports that increasing opportunities for purposeful deliberation during collaborative challenges may lead to beneficial outcomes. Less successful collaboration is often characterized by parallel working and ignorance of other group members' contributions (Haataja et al., 2022). Challenges make group members' different understandings more visible and individual emotions more explicit (Kreijns et al., 2013), which in turn offers opportunities for learners to better negotiate and align their collaboration (Rogat & Linnenbrink-Garcia, 2011). In other words, the presence of these challenges provides more opportunities and awareness for team members to purposefully regulate learning so that group goals, motivation, and beliefs can be better deliberated and aligned (Hadwin et al., 2018).

However, despite the interest in these deliberative interactions, a dearth of past research has focused on examining group regulation from a negotiation-based deliberative perspective. Most research on regulation has been explored from a macro-perspective at the level of an episode (Nguyen et al., 2023) rather than a more granular perspective required to effectively study back-and-forth negotiation. Therefore, our study explores regulation from a fine-grained lens at the unit of a single discussion contribution to better examine patterns during deliberative negotiation.

Research Methods

Participant, Context, Research Design

Data collection involved thirty secondary school students (*N*=30) working on a face-to-face collaborative learning task for 30-40 minutes. They are randomly assigned into 10 groups of three students each then being required to plan together a healthy breakfast smoothie based on nutritional needs. Each group has a shared document for the task and each student has their own laptop. After the first half of the learning task, the cognitive trigger will be presented to the group in the form of a customer voice message, stating an allergy to a certain product. This is followed by an emotional trigger after three minutes, with the customer calling to express impatience in an unpleasant voice. Video and audio data were collected using Insta360 Pro video cameras and a group microphone.

Data Analysis

To answer the research questions, we first examined group interactions based on their regulatory and deliberative characteristics through qualitative coding and content analysis of video-recorded student collaborative learning sessions. A granular coding was conducted for the period from 2 minutes prior to the first cognitive trigger to 3 minutes after the emotional trigger. While quantitative statistical analyses were performed to check the correctness of our assumption, a process mining approach was utilized to reveal the patterns within these characteristics.

Video Qualitative Analysis

As a means of capturing the relatively abstract phenomenon of SSRL that is suitable for sophisticated AI analysis, two coding schemes for qualitative video analysis are employed, one for high-level regulatory (SSRL) characteristics and one for low-level deliberative characteristics of group interactions that is easier to conceptualize, code, and capture in the data. This enables the modelling of high-level SSRL on low-level activities for a more comprehensive and accurate understanding of the multi-level complexities of SSRL. First, to identify different types of regulatory characteristics of interactions, a coding instrument was adopted from prior studies (Näykki et al., 2021; Nguyen et al., 2022). Four different categories (as described in **Table 1**) were included: metacognitive interaction, cognitive interaction, socio-emotional interaction, and task execution interaction. This study adopted Järvelä et al. (2023)'s human-AI collaboration approach, in which a micro-analytical recording technique was employed to enable fine-grained qualitative video coding of students' every speaking turn. This approach allowed for a more sophisticated and detailed analysis in contrast to the previous episode-level coding approach. The data were then coded by a researcher, which included 1,220 utterances with different regulatory characteristics defined in total ($f_{\text{Metacognitive}} = 407$, $f_{\text{Cognitive}} = 379$, $f_{\text{Socio-emo}} = 61$, $f_{\text{Task execution}} = 373$). A reliability test of the coding was done with two coders for 239 utterances resulting in moderate to high Cohen's Kappa value ($\kappa_{\text{Task execution}} = 0.63$; $\kappa_{\text{Cognitive}} = 0.69$; $\kappa_{\text{Metacognitive}} = 0.71$; $\kappa_{\text{Socio-emo}} = 0.88$).

Table 1

Coding scheme for video quantitative analysis

Categories	Description	Example
Regulatory characteristics of interactions		
Metacognitive interaction	Meta-level mental processes toward the control and monitoring of cognitive and emotional activities (orienting, planning, monitoring, evaluating, and regulating). The connection and reflection are aimed at task-related strategies, group processes, or dynamics.	*S1: By the way, I don't use this ingredient page at all, I just put it in there and see what happens.* *S2: If we just keep the ingredients the same, but increase their number in the same ratio, so then those percentages go absolutely nowhere.*
Cognitive interaction	Interaction focuses on higher-order learning-related thinking skills such as understanding, analyzing, reasoning, and evaluating at the object-level related to task content.	*S2: Well, here are the others, here are all the chia seeds, hazelnut spread, whey protein powder.* *S1: But here would be pineapple or blueberry, then they would be the kind where there would be very little of everything.*
Socio-emotional interaction	Action and interaction relevant to the expression of one's emotion in social contexts with clear negative/positive affect nature (e.g., showing gratitude, joking, disputing)	*S1: Oh good time, this guy first orders a smoothie, and then tells us to make it again and then complains that it's taking us a long time to make it this. [Express annoyance with group show shared feeling]*
Task execution interaction	Actions and interactions that primarily focus on carrying out task requirements, and completing the task include: i.e. typing on the computer, reading the instruction	*S1: Yeah, I'll change them to one hundred and twenty-five. [Inform current process]* *S2: One hundred and twenty-five. OK that should be twenty-five then.*

