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Tiina Törmänen

EMOTION REGULATION IN COLLABORATIVE LEARNING

STUDENTS' AFFECTIVE STATES AS CONDITIONS FOR SOCIALLY SHARED REGULATION

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TIINA TÖRMÄNEN

EMOTION REGULATION IN COLLABORATIVE LEARNING

Students' affective states as conditions for socially shared regulation

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Supervised by
Professor Hanna Järvenoja
Professor Sanna Järvelä
Doctor Kristiina Mänty

Reviewed by
Professor Thomas Martens
Doctor Nikki Lobczowski

Opponent
Associate Professor Jason M. Harley

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University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Emotions set the conditions for collaborative learning but can be also evoked by the learning activities. With emotion regulation, students can alter these affective conditions for their collaboration. Although it is central for learning, emotion regulation has not been systematically studied in a collaborative learning context. This dissertation focuses on individuals' and groups' affective states during collaborative learning, as well as the interrelations between affective states and the co- and socially shared regulation of learning. Furthermore, it aims to explore the potential of multichannel process data in detecting students' affective states and regulation.

Two data sets were collected in authentic learning situations. In Data I, participants were 6th grade students (N=31, 10 groups) performing a collaborative task. In Data II, 7th grade students (N=54, 18 groups) collaborated across four lessons. Collaboration was videotaped and students' electrodermal activity was measured. The analyses were based on video observations of students' emotional expressions (valence) and regulation. The codes were integrated with electrodermal activity data (activation) and the resulting multichannel data sets were analyzed with statistical and process analysis methods.

The results revealed various individual- and group-level affective states fluctuating during collaborative learning. Activated affective states were triggered by factors deriving from the learning task and from social aspects of collaboration. The groups utilized regulation to overcome negative and mixed affect but also to strengthen positive affect within the group. However, regulation was rare compared to the observed need. The results highlight individual learners' agentic role in co- and socially shared regulation. Methodologically, the results indicate that capturing valence and activation with separate data channels can provide further insights into students' emotional and regulatory processes.

This study contributes to the theoretical development of the role of affect in socially shared regulation. For educational practice, the findings highlight the need to provide more support and guidance for students and teachers in how to apply emotion regulation as a part of successful collaborative learning. The results can also be utilized in designing regulation support for collaborative learning.

Keywords: affect, co-regulation, collaborative learning, emotion, emotion regulation, multimodal multichannel data, process-oriented approach, socially shared regulation, socio-emotional interaction

Törmänen, Tiina, Oppilaiden tunteet ja niiden sosiaalisesti jaettu säätely osana yhteisöllistä oppimista.
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Tiivistelmä

Oppilaiden tunteet luovat olosuhteet yhteisölliselle oppimiselle, mutta vastavuoroisesti myös oppimistilanteet herättävät oppilaissa monenlaisia tunteita ja muokkaavat ryhmän yhteistä tunnetilaa. Vaikka tunteet ja niiden säätely luovat pohjan oppimiselle, ilmiötä ei ole juurikaan tutkittu yhteisöllisessä oppimisessa. Tämä väitöstutkimus tutkii peruskouluikäisten oppilaiden tunteita ja niiden sosiaalisesti jaettua säätelyä osana yhteisöllistä oppimista. Lisäksi tavoitteena on tarkastella monikanavaisen aineiston mahdollisuuksia oppilaiden tunnetilojen ja oppimisen säätelyn tutkimisessa.

Tutkimus koostuu kahdesta aineistosta, jotka on kerätty aidoista oppimistilanteista. Ensimmäisessä aineistossa kuudennen luokan oppilaat (N=31, 10 ryhmää) suorittivat yhden yhteisöllisen oppimisen tehtävän. Toisessa aineistossa seitsemännen luokan oppilaat (N=54, 18 ryhmää) opiskelivat pienryhmissä neljän yhteisöllistä oppimista sisältävän oppitunnin ajan. Ryhmien työskentely videoitiin. Videolta havainnoitiin oppilaiden vaihtelevia tunnetiloja sekä vuorovaikutuksessa tapahtuvaa oppimisen sosiaalisesti jaettua säätelyä. Oppilaiden tunnetilan aktivaatiotason mittaamiseen hyödynnettiin ihon sähkönjohtavuutta. Monikanavaista aineistoa analysoitiin useilla tilastollisilla ja prosessianalyysimenetelmillä.

Tulokset osoittivat, että oppimisen aikana oppilaiden tunnetilat vaihtelivat paljon sekä yksilöettä ryhmätasolla. Ryhmät hyödynsivät tunteiden säätelyä päästäkseen yli negatiivisista tunteista, mutta myös vahvistaakseen ryhmän yhteistä positiivista tunnetilaa. Aina ryhmän tunteiden säätely ei kuitenkaan toteutunut. Tulokset korostavatkin yksilön oman tunteiden säätelyn merkitystä sosiaalisesti jaetun säätelyn toteutumiselle. Menetelmällisesti tutkimus osoitti, että monikanavaista aineistoa hyödyntämällä voidaan saavuttaa syvällisempää tietoa yksilöiden ja ryhmien tunnetiloista sekä oppimisen säätelyprosesseista.

Tämä väitöstutkimus osallistuu oppimisen jaetun säätelyn teorian kehittämiseen huomioiden erityisesti tunteiden merkityksen. Tulokset korostavat tarvetta lisätä entisestään oppilaiden ja opettajien tietoisuutta tunteiden säätelystä ja sen merkityksestä onnistuneelle yhteisölliselle oppimiselle. Tuloksia voidaan hyödyntää myös kehitettäessä uutta teknologiaa tukemaan oppimisen säätelyä.

Asiasanat: kanssasäätely, monikanavainen aineisto, oppimisen jaettu säätely, prosessianalyysi, sosioemotionaalinen vuorovaikutus, tunnetila, tunteet, tunteiden säätely, yhteisöllinen oppiminen

Shared joy is a double joy; shared sorrow is half a sorrow.

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In Oulu, October 28, 2022 Tiina Törmänen

Abbreviations

ANS	autonomic nervous system
COPES	conditions, operations, products, evaluations, and standards
CoRL	co-regulation of learning
EDA	electrodermal activity
ERAS	emotion regulation in achievement situations
FRECL	formation and regulation of emotions in collaborative learning
MHMM	mixture hidden Markov models
NS-SCR	non-specific skin conductance response
OECD	Organisation for Economic Cooperation and Development
PNS	parasympathetic nervous system
ppm	peaks per minute
SCL	skin conductance level
SCR	skin conductance response
SNS	sympathetic nervous system
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 to throughout the text by their Roman numerals:

I Törmänen, T., Järvenoja, H., & Mänty, K. (2021). Exploring groups' affective states during collaborative learning: What triggers activating affect on a group level? *Educational Technology Research and Development, 69*, 2523–2545. https://doi.org/10.1007/s11423-021-10037-0

II Järvenoja, H., Törmänen, T., & Mänty, K. (2022). *Affective conditions for collaborative learning: When do groups engage in emotion regulation?* Manuscript submitted for publication.

III Törmänen, T., Järvenoja, H., & Mänty, K. (2021). All for one and one for all – How are students' affective states and group-level emotion regulation interconnected in collaborative learning? *International Journal of Educational Research, 109*(September), Article 101861. https://doi.org/10.1016/j.ijer.2021.101861

IV Törmänen, T., Järvenoja, H., Saqr, M., Malmberg, J., & Järvelä, S. (2022). Affective states and regulation of learning during socio-emotional interactions in secondary school collaborative groups. *British Journal of Educational Psychology,* 1–23. https://doi.org/10.1111/bjep.12525

Contents

1 Introduction

Classroom learning can be very emotional for students (Baker et al., 2013; Boekaerts & Pekrun, 2016). Students can feel excitement when studying an intriguing topic, pride when they succeed, anxiety when facing challenges, or boredom when the task seems too easy or uninteresting (Pekrun et al., 2002). Previous research has shown that affect experienced in learning situations can have various effects on learning motivation, engagement, and outcomes (Linnenbrink, 2007). How affect plays a role in learning depends not only on the emotional experiences themselves, but also on how students are able to deal with their emotions, in other words, to regulate them (Harley, Pekrun, et al., 2019). The importance of emotion regulation has also been considered in the Finnish curriculum of basic education (Opetushallitus, 2016), which states that students should learn how to recognize, control, and express their emotions appropriately in diverse situations. Supporting children and adolescents in developing emotion regulation skills throughout basic education is important, since socio-emotional skills are needed not only in classroom learning, but also in tackling everyday challenges, creating positive lifepaths, and succeeding in working life (Boekaerts, 2011; Organisation for Economic Cooperation and Development [OECD], 2015; Weissberg et al., 2015; World Economic Forum, 2016). According to OECD (2018), individuals' skills in controlling their emotional responses and affective states in general have an impact on the quality of life, psychological and physiological health, and wellbeing. Moreover, socio-emotional skills have a larger societal impact, since citizens' ability to adapt, be resourceful, work with others in a respectful manner, and take personal and collective responsibility are the cornerstones of a well-functioning society (Chernyshenko et al., 2018).