Since the present study has been one of the first attempts to thoroughly examine the deliberative characteristics of interactions in SSRL at the granular level, there is no existing coding scheme found suitable. Accordingly, we conducted the qualitative content analysis for deliberative characteristics by following Onwuegbuzie et al. (2009)'s constant comparison method. Group utterances first underwent an open coding stage, in which each was assigned a descriptor that describes an aspect of the deliberation process. Next, researchers developed and refined themes that express the content of each code or group of codes. Notwithstanding more comprehensive reliability testing should be conducted to establish a formal coding scheme for deliberative characteristics, the results of the content analysis certainly add to our understanding of the processes of deliberation in SSRL. The resulting coding themes are reported in **Table 2**.

Table 2

Types of deliberative characteristics of interactions as the results of constant comparison analysis

Deliberative characteristics of interactions		
Define the problem	Share understanding of the problem, defining the present situation and the desired future, to make the current issues problem clearer to group members.	*S1: So, what couldn't be there?* *S2: Natural rubber and milk protein allergy.* *S1: Well, should the natural rubber be that low or…* *S2: Yes, all of them should be low. [..] It's not good when hazelnut spread has natural rubber so high…*
Establish strategy	Suggestion and implementation of process steps (how to approach the tasks, ways of executing certain aspects of the task)	*S1: […] we need another 250 kilocalories, half of it.* *S2: Yes, […] And then we'll get increased protein and fat if we only put these […] Let's raise everyone a little, so it won't change these ratios.* *S1 & S3: Yeah. (Okay).*
Specify information needs	Identify technical background information that is pertinent to the issue; identify information that is available and information that is needed.	*S1: Where does it say natural rubber?* *S2: It reads over there, on the other side.* *S3: That last one of those nutrients.*
Educate each other	For back-and-forth discussions of group members trying to work on disagreement and align shared understanding by identifying and sharing understanding, interests, reasons, needs, etc.	*S1: Well, but you mustn't bring a lot of fat at once.* *S2: We already have a package.* *S3: Let's put something in it.* *S2: We don't have that […] You can't put anything left.*
Generate options	Brainstorm and generate a solution for task-related problem-solving: offer alternatives of choices.	*S1: Where can I get more energy?* *S2: Shall we put that oatmeal in there?*
Evaluate options	Make a judgment about the generated options	*S1: Shall we put kale in there when?* *S2: It sounds a bit strange*
Reach agreement	Confirm shared agreement on the options, ideas, and opinions.	*S1 & S2: Oat or almond, is it either?* *S3: Oat drink* *S1: Okay, let's make an oat drink.*
Implement the agreement	Carry out the selected options or attempt ideas.	*S1: Yeah, I'll change them to one hundred and twenty-five. [Inform current process from previous agreement]*
Attempt ideas	Apply for testing out alternatives/solutions without forethought & discussion between group members.	*S1: I'm going to try a bit of randomness here now, there's a moderate one, so not really*
Monitor the time	Keep track and check on the time	*S1: There are now four hundred and ninety-eight calories. Isn't it about time?* *S2: I don't think it's the time*
Monitor group operation	Observe and check on the group's focus and shared agreement, current progress within the task, and quality of the procedure.	*S1: It's time we think about how we can produce protein* *S2: So here…*
Monitor environmental context	Observe and check on other conditions around the task, i.e., technical and resources; social conditions.	*S1: Oh yeah, isn't it, and it's just a visual glitch of ours that the fat is half of what it should be?*
Monitor the result	Check on task requirements and how the current result is meeting those.	*S1: Now we have a little too many calories.* *S2: Isn't the maximum - about 500 didn't read here?*
Evaluate group operation	Make a judgment about group focus, shared agreement, current progress, and procedure quality.	*S1: Now it's good. Wise one about 500 [Complement group's strategy]*
Evaluate the result	Make a judgment about the current result in accordance with the task requirement.	*S1: If we score it 15 g, then five hundred and five, pretty much those. I guess there is nothing to complain.*
Regulate group emo-mo	Interaction with the intention of regulating group focus or emotional - motivation about the situation	*S1: Well, it's probably right for us.* *S2: If it's the same for you, then we'll trust it.*
Positive socioemotional interaction	Positive socio-emo interaction without the intention of regulation.	*S1: Well, it's not- (It's my own fault when I forgot my allergy.)* *S2 & S3: synchronous laughing and agreeing to*
Negative socioemotional interaction	Negative/ neutral socio-emo interaction without the intention of regulation.	*S1: Well, if only we scored something. [all group member non-verbal show lack of motivation]*