This dissertation views emotion regulation as a learning skill that can be practiced and learned in everyday classroom learning situations at school (Järvenoja, Järvelä, & Malmberg, 2020; Kurki et al., 2017; Tolmie et al., 2010). In learning situations, *emotion regulation* refers to the student's ability to monitor, control, and reflect which emotions they have and when, and how they experience and express these emotions (Gross, 1998; Harley, Pekrun, et al., 2019). Emotion regulation involves also the student's ability to recognize and understand emotions as well as responses related to them (Boekaerts, 2011). So far, studies of emotions in learning have mainly focused on emotional experiences in individual learning contexts. However, social learning situations are an inherent part of classroom learning, which means that the social aspects of affect are equally important (Baker

et al., 2013). In particular, collaborative learning is increasingly used to enable co-construction of knowledge and shared understandings in peer interactions (Dillenbourg, 1999). Collaborative learning situations can, however, be challenging for emotion regulation, since groups can face multiple types of challenges deriving also from motivational and emotional starting-points (Järvenoja et al., 2019; Koivuniemi et al., 2018). This can be the case especially during adolescent years when social environments can elicit intense, exaggerated emotional responses (Somerville, 2016), which, if unregulated, can even lead to socio-emotional conflicts between the group members (Näykki et al., 2014).

Affect experienced during group work, and how the students respond to them, shape the social interactions between the group members, which in turn sets the stage for the shared cognitive processes needed to facilitate high-quality collaborative learning (Isohätälä et al., 2018; Järvelä, Järvenoja, et al., 2016). Although affect and emotion regulation seem to be the key factors for the success of collaborative learning, the field of learning research lacks empirical studies uncovering the role and function of affect and its regulation as a part of collaborative learning. That is, more research-based knowledge is needed to advance our theoretical understanding of the phenomenon. This will help in providing classroom teachers with the skills needed to support their students' emotion regulation in various learning situations.

In this dissertation, emotion regulation in collaborative learning is viewed as a part of *socially shared regulation of learning* (SSRL), that is, the group members' ability to plan, monitor, and control their cognitive, motivational, and emotional learning processes in order to reach their shared goals (Hadwin et al., 2018; Winne & Hadwin, 1998). Within this framework, this dissertation aims to investigate the interplay of 6th and 7th grade students' affect and regulation of learning. It implements multichannel process data that enables us to detect how affective states and the related regulation manifest in the social interactions between the collaborative group members. By studying students' affective states and their antecedents, this study seeks to understand groups' emotional basis for collaboration. Moreover, by targeting the interrelations between affective states and emotion regulation, this study provides new knowledge on the role and function of affect and emotion regulation as a part of SSRL.

Altogether, this dissertation aims to contribute to the theoretical developments related to the interrelations between affect, emotion regulation, and SSRL. This can provide a better understanding of the importance of emotion regulation as a part of learning skills, and of how students could apply it together to overcome socio-

emotional challenges in collaborative learning. This is crucial to improving teachers' skills in supporting their students' learning and emotion regulation during everyday classroom activities. The results of this study can also benefit educational technology developers by providing information on the novel methodologies and different indicators of multichannel data that could be harnessed to design adaptive regulation support for collaborative learning.

2 Theoretical framework

This dissertation takes a constructivist perspective, where learning and understanding are considered inherently social (Palincsar, 1998). In the constructivist approach, the main focus lies in the social interaction between a learner and environment, which promotes higher levels of reasoning and learning of the individual (O'Donnell & Hmelo-Silver, 2013; Palincsar, 1998). Social interaction provides a platform for the learner to evaluate their existing understanding in relation to their current experiences, enabling cognitive development through a disequilibration that encourages the learner to develop new ideas (Palincsar, 1998). This can be facilitated for example through processes of questioning, reasoning, and argumentation (Baker, 1999). Damon (1984) suggested that this type of development, in which abandoning one's prior understanding is essential for reaching new perspectives, could be best achieved via peer interactions. Collaborative learning activities performed in small groups of learners provide a fruitful context for this to occur, and thus are increasingly applied in different educational contexts (O'Donnell & Hmelo-Silver, 2013).

Broadly defined, *collaborative learning* includes two or more people attempting to learn something together (Dillenbourg, 1999; Smith & MacGregor, 1992). However, this type of a situation does not automatically lead to *collaboration* (Barron, 2003; Summers & Volet, 2010). Collaboration requires mutual engagement of group members in working together towards a shared goal, which includes coordinated actions and negotiations to reach a shared understanding and solution (Dillenbourg, 1999). Therefore, collaboration can be distinguished from cooperation, in which group members work on a joint task but instead of truly working together, construct their final output by combining the sub-tasks they each performed individually (Baker, 2015; Dillenbourg, 1999). That is, a classical definition of collaborative learning proposed by Roschelle and Teasley (1995) conceptualizes collaborative learning as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p. 70).

In collaborative learning, to reach the shared learning goal successfully, group members need to effectively coordinate their joint cognitive processes but also be able to balance them with the socio-emotional aspects of working together (Isohätälä et al., 2018; Li et al., 2021; Mullins et al., 2013). This requires abilities to regulate their cognition, motivation, behavior, and affect (Winne & Hadwin, 2008). This dissertation focuses on students' affect and regulation of learning in a

collaborative context. To understand how affect is intertwined in collaborative learning as a part of the group's regulation process, this dissertation brings together the SSRL framework (Hadwin et al., 2018) and theoretical viewpoints on affect and emotion regulation in learning contexts (Harley, Pekrun, et al., 2019).

To build up the theoretical framework for this dissertation, affect is first conceptualized within the context of collaborative learning in Sub-chapter 2.1. Second, the theoretical underpinnings of the interrelations between affect and regulation in collaborative learning are described in Sub-chapter 2.2, where regulation is conceptualized based on the framework of self-regulated learning (SRL), co-regulation of learning (CoRL), and SSRL (Hadwin et al., 2018). Third, the methodology is built on the multi-componential nature of emotions, acknowledging the components of subjective experience, expressive behavior, and peripheral physiological responses (Gross & Barrett, 2011; Shuman & Scherer, 2014). Methodological perspectives used to study affective states during a learning process are described in Sub-chapter 2.4, with a particular focus on observational methods and measurement of sympathetic arousal.

2.1 Affect in collaborative learning

Affect is a ubiquitous feature of learning (Boekaerts & Pekrun, 2016). Especially collaborative learning can be a very emotional context for students (Baker et al., 2013; Järvenoja & Järvelä, 2013). In collaborative learning, each individual brings their own emotional experiences into the learning situation (Bakhtiar et al., 2018; Linnenbrink-Garcia et al., 2011; Mänty et al., 2020). However, individuals' emotional experiences are also constantly reshaped by the group learning processes (Duffy et al., 2015; Kleef & Fischer, 2016), which can lead to synchronous and interactive experiences of group-level affect (Barsade & Knight, 2015; Menges & Kilduff, 2015). Thus, this dissertation considers affect as both an individual- and group-level phenomenon. Conceptual foundations of affect from the individuals' point of view are presented in Sub-chapter 2.1.2. Sub-chapter 2.1.3 then describes how in the context of collaborative learning, affect can also be considered as a group-level phenomenon emerging in group members' social interactions.

2.1.1 Conceptual foundations of affect

In general, the field of emotion research conceptualizes its object in various ways with slight theoretical differences between them. *Affect* can be considered either as

an affective trait or as a state. Where *affective traits* are seen as relatively stable tendencies in a person's emotional responding, *affective states*, including emotions and moods, are regarded as situation-specific responses to the changing environment (Rosenberg, 1998). *Moods* are affective states that fall in-between affective traits and emotions (Shuman & Scherer, 2014). In general, moods can be experienced as simply pleasant or unpleasant without any specific affective features, or they can be also qualitatively distinct, such as a joyful or angry mood (Pekrun, 2016a). Moods are transient states but longer-lasting than emotions and more consciously experienced than affective traits (Gross, 2014; Rosenberg, 1998). Unlike emotions, moods may not be directly linked to a specific academic activity, but can still impact the way the student engages in the task at hand (Pekrun, 2016a).

When it comes to defining emotions, even after millennia of debate and research, different traditions and theories persist (Moors, 2009; Scarantino, 2016). However, there is a consensus that an *emotion* is a collection of psychological states that include the components of subjective experience, expressive behavior (e.g., verbal, bodily, facial), and peripheral physiological responses (e.g., arousal) (Gross & Barrett, 2011; Shuman & Scherer, 2014). Beyond this, theories differ in whether they see emotions as special mental states that can be acted upon by other processes (i.e., regulation) and whether emotions themselves are caused by distinct and specific processes (Gross & Barrett, 2011). Furthermore, there is an ongoing debate on whether emotions cause or are caused by their measurement indicators such as changes in physiology (Moors, 2009; Scarantino, 2016). This dissertation concentrates on affective states, including emotions and moods. However, attention is not paid to the distinction between emotions and moods in students' emotional responses considered, which can be challenging especially in authentic learning contexts (Shuman & Scherer, 2014). Accordingly, the terms "affect" and "affective state" are used when referring to empirical research and results of this dissertation.

This study focuses on the interplay between affective states and regulation during a collaborative learning process. Since the conceptualization of emotion regulation in general (Gross, 2014) as well as in the academic contexts (Harley, Pekrun, et al., 2019) used in this study derives mainly from the appraisal theories of emotions, this study also builds on these theories in terms of how emotions are defined. In *appraisal theories*, emotions are considered to arise when an individual attends to and evaluates a situation as relevant to their goals (Gross, 2014; Smith & Lazarus, 1990). Aligned with appraisal theories, in Gross's *modal model of emotions*, emotions include transactions between person and situation: an emotional sequence begins with a psychologically relevant situation, which draws

a person's attention. This situation is then assessed in relation to the person's relevant goals. These appraisals create emotional responses that involve changes in experiential, behavioral, and neurobiological response systems and this, again, creates conditions for the next situation the person attends (Gross, 2014). Accordingly, this study bases its methodological choices on the assumption that when emotions are experienced as a response to the learner's individual situational appraisal, it can be detected from the behavioral and physiological markers. However, it is acknowledged that these markers as such cannot be uniquely and directly linked to a certain distinct emotion nor are the subjective experience, expressive behavior, and physiological responses necessarily tightly coupled. Instead, these markers are regarded as ingredients in emotion construction process (Barrett, 2017).

The term *academic emotions* has been used in conceptualizing emotions that are linked to academic learning, classroom instruction, and achievement (Pekrun et al., 2002). In line with the appraisal theories of emotions, Pekrun (2016a) views appraisals as playing a key role in how emotions are determined in academic achievement situations. The *control-value theory of achievement emotions* posits that students experience emotions deriving from their feelings of being in or out of control, as well as from the perceived value of the learning activity or outcome. That is, different combinations of control and value appraisals are expected to give rise to different kinds of emotions. When defining the properties of different emotions, the academic emotions framework integrates the discrete emotions approach[1] and dimensional approach[2] by regarding the dimensions of valence and activation as common factors characterizing the distinct emotions (Pekrun, 2016a). The dimensions of valence and activation are also used in the *psychological construction approaches* to emotions; they are viewed as the two dimensions of core affect, that is, the underlying feeling of pleasantness or unpleasantness, and tension or relaxation, which is used as a one ingredient in the construction of emotions (Russell & Barrett, 1999). *Valence* separates positive affect from negative, whereas *activation* refers to the extent of physiological arousal the affect is causing (Ben-Eliyahu & Linnenbrink-Garcia, 2015; Boekaerts & Pekrun, 2016). According to Linnenbrink (2007), the dimensions of valence and activation can be used in the affective circumplex to categorize different types of affective states, which is demonstrated in Fig. 1. That is, in a learning situation a person can feel *positive* and

[1] The discrete emotions approach regards different emotions as distinct phenomena.
[2] The dimensional approach uses different dimensions to describe human affect.

activated (e.g., enjoyment, pride), *negative* and *activated* (e.g., anxiety, anger), *positive* and *deactivated* (e.g., relief), or *negative* and *deactivated* (e.g., boredom, hopelessness) (Pekrun et al., 2002). This study aligns with Linnenbrink's (2007) perspective and uses the affective circumplex model as an organizational framework to track and categorize individuals' and groups' affective states during collaborative learning.

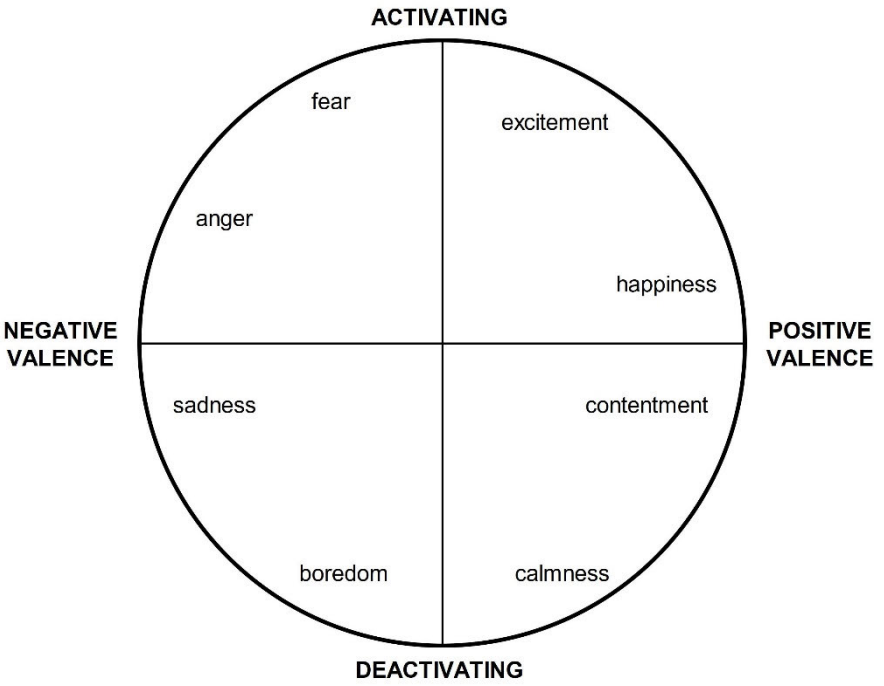

Fig. 1. The affective circumplex model (Adapted from Russell and Barrett, 1999; under CC BY 4.0 license from Article I © 2021 Authors).

The factors triggering students' affective states during collaborative learning can derive from both task- and socially-related aspects of the learning situation (Lobczowski, 2020). When emotions arise in relation to learning activities or outcomes that are evaluated against standards, *achievement emotions* are experienced (Pekrun & Stephens, 2010). Achievement emotions can be related to the activity itself, such as boredom during an uninteresting task, or to the outcome, such as a feeling of pride in relation to successful performance. In addition to the activity and outcome, emotions can derive from the epistemic aspects of cognitive

activities (*epistemic emotions*) or from the contents of the learning material (*topic emotions*) (Pekrun, 2016a). Epistemic emotions can include for example surprise, confusion, or curiosity when studying new information, whereas topic emotions can include for example feelings of empathy towards a protagonist of a story read as a learning task. Empirically, Zschocke et al. (2016) for example studied emotions arising in the group work in relation to individuals' group work appraisals and found that appraisals of the cognitive benefits of group work were a significant predictor of positive activating emotions, while experiences of negative activating and deactivating affect were mostly associated with task management and group assessment aspects.

Even though emotions can be viewed as an individual experience (Zembylas, 2007), academic learning is always situated in a social context. The social dimension is particularly evident in collaborative learning (Järvenoja et al., 2015), where also *social emotions* (i.e., emotions related to other persons) are central antecedents of emotions. In collaborative learning situations these could include for example admiration or envy related to the achievement of others, but also emotions related to personal relationships between the group members (Pekrun, 2016a). When the group members identify themselves as members of the group, individuals can experience *intergroup emotions*, that is, group-based emotions that are elicited in an individual when the group has caused or been the target of an emotionally laden event (Smith & Mackie, 2016). More broadly, *sociological definitions of emotions* posit that culturally and historically varying norms define what should be felt and expressed in various situations. Thus, emotional experiences and expressions are shaped by social structures (Lively & Weed, 2016).

Empirical research has found that, in general, when directed toward the task, positive emotions can enhance students' engagement, motivation, interest, and the use of flexible, creative, and deep learning strategies (Pekrun, 2016a), whereas negative emotions often have the opposite effects (Pekrun et al., 2002). However, affect experienced during learning and its effects on the learning process are not straightforward. For example, person-centered research has evidenced that learning contexts involve a multiplicity of individual differences in students' affect (Ganotice et al., 2016; Karamarkovich & Rutherford, 2021; Robinson et al., 2017). Karamarkovich and Rutherford (2021) have examined the affective profiles of elementary mathematics students and identified two positive emotions profiles, one negative emotions profile, and a mixed emotions profile. Furthermore, Robinson et al. (2017) have discovered four affective profiles (positive, deactivating, negative, and moderate-low) among college students. In both studies, negative-profile

students were more disengaged and displayed lower levels of achievement compared to students with positive profiles. Interestingly, both studies describe a mixed profile of students who reported experiencing both positive and negative affect during the learning process (Karamarkovich & Rutherford, 2021; Robinson et al., 2017).

Positive deactivating emotions can sometimes result in decreased task motivation and disengagement, whereas negative activating emotions can enhance motivation and effort investment in order to prevent failure (Pekrun et al., 2002). Furthermore, process-oriented research on affect in learning has demonstrated that affect is not static, and affective states can fluctuate during and across the different learning situations (Ketonen et al., 2017; Moeller et al., 2020). Using the experience sampling method, Ketonen et al. (2017) discovered that intraindividual fluctuation in both non-academic and academic emotions was stronger on a situation level within a day than between the days. Thus, when studying the role of affective states in the collaborative learning process, the temporally unfolding nature of affect should be acknowledged (Jones et al., 2021).

2.1.2 Group-level affect

In addition to individual emotional experiences deriving from the social group work context, individuals in a group can also converge in their affective states (Duffy et al., 2015; Kleef & Fischer, 2016), leading to the experience of group-level affect (Barsade & Knight, 2015; Menges & Kilduff, 2015). There is a lack of both theoretical and empirical work on group-level affect in collaborative learning settings. However, Lobczowski (2020) has introduced the *Formation and Regulation of Emotions in Collaborative Learning* (FRECL) model, which also considers interpersonal factors in emotion formation in social learning situations. Aligned with Gross's (2014) modal model of emotions, in the FRECL model emotions develop within four stages: context and situation, stimulus event, appraisal, and emotional response. Group-level affect is considered through socio-emotional interactions[3] and the socio-emotional climate[4], as well as through co-constructed emotions related to the task. The FRECL model posits these as factors of the context and situation stage that play a role on how the individuals in a group

[3] Interactions including expressions of emotions or taking other actions that contribute to socio-emotional aspects of group work (Bakhtiar et al., 2018; Kwon et al., 2014).