<u>Process Mining</u>

A process-oriented analysis is utilized to identify and describe the sequences and patterns of regulatory and deliberative characteristics of group interactions throughout regulatory triggers. Fuzzy Mining, a process-mining algorithm, was used to explore the time-related pathways among different phases before the cognitive trigger (269 utterances), after the cognitive trigger (483 utterances), and after the emotional trigger (468 utterances). The analysis was performed using Fluxicon Disco, a process mining software program commonly used in learning sciences research for describing sequences in learning logs or activities (e.g., Nguyen et al., 2022).

Result and Findings

RQ1: Is there a relationship between regulatory and deliberative characteristics of interactions in response to cognitive and emotional regulatory triggers?
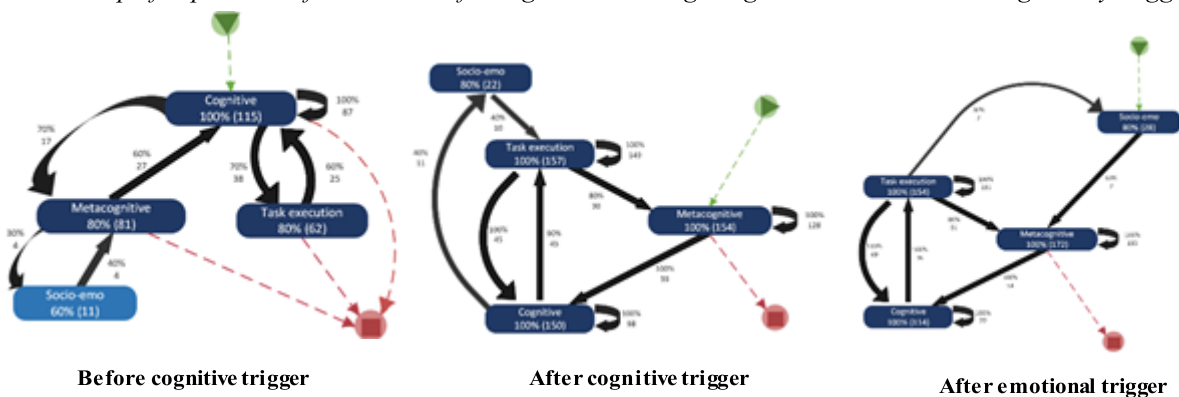
To answer this research question, Chi-square and Cramer's V tests were applied to first validate the impact of regulatory triggers on the regulatory and deliberative characteristics of group interactions, then to examine the correlation between these two types of characteristics. First, we assessed the distributions of interactions based on their regulatory and deliberative characteristics among three timespans: before triggers; after the cognitive trigger; and after the emotional trigger. The result showed that the distribution of regulatory characteristics of interactions significantly differed among the timespans before and after the regulatory triggers ($\chi2 = 76.7$; $df = 12$; $p < .001$). The effect size for this finding, Cramer's V, was small, 0.12 ($df = 3$). This finding validated the effects of our experimental treatments as regulatory triggers and corresponded with existing literature on social forms of SRL which found that negative incidents and challenges raise students' metacognitive awareness and trigger more interactions for regulation (Järvelä et al., 2016; Saariaho et al., 2019). However, some dynamic factors of the group, such as participation levels or group characteristics (Ucan, 2017) may mediate the effect on the occurrence of regulatory characteristics manifested in interactions, which would explain the small magnitude of the effect. Second, the Chi-square and Cramer's V tests for deliberative characteristics of interactions and the timespans indicated a significant difference in the proportions associated with each timespan with a medium effect ($\chi2 = 503.9$; $df = 68$; $p < .001$, $V = .26$). This result again confirmed the role of the regulatory triggers in activating group regulation and altering the dynamics of deliberative characteristics in collaborative learning. Last, we examined the association between the distributions of regulatory and deliberative characteristics of interactions. The results showed that the amount of variance in different types of interactions for regulation based on the deliberative interactions was significant ($\chi2 = 3006.2$; $df = 51$; $p < .001$) with a large effect size ($V = .75$, $df = 3$). It was thus appropriate to say that there was a significant association between different types of regulatory and deliberative characteristics of group interactions.

RQ2: What are the patterns of interactions for regulation and deliberative interactions through different types of regulatory triggers?

The process maps (see **Figure 1**) showed the most dominant trajectory of regulatory characteristics, which were engaged in different phases before and after regulatory triggers by all groups. The maps reported absolute frequency and case coverage in the percentage of interactions for regulation of all groups.

Figure 1

Process maps for patterns of interactions for regulation through cognitive and emotional regulatory triggers

Before cognitive trigger   After cognitive trigger   After emotional trigger

Overall, it is evident that there has been a clear shift in the pattern of regulatory characteristics in response to different triggers. The result indicates that prior to regulatory triggers, most groups started by engaging in *cognitive interaction* (f = 100%) repeatedly which then led to *task execution* ($f_{\text{Cognitive -> Task execution}} = 70\%$) and looped back. After the first cognitive trigger, the most dominant process flow started instead with 1) *metacognitive interaction* (f = 100%) then in a path in the following sequence: 2) *cognitive interaction*, 3) *task execution interaction*, and looped back. Succeeding the emotional trigger, the majority of groups became involved in *socio-emotional interaction* (f = 80%) then followed by the previously observed pathways after the cognitive trigger. We also examined the absolute frequency of regulatory characteristics of interactions. There was a significant increase in instances of metacognitive ($f_{\text{Before CT}} = 62 \rightarrow f_{\text{After CT}} = 154$) and socio-emo interactions ($f_{\text{Before CT}} = 11 \rightarrow f_{\text{After ET}} = 28$). In addition to confirming previous studies that have discussed the impact of cognitive and social challenges on facilitating regulation (Näykki et al., 2021), our results provide empirical evidence for the potential of triggers to locate and capture the types and sequences of regulatory characteristics of interactions as they occur in practice. Moreover, the shared sequence of regulatory characteristics manifested in interactions in response to cognitive and emotional triggers identified in our study can be an indicator of strategic actions that are more adaptive to learning.

Turning to the patterns of deliberative characteristics through cognitive and emotional triggers, the process maps in **Figure 2** revealed the difference between phases of regulatory triggers. Our results showed that immediately preceding the regulatory trigger, most groups engaged in a deliberative pattern that is adequately conventional in collaborative learning contexts, starting with *generate options* (f = 80%), followed by *reach agreement* ($f_{\text{Generate options -> Reach agreement}} = 30\%$), and then *implement the agreement* ($f_{\text{Reach agreement -> Implement agreement}} = 30\%$). However, group deliberative characteristics after cognitive and emotional triggers shifted more toward metacognitive in nature such as focusing on the strategies to complete the tasks or providing support to one another. While this shift is highly correlated with that regulatory characteristics, our study found that the patterns and utterance types groups engaged in were different between cognitive and emotional triggers. After the

Figure 2

Process maps for patterns of deliberative interactions through cognitive and emotional regulatory triggers