[4] i.e., socio-emotional atmosphere; the collective affective state, defined by the overwhelming presence of either positive or negative emotions (Bakhtiar et al., 2018; Lobczowski, 2020).

respond to the collaborative learning events. That is, these interpersonal interactions influence group members' appraisals of the stimulus event, and the individual appraisals then define whether the group members have similar or different responses to the stimulus event (Lobczowski, 2020). In this dissertation, group-level affect is not considered solely as a contextual and situational factor; rather in addition to individual-level affect, group-level affect is studied as a separate phenomenon playing a role in group-level regulation.

In the context of teams in working organizations, there is a long research tradition aiming to unpack the formation and effect of group-level affect in the group's coordinated actions (Barsade & Knight, 2015). Kelly and Barsade (2001) use a concept of *group affect*. In their conceptualization, group affect derives from the combinations of individual group members' affective factors and from group- or context-related factors that shape the affective experience of the group. Initially, affect is an individual internal condition that each group member brings with them into the group interactions. Then, individual emotional inputs are communicated to other group members through a variety of explicit (e.g., affective influence and affective impression management) and implicit emotional sharing processes (e.g., emotional contagion, vicarious affect, behavioral entrainment). This way, individual-level affect is spread and shared, forming a "bottom-up" process of group affect composition (Kelly & Barsade, 2001). In collaborative learning, socio-emotional interactions within the group can be seen as a main operation through which emotional sharing processes can occur (see Sub-chapter 2.2.2). Socio-emotional interactions including emotional expressions are operations that shape the group's affective state (Bakhtiar et al., 2018; Kwon et al., 2014). Affective states are considered as short-term and as emerging within the socio-emotional atmosphere (i.e., climate). That is, in an overall positive socio-emotional atmosphere, there can be instances of negative affective states, which in turn can influence the behaviors and interactions that determine group members' perceptions of the atmosphere in a longer run (Bakhtiar et al., 2018).

According to the situative perspective, learning takes place in a social environment involving interaction with the learning context and other learners (Greeno, 2006; Järvenoja et al., 2015). Unique learning situations are formed through individual learners' characteristics, task features, and the classroom structure (Greeno & Engeström, 2014). Hence, in addition to the "bottom-up" formation process of group affect, there are "top-down" factors in the context that may influence the ways the group experiences or expresses affect. These can include, for example, emotional norms within an organization or a group itself and

the group's emotional history. Ultimately, the combination of the context and the group's affective composition leads to the formation of the group affect in the particular moment (Kelly & Barsade, 2001).

Empirical studies done within the organizational context indicate that group affect can influence various group processes such as cooperation, conflict, coordination, joint decision-making, and performance (Barsade & Knight, 2015). In general, positive group affect seems to promote these processes whereas negative group affect can inhibit them (Barsade & Knight, 2015). However, research findings have been more divergent in terms of negative affect, indicating that those might be more sensitive to situational factors and thus also sometimes lead to positive outcomes (Knight & Eisenkraft, 2014). Only few studies in the field of collaborative learning, however, have attempted to detect group-level affect during collaboration or relate it to the group's learning processes and outcomes (Pietarinen et al., 2020). Instead, group-level affect has been mainly studied through the operation of socio-emotional interaction, where affect is constructed in group members' interactions (Jones et al., 2021). Previous research findings support the theoretical notion that positive socio-emotional interactions are linked to the positive affect of group members (Linnenbrink-Garcia et al., 2011) and a favorable socio-emotional atmosphere (Kwon et al., 2014). Furthermore, positive socio-emotional interactions seem to indicate group members' social engagement (Sinha et al., 2015) and set the stage for processes that are beneficial for collaborative learning such as high-level cognitive processes (Isohätälä et al., 2018; Järvelä, Järvenoja, et al., 2016). Some evidence suggests that socio-emotional interaction may facilitate or inhibit group-level regulation (Bakhtiar et al., 2018; Linnenbrink-Garcia et al., 2011; Rogat & Adams-Wiggins, 2015). Furthermore, Mänty et al. (2020) explored 6th-grade students' emotional experiences after collaborative learning and found that negative group interactions during collaboration negatively influenced students' emotional experiences after the task.

Existing research has typically concentrated on either positive or negative convergence in group-level affect or socio-emotional interactions (Barsade & Knight, 2015; Jones et al., 2021). However, as pointed out by Lobczowski (2020), collaborative learning events can cause diverse emotional responses between the group members. That is, some of the group members may remain positive while others encounter emotional challenges, resulting in a divergent affective state within the group (Barsade & Knight, 2015). These kinds of mixed emotional situations may hamper the group's coordinated efforts (Barsade & Gibson, 2012) and call for regulation despite the favorable affective conditions of some of the

group members. Even though studies have started to acknowledge the existence of mixed affect within individuals in learning situations (Ganotice et al., 2016; Karamarkovich & Rutherford, 2021), there is a lack of empirical research taking into account the different compositions of group-level affect. However, in the context of collaborative high school students, Pietarinen et al. (2020) studied groups' affective states using self-reports and video observations, and found that the valence of group-level affect, as such, was not related to group learning outcomes. Instead, extremely high- and low-performing groups exhibited greater within-group emotional consistency while affect was more ambiguous in average-performing groups. These results offer preliminary evidence of the existence of group-level affect in collaborative learning and how it may play a role in joint functioning and performance.

2.2 Emotion regulation in collaborative learning

Even though collaborative learning can promote multiple active learning processes that also benefit individuals' learning, it is not inherently successful in doing so (Barron, 2003; Summers & Volet, 2010). Prior research has revealed various types of factors that might challenge collaboration deriving from cognitive, motivational, emotional, and social starting-points (Barron, 2003; Järvenoja et al., 2019; Koivuniemi et al., 2018). When the group's collaboration is challenged, they can engage in regulation of learning to make adaptive changes to cognition, motivation, affect, and behavior to secure their grounds for collaboration and continue progressing towards the shared goal (Hadwin et al., 2018; Järvenoja et al., 2019). In regulation of learning, a learner or a group of learners take on the responsibility of coordinating their learning process as active agents (Greene & Azevedo, 2007; Panadero, 2017). In collaborative learning, students regulate their learning individually through SRL, but also together as a group. When a group of learners together regulate their shared cognition, motivation, affect, and behavior to reach their shared learning goal, SSRL occurs. Group members can also support each other's learning, and for example help each other to regulate learning-related emotions through CoRL (Hadwin et al., 2018). This dissertation uses the term "group-level regulation" when referring to both SSRL and CoRL. The different modes of regulation are further described in Sub-chapter 2.2.1.

The role of affect in individual learning is widely acknowledged, including the SRL theories (Boekaerts & Pekrun, 2016). Previous studies have mostly considered how distinct emotions experienced in learning influence students' motivation, SRL,

performance and academic achievement with static self-report measures (Pekrun, 2016a). However, affect in learning is not static but can shape and be shaped by the learning process on a micro-level. Thus, this interplay should also be theoretically and empirically considered. In this dissertation, regulation of learning is viewed through Winne and Hadwin's (1998, 2008) model, which accounts for the micro-level interplay between conditions, operations, products, evaluations, and standards (COPES) within regulation of learning. Lately, along with increasing interest in SSRL, the COPES model has been extended to theorize the role and function of affect as well as socio-emotional interactions in groups' regulation of learning (see Sub-chapter 2.2.2). In the COPES model, affective states are viewed as conditions and products in the regulation of learning. Furthermore, emotion regulation can be viewed as a separate function within the regulation of learning, focusing especially on monitoring and controlling learning-related affect (Harley, Pekrun, et al., 2019). Individual and group-level emotion regulation in a learning context are described in Sub-chapter 2.2.3.

2.2.1 Modes of regulation

When a group is collaborating on a task or project, it can be viewed as a social system constituted by multiple self-regulating individuals (Volet et al., 2009). They simultaneously guide and support regulation but also regulate jointly as a social entity (Hadwin et al., 2018; Volet et al., 2009). That is, collaborative learning involves an interplay between three modes of regulation (Hadwin & Oshige, 2011; Järvenoja et al., 2015). In SRL, individual learners take metacognitive control of their own cognitive, motivational, emotional, and behavioral states during the learning process (Winne & Hadwin, 1998). Although SRL is targeted to the individual, it is vital for the success of collaboration as well as for other modes of regulation. That is, taking responsibility for one's own learning is a prerequisite for being able to work with others and contribute in a timely and productive way to the group's shared processes (Miller & Hadwin, 2015). For example, Zheng et al. (2019) studied patterns in SRL and SSRL emerging in high school and college students' collaborative learning. Their results showed that the successful groups were consistent in the different regulatory processes they applied and engaged in both SRL and SSRL; they used SRL especially for monitoring and elaborating, and SSRL for analyzing the task together (Zheng et al., 2019).