Before Triggers

After Cognitive Trigger

After Emotional Trigger
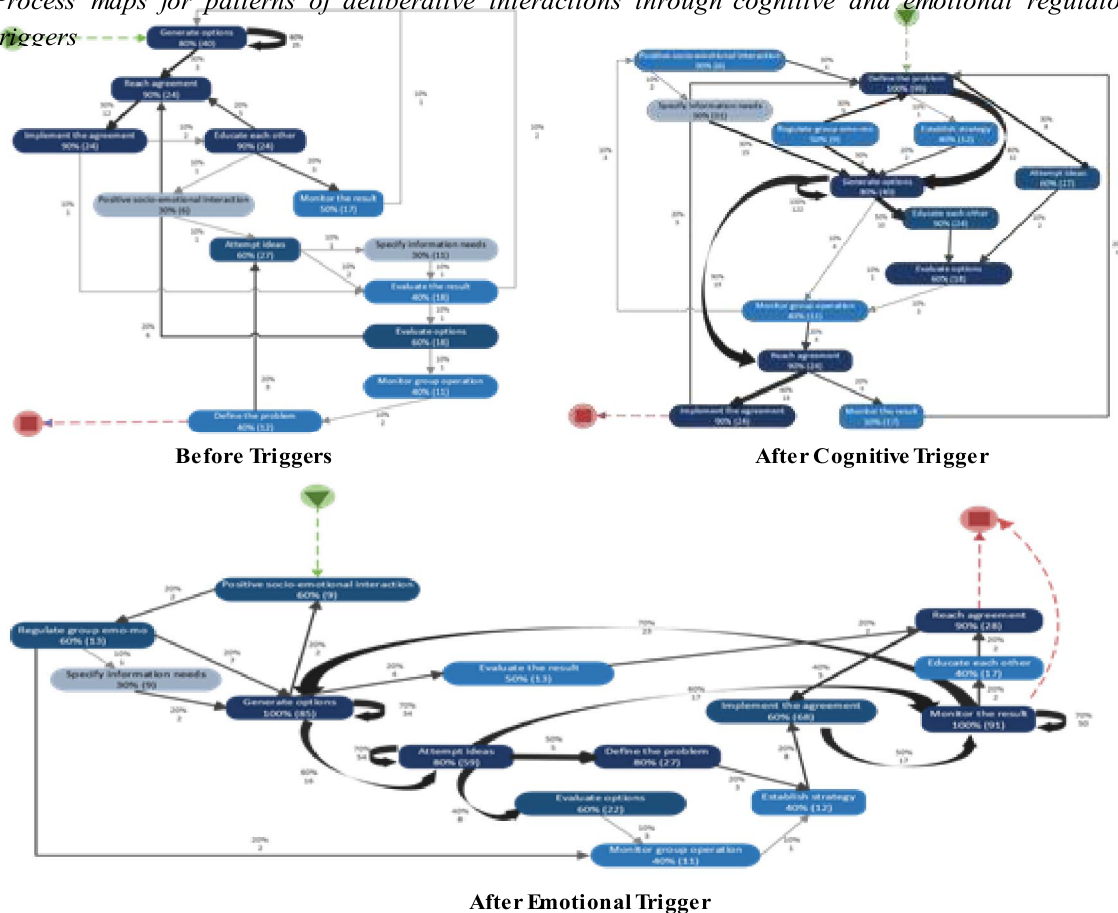
cognitive trigger, the most dominant process flow started instead with *define the problem* (f = 100%). While the expected path for collaborative learning remains prominent, the patterns of deliberative utterance types prior to and after *generating options* are different from those of the previous stage. Most groups engaged in *regulate group emo-mo* (f = 50%) or *establish strategy* (f = 40%) as a prelude to *generate options* and followed by *educate each other* (f = 50%) or *monitor group operation* (f = 10%) before *reach agreement*. The deliberative pattern reflects a strategic control of group behavior to solve problems that are cognitive in nature. In comparison, the deliberative characteristics after the emotional trigger focused more on group emotion regulation, beginning with *positive-socioemotional interaction* (f = 60%), followed by *regulate group emo-mo* (f = 60%) before *generate options* (f = 85). Taken together, these findings support our assumption of using deliberative utterance as a lens for examining how SSRL occurs in collaborative learning at a more granular level.

Discussion and Implications

The aim of this study was to provide empirical evidence of how regulatory triggers can be utilized as a part of (S)SRL research designs to capture critical in-situ regulatory phases in challenging learning situations. Previous studies have pointed out a significant link between challenging situations and their ability to invite metacognitive awareness and create opportunities for regulatory activities (Järvelä et al., 2019; Näykki et al., 2021). However, it is well established that (S)SRL is a complex, dynamic, cyclical, and multifaceted process that is difficult to capture and rarely happens in most learning contexts (Nguyen et al., 2022) and more is needed to examine this relationship (Raković et al., 2022). Recent research has introduced the trigger concept to examine SSRL (Järvelä et al., 2023). Our study is one of the first to attempt to introduce control treatments of regulatory triggers and to examine SSRL processes in the context of face-to-face collaborative learning at a granular level.

This study provided evidence that regulatory triggers facilitate regulatory processes in collaborative learning and confirm our theoretical predictions (Järvelä et al., 2023). Our findings revealed a significant difference in the proportions of different types of regulatory and deliberative characteristics manifested in interactions before and after regulatory triggers. More specifically, our findings revealed that groups switched from a more cognitive collaborative task-solving process to engage in more metacognitive interactions after the cognitive trigger and socio-emotional interactions after the emotional trigger. In light of these findings, it is argued that regulatory triggers could serve as a marker to locate the regulation taking place to overcome it. This current study responds to a recent call for a new methodological approach to effectively obtain richer data to advance our understanding of SSRL and how to support it in the face of collaborative challenges (Järvelä et al., 2019).

The second objective of this study was to examine how the deliberative characteristics of interactions progressed throughout SSRL in collaborative learning. Based on the progress in understanding and conceptualization of SSRL over the past two decades, the current SSRL theory posits that in collaboration, all three forms of regulation (SRL, CoRL, and SSRL) co-exist and influence each other via negotiation and social interactions (Bakhtiar & Hadwin, 2020; Järvelä et al., 2019). Despite the importance of the negotiation mechanisms for regulation in collaborative learning, there is little published data that examine group regulation through the lens of negotiation processes. Accordingly, this study appears to be one of the first studies to closely examine the deliberative negotiation process in SSRL.

It has been argued that the existing studies often examined SSRL from a macro perspective of phases and meaningful episodes with fixed time intervals, which has been deemed inadequate for advanced methods such as machine learning (Nguyen et al., 2022). Furthermore, although prior studies offered valuable insights into SSRL, the current approaches with fixed time intervals are not sufficient for examining regulatory adaptation at different levels of granularity to comprehensively address the cyclical and dynamic nature of SSRL (Järvelä et al., 2019). Our study attempts to bridge this gap by exploring the possibility of analyzing SSRL from a deliberative process perspective incorporated within fine-grain utterances for every discussion contribution. The present study not only contributes to a better understanding of SSRL, but also delivers a methodological contribution with a novel video analysis approach to examine SSRL in collaborative learning (Järvelä et al., 2019).

The current study has some limitations. First, this study has a small sample size. Moreover, the high level of contextualization in the collaborative task limits the generalizability of these findings to other learning environments. Second, as aforementioned in the video analysis, further research is needed to thoroughly examine the reliability of the content analysis results for deliberative characteristics of interactions. In spite of its limitations, the study contributes to a better understanding of SSRL in collaborative problem-solving contexts, establishing a new basis for methodological and theoretical progression, thus potentially increasing our understanding of how SSRL manifests. Further research could be conducted to investigate how to utilize and apply AI techniques to comprehend the fine-grain analysis approach for offering a new lens through which SSRL could be better understood and support could be designed for promoting SSRL in face-to-face collaborative learning settings.

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Clustering Deliberation Sequences through Regulatory Triggers in Collaborative Learning

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Abstract— Recent advances in Learning Analytics (LA) and Artificial Intelligence (AI) have enabled us to gain a better understanding of socially shared regulation (SSRL), which is in collaborative learning. Although recent progress in studying SSRL with LA and AI has provided holistic insights into the temporal and cyclical processes of SSRL, few studies have investigated SSRL processes at a granular level. To address these limitations, we utilise AI techniques to explore *the sequences of group-level deliberation as a process and its pattern through cognitive and emotional regulation triggering events in the context of face-to-face collaborative learning.* This study involved ten triads of secondary students (N = 30) working on a collaborative learning task and receiving regulation triggering events during their learning. Results from Agglomerative Hierarchical Clustering (AHC) identified two distinct types of deliberation sequences with different approaches to regulation and collaboration practices: 1) the plan and implementation approach (PIA) focused on analysing, discussing, and collaborating; and 2) the trials and failures approach (TFA) focused on random idea testing. Interestingly, we found that most groups maintain the same approach in response to triggering events, emphasizing the importance of supporting learners to recognize and react to the emerging needs of regulation.

Keywords—Socially shared regulation, negotiation, agglomerative hierarchical clustering, artificial intelligence.

INTRODUCTION

Socially shared regulation in learning (SSRL) has been recognised as an essential aspect of successful collaborative learning. Several empirical findings have highlighted that social interactions involving deliberative negotiation are at the core of SSRL in which the groups collectively discuss, realign, or adapt their shared regulatory process, beliefs, and knowledge. Despite its centrality to the regulation processes, there remain few published studies that examine deliberative negotiation in SSRL. Accordingly, this study aims to address this gap by investigating the deliberation aspect of SSRL. Our study attempts to utilise learning analytics (LA) and Artificial Intelligence (AI) to investigate the sequences of group-level interaction for deliberation in response to different cognitive and emotional regulation triggering events. Our AI-enabled granular process-oriented approach seeks to shed light on the patterns underlying group deliberation that, as SSRL theories have argued, is one of the key mechanisms to cyclical adaptation in regulation [1].

METHODS

Data Collection

This study included 30 secondary school students (N=30, male/female = 21/9), randomly divided into 10 groups of three each. They worked on a collaborative task in which they had to plan together a healthy breakfast smoothie based on nutritional needs with a shared document for the task and each student had their own laptop. The task lasted for 30-40 minutes. After the first half of the task, a cognitive regulation triggering event (CT) is presented. This is followed by three emotional regulation triggering events (ET) at 3-minute intervals. High-quality video and audio data were collected from each group.