When regulation is not targeted to the individual's learning but the joint processes of the group, regulation moves to the group level (Järvenoja et al., 2015).

The core feature of group-level regulation is that the regulatory actions are all executed through interaction (Isohätälä et al., 2017). In SSRL, both individual and collective beliefs and experiences form the shared conditions for the group's task engagement (Järvenoja et al., 2015). SSRL takes place when a group of learners jointly monitor and control their cognition, motivation, affect, and behavior through iterative negotiations (Hadwin et al., 2018). For regulation to be truly socially shared, it needs to be transactive, that is, to include multiple individuals' contribution to the joint cognitive, motivational, and affective states (Hadwin et al., 2018). Moreover, processes of monitoring, evaluating, and controlling are shared to enable adaptation, and are guided by joint goals and standards among group members (Haataja et al., 2021; Hadwin et al., 2018; Sobocinski et al., 2020).

Previous studies have indicated that group members' active and joint participation in task activities is an important foundation for successful collaboration and the emergence of SSRL (Isohätälä et al., 2017; Nguyen et al., 2021; Volet et al., 2009) and the potential of using SSRL increases with the time spent working together (DiDonato, 2013; Ucan, 2017). While SSRL is built up in interaction among group members, group members can enact different roles in the regulatory activities. An important aspect of regulation is to understand and recognize one's own and others' cognitive, motivational, and affective conditions for learning and furthermore, when a challenge is recognized, to be able to *initiate* appropriate individual and group-level regulation (Boekaerts, 2011; Järvenoja et al., 2015). After regulation is initiated by a group member, others can shape the course of regulation by *contributing*, adding new elements into the regulatory discussion (Hadwin et al., 2018). Furthermore, especially when the need for regulation rises from an individual group member's challenges, CoRL activities can be particularly *targeted* at the student to prompt SRL (Bakhtiar & Hadwin, 2020).

Among the different modes of regulation, CoRL has a mediating role between SRL and SSRL: When necessary, CoRL can be applied by an individual in a group to support the other group members' SRL through interpersonal interactions or to shift the group towards more productive SSRL (Hadwin et al., 2018). DiDonato (2013) empirically demonstrated this interplay and studied SRL and CoRL in middle school students' collaboration over nine weeks. The results showed that while students' SRL increased in the course of the collaborative learning period, this relationship was moderated by CoRL (DiDonato, 2013). That is, CoRL has a meaningful role in supporting the individuals' learning process (Saariaho et al., 2016). In addition, CoRL actions can be embedded or prompted through the features of the learning environment, designs, or technological tools (Järvelä,

Kirschner, et al., 2016; Kwon, 2020; Lai, 2021; Lavoué et al., 2020). Järvenoja, Järvelä, and Malmberg (2020), for example, showed that increasing group members' awareness of their motivational and affective state with the S-REG tool[5] before they started to collaborate increased the amount of CoRL the group members were able to actualize themselves during the first time sequence of collaboration. That is, CoRL can aid the group members in increasing their awareness of each other's goals, beliefs, and experiences and the joint task progress (Hadwin et al., 2018).

2.2.2 Affect as a condition and product

There are multiple theoretical models of the regulation of learning with both similarities and differences (Puustinen & Pulkkinen, 2001). In general, different models share the idea that regulation of learning is a complex, cyclical metacognitive and social process, and that it includes different phases (Panadero, 2017). In Winne & Hadwin's COPES (1998) model, regulation is viewed through four recursive phases: task definition, goal setting and planning, enactment, and adaptation. When engaging in group work, in the *task definition* phase the group members form a shared perception of the task itself and of the possible resources and constraints, including emotional starting-points they approach the task with (Winne & Hadwin, 1998). Research has shown that task definition serves as an important basis for groups' regulation of learning as it is used in the *goal setting and planning* phase to negotiate a joint goal for the task as well as the learning strategies that the group plans to implement (Greene et al., 2012; Hadwin et al., 2018). Goals can manifest as forms of cognitive engagement, but include also overt behavior and changes in motivational and affective state (Winne & Hadwin, 2008). For example, if a student's perception of the task includes feelings of anxiety related to their ability to perform the task, a goal might be set to lower the anxiety and the chosen strategies and behaviors might be aligned to ensure well-being, but not be optimal for learning and performance (Boekaerts & Pekrun, 2016; Winne & Hadwin, 2008). That is, to successfully engage in the task, the student or group needs to choose strategies that reflect goals simultaneously in the cognitive, behavioral, motivational, and emotional aspects. The plans are put into action in the *enactment* phase where the group activates the study tactics and other types of

[5] S-REG is a tool for supporting group members' awareness of their cognitive, motivational, and emotional states related to collaborative learning, and if needed, prompts the group to activate appropriate regulation (Järvenoja et al., 2020).

activities to reach their goal (Winne & Hadwin, 1998). Finally, in the phase of *adaptation*, the group members make changes to their individual and shared cognitive, motivational, and emotional structures, which will play a role in how they approach future learning tasks (Winne & Hadwin, 1998).

The four stages describe the process of regulation as a macro-level process, but the COPES architecture also includes a more micro-level view of processes underlying the different phases (Greene & Azevedo, 2007). That is, each stage includes a similar architecture of COPES. *Conditions* are internal (i.e., prior knowledge, skills, motivation, and affect) and external (i.e., task demands, resources, and constraints) factors that impact the student's engagement in the task at hand (Winne & Hadwin, 1998). According to the COPES model (Winne & Hadwin, 2008), affect is viewed as a student's internal condition that, among other conditions, operations, and standards, is a target for regulation. In group learning, the role of affective states as conditions and products becomes multi-layered; each student brings their own internal conditions into the learning situation, which then together influence the behaviors and interactions among the group members (Lobczowski, 2020).

However, affect is not viewed only as a static condition that the student brings to a learning situation. Instead, affect is dynamic and unfolds over time as a part of the regulation process: Affective states are constantly modified through the different operations students implement during the learning process. *Operations* are the activities, tactics, and strategies that the student or group uses to address the task. These can include, for example, cognitive manipulations of information through searching, monitoring, assembling, rehearsing, and translating (Winne, 2018), but also strategies that aim to shape the motivational and affective state (Bakhtiar et al., 2018). Socio-emotional interactions, in particular, can serve as operations that shape individuals' affective states but also the groups' shared affective conditions (Bakhtiar et al., 2018; Törmänen et al., 2022). In socio-emotional interactions, group members can make their internal affective conditions visible by expressing emotions or taking other actions that contribute to socio-emotional aspects of group work (e.g., group formation and dynamics, social relationships, a sense of community; Kreijns et al., 2003; Kwon et al., 2014). These interactions between the group members, in turn, shape the group members' perceptions of their shared affect serving as a mechanism for individuals' affective states to converge (Barsade & Knight, 2015).

When operations are applied, they create *products* of the phase, which in turn serve as conditions for the following phase (Winne & Hadwin, 1998). These

products can be internal or external cognitive representations of the task such as a mind map, but also affective and motivational products, for example, a particular affective state (Winne & Hadwin, 2008). That is, when affective states are shaped by operations, they turn into affective products that in turn become the conditions for the ongoing learning activities (Bakhtiar et al., 2018). In each stage, the products are *evaluated* against *standards* (Winne & Hadwin, 1998). The standards can be set externally, for example by the task evaluation criteria, but it is important to acknowledge that students have standards also in terms of motivational and emotional aspects deriving from their prior experiences and social context (Lively & Weed, 2016; Winne & Hadwin, 2008). Experienced affect can also be used to evaluate the task itself; students can evaluate the activity to be for example enjoyable or boring (Winne & Hadwin, 2008). In the process of evaluating products against standards, recognizing the need for a change plays a central role (Winne, 2018). When students metacognitively *monitor* the product against standards, they generate cognitive evaluations of whether the product is on a target and whether the operations they are performing are appropriate. *If* these evaluations show that actions are needed to keep the learning process on the target, *then* metacognitive *control* is activated to make appropriate changes in both individual and shared conditions, standards, or enacted operations (Winne, 2018). In particular, when affective products are evaluated against standards and a need for change is perceived, the group members can strategically control their shared affect together by engaging in emotion regulation (Järvenoja et al., 2019).

Empirically, regulation in collaborative learning has mostly been studied by focusing on the occurrences and patterns in different regulatory phases (Järvelä, Järvenoja, et al., 2016; Malmberg et al., 2017; Zhang et al., 2021) or for example by studying emotion regulation as a separate phenomenon (Järvenoja et al., 2019; Lobczowski et al., 2021). However, the research seeking to unravel the more micro-level interplay between the different components described in the COPES model as well as their interrelations with monitoring and control remains scarce. According to Bakhtiar et al. (2018), when considering affective conditions and products as a part of regulation of learning, the investigation should not be limited only to the strategic emotion regulation; cognitive and behavioral processes can also create affective products. That is, regulation targeted to cognition, motivation, and behavior also has a potential to alter affect. In particular, when regulation is targeted to cognitive operations or standards, it can produce changes in affective states as well. For example, when a group faces a cognitive challenge and decides to alter their standards for the end product to overcome the challenge, it can also

change their negative emotions towards the task progress into more positive ones. This is because the product is now evaluated to be better aligned with the standards (Järvenoja et al., 2019; Winne & Hadwin, 2008).

2.2.3 From individual to shared emotion regulation

While various operations during learning can alter students' affect indirectly, students can also strategically alter their affect when needed to guarantee motivated learning (Järvenoja & Järvelä, 2013; Wolters, 2003). That is, positive or negative affect in learning situations does not inherently lead to either positive or negative outcomes; rather emotional effects on learning and achievement depend on how students are able to deal with their affect, in other words, to engage in emotion regulation (Harley, Pekrun, et al., 2019). In this dissertation, "emotion regulation" is used as a broad term to refer to regulation targeted to affect. Emotion regulation is viewed as a separate process within the regulation of learning particularly targeted to monitoring and controlling affect in a learning situation. According to Gross (1998, p. 275), emotion regulation occurs when "individuals influence which emotions they have, when they have them, and how they experience and express these emotions." The *process model of emotion regulation* from Gross (1998, 2014) builds on the modal model of emotions and aligns emotion regulation with the sequence of processes involved in emotion generation. However, Gross's process model of emotion regulation presents a general framework of individuals' emotion regulation, and it does not specifically focus on learning situations. To address this gap, Harley, Pekrun, et al. (2019) conceptualized *emotion regulation in achievement situations* (ERAS) by integrating the process model of emotion regulation with Pekrun's control-value theory of achievement emotions.

Aligned with the process model of emotion regulation, the ERAS model organizes emotion regulation strategies into five families, each targeted to a certain point in the emotion generation process: situation selection, situation modification, attentional deployment, cognitive change, and response modulation (Gross, 1998; Harley, Pekrun, et al., 2019). Situation selection can be used to take actions that either increase or decrease the possibility of ending up in the situation that is expected to elicit positive or negative affect. Situation modification includes modifying the aspects of the situation, whereas attentional deployment can be used to direct attention within the situation to change its emotional impact. Affect can also be regulated by reappraising the situation and making a cognitive change. When an emotion has already been generated, response modulation can be used to

regulate how one expresses the emotion by influencing experiential, behavioral, or physiological components of the emotional response (Gross, 2014; Harley, Pekrun, et al., 2019). Based on their findings, Matthews et al. (2021) suggested that the choice of the regulation strategy in a particular situation depends on the emotional intensity, the target of regulation, and whether people choose to regulate their own emotions or co-regulate another person's emotions. Even though the ERAS model focuses on individual learning situations, it acknowledges that to be effective in social collaborative learning situations, emotion regulation of both one's own and other group members' emotions are needed (Harley, Pekrun, et al., 2019). That is, especially when the group members have divergent goals or unresolved conflicts hinder the group work, self-regulation might not be enough and group-level emotion regulation is needed (Harley, Pekrun, et al., 2019; Näykki et al., 2014).

In a collaborative learning context, prior research has explored both manifestations of group-level emotion regulation as well as different strategies that the group members use to influence their shared socio-emotional grounds (Järvenoja et al., 2019; Järvenoja, Järvelä, & Malmberg, 2020; Järvenoja & Järvelä, 2009; Lobczowski et al., 2021; Mänty et al., 2022). In general, prior research seems to indicate that in collaborative learning, group-level emotion regulation occurs especially in groups that share an overall positive socio-emotional atmosphere (Bakhtiar et al., 2018; Rogat & Linnenbrink-Garcia, 2011; Lajoie et al., 2015; Lobczowski, 2020). However, compared to regulation targeted to solely cognitive aspects of learning, emotion regulation seems to be rare (Järvenoja, Järvelä, & Malmberg, 2020). Koivuniemi et al. (2018) studied learning challenges of teacher education students and showed that motivational and emotional challenges were not recognized and solved as often as other types of challenges. This lack of awareness might explain the rare occurrence of emotion regulation, even though it would be needed.

In the similar context of teacher education, Järvenoja et al. (2019) studied challenges in collaborative learning situations and identified the group-level emotion regulation strategies that the groups applied to overcome the challenges. As emotion regulation can be considered to be one strategy to regulate motivation (Wolters, 2003), Järvenoja et al. (2019) used strategies deriving from both the emotion and the motivation regulation literature to disclose the different types of strategies. As a result, they identified four different categories deriving from the video observations of groups' collaboration: encouragement, increasing awareness, social reinforcement, and task structuring. Lobczowski et al. (2021) studied the emotion regulation strategies of graduate pharmacy students when they worked in

groups in a project-based learning environment. They grouped the identified strategies into five themes: behavioral, interpersonal, cognitive, motivational, and a combination of motivational and cognitive strategies. As in the study of Järvenoja et al. (2019), these strategies showed that in collaborative learning, emotions can be regulated through various strategies targeted to emotions directly but also with strategies that aim to change the features of the learning task (e.g., by structuring the task activities) or behaviors of other group members to alter the emotional impact of the situation. Furthermore, in the context of 6th grade students' collaborative learning, Mänty et al. (2022) concluded that when it occurs on a group-level, emotion regulation is constructed in a series of strategic regulatory actions, which mostly begin with sharing an awareness of the emotional trigger. That is to say, in a collaborative learning context, emotion regulation strategies are even more multifaceted in nature than in the individual learning situations and are temporally constructed when group members build on each other's regulatory contributions in interaction (Järvenoja & Järvelä, 2013).

2.3 Measuring affective states and regulation during a learning process

The choice of methods applied in a study should always be guided by the underlying theoretical assumptions of the phenomena of interest (Järvelä & Bannert, 2021; Molenaar & Järvelä, 2014; Porayska-Pomsta et al., 2013; Zembylas, 2007). The phenomena of interest of this study require the application of methods that can capture these phenomena through multiple components and their temporal variation during the learning process, situated in the context in which they occur (Järvenoja et al., 2015; Järvenoja, Järvelä, et al., 2018). In general, the measures used to capture both affect and regulation in learning situations can be divided based on their timeframe (Azevedo et al., 2010). *Offline measures*, such as self-reports, are used with prospective and retrospective timeframes to either capture an activity that occurs before or after the learning task, or to retrospectively describe the processes that occurred during the task (Azevedo et al., 2010; Pekrun, 2016b); while *online measures*, such as facial expressions, physiological measures, observational methods, eye-tracking, and log-data, offer a way to capture the activities and processes continuously during the actual learning task (Azevedo et al., 2010; Harley, 2015). Accordingly, it is evident that when the interest is in studying affect and related regulation in the learning process, online measures can be considered more suitable. However, to capture the multiple components of affect,

one source of data is not sufficient, and a combination of different online measures is needed (Järvenoja, Järvelä, et al., 2018). Observational and physiological online measures are described below, with a particular focus on video observations (Sub-chapter 2.3.1) and sympathetic arousal (Sub-chapter 2.3.2) for detecting emotional valence, activation, and regulation during a learning process.

2.3.1 Observational methods for detecting emotional valence and regulation

Observational methods offer some unique affordances when measuring affect and regulation during a learning process. According to Jones et al. (2021), observational data offers a possibility to capture affect not only as an individual-level phenomenon, but also as it is shared on a group level and how individual- and group-level emotional processes intertwine. Furthermore, it gives access to both verbal and nonverbal indicators of externalized affect and enables researchers to capture the temporally unfolding nature of affect (Jones et al., 2021). In learning situations, students' emotional expressions can serve as indicators of the expressive component of emotions, especially when learning occurs in a small-group context where these expressions naturally occur as a part of students' collaborative interactions (Jones et al., 2021; Linnenbrink-Garcia et al., 2011; Porayska-Pomsta et al., 2013).

Prior studies have used students' verbal expressions, their delivery (e.g., tone and volume), and nonverbal indicators (e.g., facial and bodily gestures) to investigate shared group-level affect and mood as well as the socio-emotional atmosphere in group interactions (Barsade et al., 2018; Jones et al., 2021). For example, Linnenbrink-Garcia et al. (2011) developed a video coding scheme to study affect and engagement in small groups with a circumplex approach. That is, they used students' facial expressions, body language, tone of voice, and emotional statements and comments to categorize instances in the data based on emotional valence (positive, negative) and activation (activated, neutral, deactivated). Moreover, prior studies have applied observational methods to study groups' socio-emotional processes, such as negative and positive interactions, socio-emotional challenges and conflict (Jones et al., 2021), and how these processes intertwine with CoRL and SSRL (e.g., Järvelä, Järvenoja, et al., 2016). For example, Isohätälä et al. (2020) investigated teacher education students' collaborative learning and identified situations where group members' joint participation, positive interaction, and regulation of learning converged. The results revealed that when these

processes overlapped, they served important functions for collaborative learning: establishing agreement, responding to challenges or mistakes, and discussing strengths and weaknesses (Isohätälä et al., 2020). Some observational studies have focused particularly on emotion regulation, developing video coding schemes to capture emotion regulation occurring in collaborative groups as well as revealing different strategies for group-level emotion regulation (see Sub-chapter 2.2.2; e.g., Järvenoja et al., 2019; Lobczowski et al., 2021).