Qualitative Video Coding

Järvelä, Nguyen, and Hadwin [2] 's AI-human collaboration approach for studying SSRL with a micro-analytical recording technique was utilised for qualitative video coding at a fine-grain granularity. Line-by-line coding was conducted for each single speaking turn of the students. As this is one of the first studies examining deliberative interactions in SSRL at a granular level, we conducted a qualitative content analysis with the constant comparison method [3] to define the coding scheme for deliberative interactions (Table 2). Qualitative video coding is conducted to code 2,035 utterances in 43 three-minute sequences corresponding with 5 phases: three minutes before the CT (Phase 1), after CT (Phase 2), after the first ET 1 (Phase 3), after ET 2 (Phase 4), and after ET 3 (Phase 5). One sequence of 12 utterances was excluded as an outliner because the group members failed to notice the triggering event. In total, 42 sequences with 2,023 codes were included in the analysis. An inter-rater reliability test with two independent coders was conducted for a subset of the data (2/10 sessions). Cohen's Kappa value ($\kappa = 0.76$) indicates a substantial agreement.

Agglomerative Hierarchical Clustering (AHC)

To examine the main patterns of deliberation for SSRL throughout the regulation triggering events, we applied Agglomerative Hierarchical Clustering (AHC) with Silhouette Coefficient selection methods by using Python programming language with the scikit-learn library. Based on the yielded silhouette score of AHC models, the 2-cluster model was selected as it provides the optimal fit. Furthermore, to gain a deeper understanding of the clusters, we also revisited the qualitative coding and video data to assess the characteristics of deliberations in each cluster.

CODING SCHEME FOR VIDEO QUANTITATIVE ANALYSIS

Categories	Description	Examples
Define the problem	Share understanding of the problem, defining the present situation and the desired future to make the current issues problem clearer to group members.	*S1: So, what couldn't be there?* *S2: Natural rubber and milk protein allergy.* *S1: Well, should the natural rubber be that low or…* *S2: Yes, all of them should be low. [..] It's not good when hazelnut spread has natural rubber so high…*
Establish strategy	Suggestion and implementation of process steps (how to approach the tasks, ways of executing certain aspects of the task)	*S1: […] we need another 250 kilocalories, half of it.* *S2: Yes, […] And then we'll get increased protein and fat if we only put these […] Let's raise everyone a little, so it won't change these ratios.* *S1 & S3: Yeah. (Okay).*
Specify information needs	Identify technical background information that is pertinent to the issue; identify information that is available and information that is needed.	*S1: Where does it say natural rubber?* *S2: It reads over there, on the other side.* *S3: That last one of those nutrients.*
Educate each other	For back-and-forth discussions of group members trying to work on disagreement and align shared understanding by identify and share understanding, interests -- reasons, needs, motivations; etc.	*S1: Well, but you mustn't bring a lot of fat at once.* *S2: We already have a package.* *S3: Let's put something in it.* *S2: We don't have that […] You can't put anything left.*
Evaluate options	Make a judgement about the generated options	*S1: Shall we put kale in there when?* *S2: It sounds a bit strange*
Reach agreement	Confirm shared agreement on the options, ideas, and opinions.	*S1 & S2: Oat or almond, is it either?* *S3: Oat drink* *S1: Okay, let's make an oat drink*
Implement the agreement	Carry out the selected options for attempt ideas.	*S1: Yeah, I'll change them to one hundred and twenty-five. [Inform current process from previous agreement]*
Attempt ideas	Apply for testing out alternatives/solutions without forethought & discussion between group members.	*S1: I'm going to try a bit of randomness here now, there's a moderate one, so not really*
Monitor the time	Keep track and check on the time	*S1: There are now four hundred and ninety-eight calories. Isn't it about time?* *S2: I don't think it's the time*
Monitor group operation	Observe and check on the group focus and shared agreement, current progress within the task and quality of the procedure.	*S1: It's time we think about how we can produce protein* *S2: So here…*
Monitor environmental context	Observe and check on other conditions around the task, i.e. technical and resources; social conditions.	*S1: Oh yeah, isn't it, and it's just a visual glitch of ours that the fat is half of what it should be?*
Monitor the result	Check on task requirements and how the current result is meeting those.	*S1: Now we have a little too many calories.* *S2: Isn't the maximum - about 500 didn't read here?*
Evaluate group operation	Make a judgement about group focus, shared agreement, current progress, and procedure quality	*S1: Now it's good. Wise one about 500 [Complement group's strategy]*
Evaluate the result	Make a judgement about the current result in accordance with the task requirement.	*S1: If we score it 15 g, then five hundred and five, pretty much those. I guess there is nothing to complain.*
Regulate group emo-mo	Interaction with the intention of regulating group focus or emotional - motivation about the situation	*S1: Well, it's probably right for us.* *S2: If it's the same for you, then we'll trust it.*
Positive socioemotional interaction	Positive socio-emo interaction without the intention of regulation.	*S1: Well, it's not- (It's my own fault when I forgot my allergy.)* *S2 & S3: synchronous laughing and agreeing to*
Negative socioemotional interaction	Negative/ neutral socio-emo interaction without the intention of regulation.	*S1: Well, if only we scored something. [all group member non-verbal show lack of motivation]*