However, although observational methods offer many advantages, they are not able to capture the "hidden" emotional processes, such as physiological emotional activation related to the emotional experience (Mendes, 2016). Even though these hidden states are not brought explicitly to the social plane, they influence individual students' learning processes, and thus provide additional information about the individuals in a group (Haataja et al., 2021; Pijeira-Díaz et al., 2018; Slovák et al., 2014). Furthermore, physiological emotional activation can enable researchers to distinguish how positive and negative affective states influence learning and performance (Harley, Jarrell, & Lajoie, 2019; Robinson et al., 2017). Thus, complementary data channels are needed to reveal both the valence and the activation dimension of affective states.

2.3.2 Sympathetic arousal as an indicator of emotional activation

Multiple biological systems, including the autonomic nervous system (ANS), have been implicated in emotional experiences (Mendes, 2016). The ANS includes the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The primary function of the SNS is to provide oxygenated blood to the brain and body to support movement, and thus it is responsible for the "fight or flight" response in the face of challenge and threat. In turn, PNS co-regulates SNS responses and supports homeostasis (i.e., "rest and digest") (Mendes, 2016; Palumbo et al., 2017). Even though the primary functions of SNS and PNS do not pertain to emotions as such, these systems can change when the person is experiencing emotions, and accordingly indicate implicit emotional responses, which gives us a reason the study these systems in relation to experienced emotions (Kreibig, 2010; Mendes, 2016).

An emerging body of learning research (see e.g., Donker et al., 2020; Harley, Jarrell, & Lajoie, 2019; Martens et al., 2020; Mason et al., 2018) has started to collect data on SNS and PNS activity to trace the emotional activation dimension as well as emotion regulation during a learning situation. For example, Mason et al.

(2018) used heart rate to measure emotional arousal and heart rate variability to measure emotion regulation during secondary school students' webpage reading. Their findings indicated that heart rate (i.e., emotional arousal) was a negative predictor and heart rate variability (i.e., emotion regulation) a positive predictor of students' multiple-text comprehension. Furthermore, Roos et al. (2020) conducted a systematic review on the relations between students' test anxiety and physiological arousal, which revealed that in the majority of studies, there was a positive relationship between self-reported anxiety and physiological arousal (Roos et al., 2020). However, as this line of research it still in its early states, the findings are also somewhat mixed: for example, some studies have linked increased arousal to good performance and students' engagement in learning activities (Harley, Jarrell, & Lajoie, 2019; Pijeira-Díaz et al., 2018; Villanueva et al., 2018). This is understandable considering that the physiological markers are not directly or solely linked to emotional experiences. Thus, more research into these physiological markers in a learning context is needed. The present study adds to this line of research and utilizes physiological measures to detect the level of students' emotional activation through SNS activation (i.e., sympathetic arousal), which previous research has linked strongly to emotional experiences (Kreibig, 2010).

Sympathetic arousal can be detected by measuring skin conductance with electrodermal activity (EDA), which has a strong tradition in psychological research (Dawson et al., 2007). EDA is related to the activity of sweat glands and thus can be considered to indicate only sympathetic arousal (Dawson et al., 2007). EDA signal can be divided into two components, which are phasic short-term skin conductance response (SCR) and tonic skin conductance level (SCL) (Boucsein, 2012). Previous research has claimed that SCR peaks are strongly associated with emotional responses caused by an external stimulus and more reactive to variations in experimental conditions than the slowly changing SCL (Christopoulos et al., 2019; Dawson et al., 2007). EDA values can also increase without a specific external stimulus, and those fluctuations are called non-specific skin conductance responses (NS-SCRs; Dawson et al., 2007). In general, there is a range of previous research linking increases and decreases in EDA to experienced emotions (for a review, see Kreibig, 2010) as well as emotion regulation (Matejka et al., 2013; Pizzie & Kraemer, 2021). Recently, research utilizing EDA in a learning context has started to emerge (for a review, see Horvers et al., 2021). Harley, Jarrell, and Lajoie (2019) studied medical students' emotions, emotion regulation strategies, and EDA during a diagnostic reasoning task. Their results revealed that higher habitual levels of suppression as an emotion regulation strategy positively predicted

SCL component of EDA, and SCL positively predicted anxiety and shame. However, the SCRs positively predicted students' diagnostic efficiency. Pijeira-Díaz et al. (2018) also found evidence linking SCRs positively to students' performance: they examined the relationship between high school students' arousal (SCRs) and achievement during a collaborative physics course and found a strong positive correlation between arousal during the exam and the grades achieved.

As physiological arousal is an individual measure, researchers have developed different ways to accommodate it to the needs of research targeting inter-individual processes. In particular, *physiological synchrony*, which is defined as any interdependent or associated activity in the physiological processes of two or more individuals (Palumbo et al., 2017), has been used when studying dyads and groups. For example, research attempting to explore social interactions via physiological synchrony has indicated that physiological synchrony episodes in social interaction are often emotionally relevant (Mønster et al., 2016). Already Kaplan et al. (1963) found that the synchrony in two individuals' sympathetic arousal was more likely to occur in dyads that have a strong positive or negative emotional relationship. Malmberg et al. (2019) used facial expressions together with EDA to study students' interactions in collaborative learning. Their results revealed that when group members were simultaneously in high arousal, they were mostly indicating negative facial expressions. However, neutral and positive facial expressions were also found during simultaneous high arousal episodes (Malmberg et al., 2019). Findings have also related physiological synchrony to emotional engagement (Slovák et al., 2014), construction and maintenance of a common social and emotional space (Cornejo et al., 2017), but also to feelings of non-belonging to the group (Mønster et al., 2016). That is, synchrony in sympathetic arousal may reflect emotional reactivity in situations where two people react to each other emotionally (Slovák et al., 2014).

To conclude, the prior research indicates that the relations between sympathetic arousal, experienced emotions and learning processes are not straightforward. It should be noted that when changes in the SNS occur, this does not directly indicate an emotional experience, and vice versa. Emotions can also occur without an SNS response (Mendes, 2016). All this highlights the need for complementing the physiological data with more contextualized data sources revealing the valence of the arousal episodes, and the contextual and situational factors of the learning activity (Harley, 2015; Mendes, 2016). In this study, sympathetic arousal measurement is complemented with video observations. This enables the contextualization of physiological reactions and changes in them and the

positioning of the reactions in relation to students' expressive behavior as well as their regulation of learning during collaboration.

3 Aims

The aim of this dissertation is to investigate the interplay of affect and regulation of learning in a collaborative learning context. To achieve this, the study targets students' and groups' affective states during a collaborative learning process as well as the relations between affective states and group-level regulation. Furthermore, this study pursues a methodological aim to explore the potential of multichannel process data, including video observations and physiological measures, in detecting students' affective states and regulation during collaboration.

The empirical objectives of the study are as follows:

1. To examine how individual- and group-level affective states manifest during socio-emotional interactions of collaborative learning (see Articles I and III).
2. To identify what kind of factors trigger affective states within groups during collaborative learning (see Article I).
3. To investigate how affective states are interrelated with CoRL and SSRL (see Articles II–IV).

Methodologically, the objective is:

4. To explore how the dimensions of affective states, namely valence and activation, can be detected using multichannel process data (see Articles I–IV).

4 Methods

The four articles of this dissertation are based on two data collections (see Data I and II). Both data collections were conducted as a part of a project funded by the Academy of Finland, EmReg, which studied emotion regulation in primary school students' collaborative learning. The second data collection was performed in collaboration with the CLEVER project (Eudaimonia, University of Oulu, Finland), which aimed to support regulation of complex learning processes by identifying the triggers of regulation moments in secondary school students' collaboration and making them visible by implementing multichannel process data. This dissertation contributed to these projects by investigating students' affective states and regulation with multichannel data and a process-oriented approach.

A process-oriented approach highlights the situation- and context-specific nature of the learning processes. Instead of focusing only on the learning outcomes, it acknowledges the ongoing processes, the whys and hows, that lead to the particular outcome in the learning process (Järvenoja, Järvelä, et al., 2018). By adopting the process-oriented approach, this study views both affect and regulation as processes evolving through changes and sequences instead of seeing them as static, trait-like variables (Azevedo, 2014; Bannert et al., 2014; Molenaar & Järvelä, 2014). Furthermore, to capture the different components of affective states (Shuman & Scherer, 2014), this dissertation relies on collecting multimodal multichannel data: Data that goes beyond verbal interaction and derives from multiple channels, some of which extend beyond spoken or written language (Azevedo & Gašević, 2019; Noroozi et al., 2020). Affective states are operationalized through expressive (video) and physiological (EDA) components (Shuman & Scherer, 2014), assessing the dimensions of valence and activation (Pekrun, 2006). The application of a process-oriented approach together with multichannel data is grounded on three theoretical principles guiding the choice of the applied methodology (Greene et al., 1989). These principles derive from the need to take into account the multiple components of collaborative learning: individual and group learning processes, the sequence or temporality of interactions, and the learning context (Puntambekar, 2015).

First, this dissertation is grounded on the view that regulation in collaborative learning is based on the complex interplay between individual- and group-level processes (Volet et al., 2009). Hence this study explores affective states and regulation first on a group level (see Articles I, II, and IV), but then extends this

investigation to consider also individual students' affective states as both conditions and products of their group-level regulation behavior (see Article III).