AHC MODEL FIT STATISTIC

No. of Cluster	2	3	4	5	6	7	8	9	10
Silhouette score	0.116	0.111	0.056	0.053	0.068	0.070	0.075	0.077	0.076

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RESULTS AND FINDINGS

What patterns of group interaction for deliberation can be identified through different regulation-triggering events?

One objective of this study was to assess whether the proposed coding scheme is appropriate for grouping group-level interactions for deliberation within collaborative learning environments. The hierarchical cluster analysis resulted in the identification of two types of sequences in which the first type includes the top 28 sequences, while the second types comprise the remaining 14 sequences. To learn more about the characteristic of these types, we revisited video data for sequences in each clustering group. We overserved that groups in type 1 often began by defining the issue that they must address and then discussed the necessary information with the other members before generating solutions. Upon reaching an agreement, they carried forward with the implementation while closely monitoring the results. Therefore, we name type 1 sequences as the plan and implementation approach (PIA) type. While in cluster 2, most groups responded to an identified problem by trying out some ideas and closely monitoring the results. Groups often do not spend enough time considering the problem and reasoning method to solve it, instead, they just try out options if they experience undesirable results. Thus, type 2 sequences are named the trials and failures approach (TFA).

How do deliberation sequences change in response to regulation-triggering events?

We further examine the distribution of sequence types for each group throughout their five phases. The majority of groups (f = 70%) have all or almost all of their deliberation sequences belonging to only type 1 (f = 20%) or type 2 (f = 40%). The remaining groups (f = 30%) show a more dynamic pattern where the group's deliberation sequences shift between two types through different phases of the cognitive and emotional regulation triggering events. This result may mainly reflect that in most cases, groups adhere to their existing type of deliberation sequence and do not alter it in response to triggering events. These results corroborate previous research which found that students often ignore or fail to recognize and respond to emerging needs or situations that require regulation [4].

DISCUSSION AND CONCLUSION

This paper aims to examine deliberation sequences through different regulation-triggering events and provide a granular lens to examine SSRL in collaborative learning settings. While theories have emphasized the importance of deliberative negotiation as a key mechanism for regulatory adaptations [6] very little empirical research has been conducted on the deliberation process that underlies SSRL. This study is one of the first attempts to examine deliberative negotiation in SSRL.

Reflecting previous observations that found learners often fail to recognize and react to challenging conditions [4], this study shows that the majority of groups did not alter their established deliberation sequences even when faced with a triggering event. Together with our identification of two deliberation sequences, this study can inform the design and implementation of SSRL support. It also emphasizes the need

for assisting students in responding to triggering events and fostering their ability to regulate their learning.

While LA and AI techniques have been leveraged to study complex phenomena in SSRL, existing studies typically examine SSRL from a macro perspective of phases, meaningful episodes, or fixed intervals that are deemed inadequate for machine learning [5]. Current work in this field also highlights the lack of engagement from LA and AI with theories [7]. Using AI models as analytical tools and SSRL as the theoretical framework, this study attempts to bridge the gap between LA and AI and learning theories and proposes a novel approach to examining SSRL.

This study also invites the theoretical discussion regarding the integration of the deliberation process within the current SSRL model, as it allows for a more comprehensive examination of the phenomena and provides insight into how to support desired responses for adaptive regulation cycles. This study responds to the current call for revising conventional learning theories in consideration of advanced technologies [7]. The coding scheme for deliberation patterns might benefit researchers in the field of SSRL who wish to harness multimodal data to examine SSRL from a dynamic fine-grain approach that is suitable for advanced LA and AI techniques.

Our study is not without limitations. First, our study only examined a limited sample. Therefore, it is imperative to validate this exploratory approach with a larger sample size. Future research can adopt process mining analysis to help further illustrate the pathways associated with each type of deliberation. Notwithstanding these, the study serves as a starting point for future research, which is needed to study the nuances around group interaction and individual mental models that lead to variation in response to triggering events.

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