Secondly, even though there are years of research uncovering the relations between affect and learning, this research has mainly focused on the static relations between distinct emotions, learning outcomes, and achievement (Pekrun, 2014). However, in this dissertation, affect is not regarded as static. Rather, in collaborative learning, it originates from and is constructed and expressed in groups' temporally unfolding socio-emotional interactions (Järvenoja & Järvelä, 2013). Moreover, group-level regulation emerges in group members' interactions, and is therefore constructed as sequences of interaction (Mänty et al., 2022). That is to say, to understand better how affect interacts with regulation in collaborative learning, we need methods that can capture their sequential and temporal relations during the learning process (Butler & Cartier, 2005; Lämsä et al., 2021; Taub et al., 2019).

Third, in this dissertation, regulation of learning is seen as situated in multiple layers of context. Thus, understanding regulation requires collecting information about the contexts in which it occurs and interpreting the results in relation to it (Butler & Cartier, 2005). Accordingly, this study adopts a situative perspective on the regulation of learning and observes and analyzes affect and regulation in relation to the learning context in which they occur (Järvenoja et al., 2015), in this case in real classroom learning situations. This approach is assumed to increase the ecological validity of the data (Porayska-Pomsta et al., 2013).

4.1 Participants and context

The participants of the studies in this dissertation are 6th and 7th grade students in the Finnish educational context. The particular focus of this dissertation is on collaborative learning, which is a widely used learning method in Finnish classroom learning (Opetushallitus, 2016). Accordingly, two data sets (see Data I and Data II) were collected.

In Data I (for metadata, see Järvenoja et al., 2021), the participants were 6th grade students (N=31, 17 females, 14 male, aged ~12 years) from three classrooms of one primary school in Finland. The participants performed one collaborative science task in ten groups of 3–4 students. The data collection was conducted as a part of the students' environmental studies and one environmental studies class was held in a classroom-like learning and research space (LeaForum, University of Oulu). Environmental studies are already included in the Finnish curriculum of

basic education from the first grade and the curriculum involves collaborative ways of working (Opetushallitus, 2016). The collaborative task given to the groups in this study was to design and construct a miniature model of an energy-efficient house powered by solar energy. The detailed description of the participants and task is provided in Article I.

The participants of Data II (for metadata, see Järvelä, Järvenoja, & Malmberg, 2021), were 7th grade students (N=54, 31 females, 23 male, aged ~13 years) from five classrooms of one secondary school in Finland. The participants worked in 18 groups of three across four lessons, where they performed several collaborative learning tasks. The groups remained the same throughout the four science lessons. Each lesson followed a specific collaborative learning design including a specific lesson structure. Most of the lesson included collaborative learning. More information on the collaborative learning design is provided in Article IV and in Järvenoja, Malmberg, et al. (2020).

4.2 Research design and data collection

The data collection design of this dissertation is visualized in Fig. 2. Both data collections were based on the research design in which students collaborated in small groups in an authentic learning context and their collaboration was recorded with multiple data channels. Since both data collections were conducted as a part of the EmReg research project, they were performed in collaboration with several researchers. The author of this dissertation had an active role in planning and conducting both data collections. In this dissertation, two separate process data channels, namely video and EDA, were used to track group members' affective states and regulation of learning during the learning process.

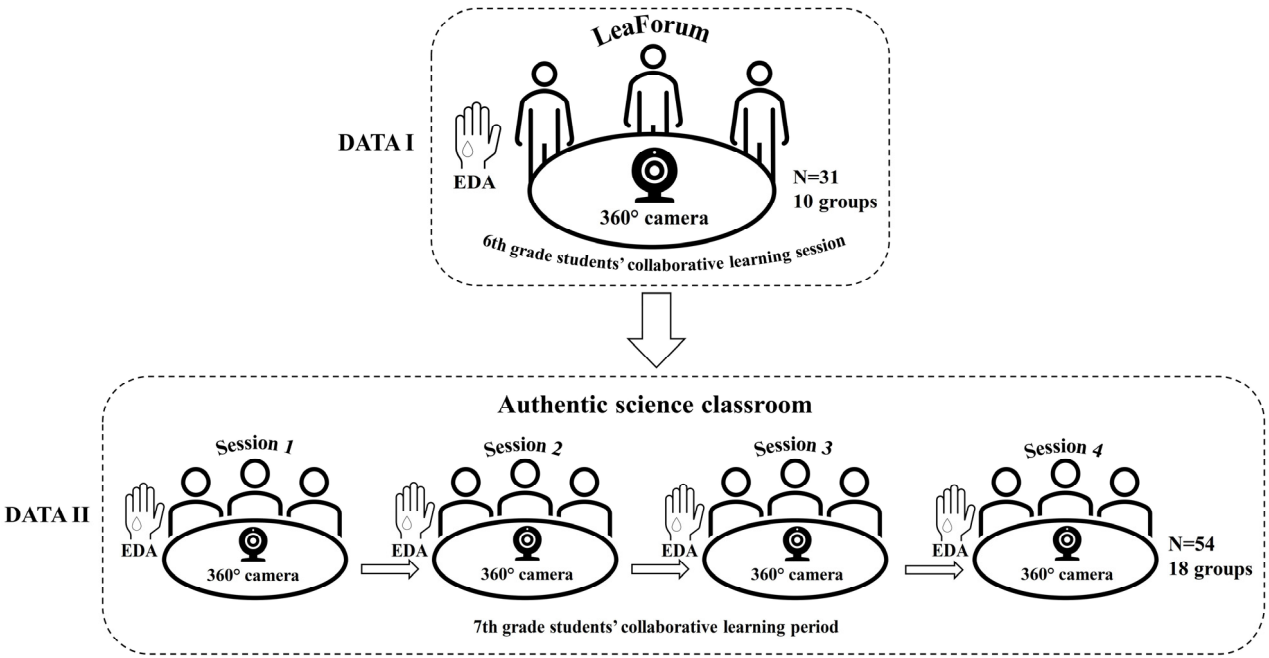

Fig. 2. Data collection design consisting of two separate multichannel process data collections implemented in the LeaForum learning and research space (see Data I) and in the authentic science classroom (see Data II).

In Data I, video and audio data were collected during the collaborative learning task. Video data were collected with 360° cameras placed in the center of each group's table. Audio data were collected with separate microphones for each student. EDA was recorded with Empatica E4 wristbands placed on the non-dominant hand of each student (Empatica Inc., Cambridge, MA, USA). Measuring EDA with the wristband was considered suitable for this study, since it enabled collection of continuous physiological data from authentic situations comfortably and without disturbing the natural flow of the learning situation. Fig. 3 presents the data collection setting of Data I.

Fig. 3. The data collection setting at LeaForum in Data I.

In Data II, video and audio data were collected continuously during the four lessons. Several small groups were present in the classroom at the same time. Four 360° cameras were placed in the different locations of the classroom, each recording two small groups. Audio was recorded with separate table microphones that were placed on the table of each group. EDA was recorded with Shimmer 3 GSR+ sensors

(Realtime Technologies Ltd, Dublin, Ireland) including two gel electrodes placed on the thenar and hypothenar eminences of the palm of the student's non-dominant hand (Dawson et al., 2007). Fig. 4 presents the data collection setting of Data II.

Fig. 4. The data collection setting in the science classroom in Data II.

4.3 Data analysis

The analysis of video data began with qualitative analysis in which affective states and regulation of learning were identified in the learning process from group members' reciprocal actions (Chi, 1997; Sawyer, 2013). To reveal interrelations, temporal sequences, as well as underlaying processes within these actions, the qualitative analysis was extended to quantifying the qualitative video codes to be further analyzed with different statistical and process analysis methods (Chi, 1997). The video data was supplemented with EDA data to indicate the activation dimension of affective states (Pekrun et al., 2002; Russell & Barrett, 1999). Before combining these data sources for analysis, both video and EDA data were processed separately. First, the video data were coded qualitatively for group emotional valence and regulation. Second, individuals' EDA data signals were processed and later aggregated into a group level. Finally, the processed video and EDA data sets were integrated for the data analysis.

4.3.1 Video data coding

The video data analysis was based on the coding and counting approach (Chi, 1997; Derry et al., 2010). The coding schemes applied in this dissertation were based on theories and prior research (Jones et al., 2021; Linnenbrink-Garcia et al., 2011) but were developed and refined to fit the purpose and data of this study. The coding scheme was developed when analyzing Data I, and later applied also in Data II. The qualitative coding of video data started with a three-step video coding scheme, which included 1) segmenting the video data into 30-second segments, 2) locating the segments including socio-emotional interaction, and 3) coding the group's emotional valence in each segment. After this, the video coding continued based on the focus of the article in question. Fig. 5 presents an overview of the video data coding of each article. For each step of the video coding, interrater reliability was analyzed using Cohen's kappa statistics. When the coding procedure was completed, the coding results were adapted into quantitative, time-ordered form to enable statistical and process analyses (see Sub-chapter 4.4.3).

Three-step video coding scheme

The video data were processed using Observer XT software (Noldus Information Technology). In the first step, the video data were segmented into 30-second

segments to enable their integration with EDA data, which has a different granularity size by nature. With Data I, a preliminary video coding of socio-emotional interaction episodes was performed for three videos to estimate a proper time-window for the data segmentation; episodes including socio-emotional interaction were located, and the duration of each episode was coded. Based on the mean duration (24.6 s) of socio-emotional interaction episodes, the 30-second period was chosen. This time segment seemed valid considering the focus of the study, which was on collaborative group members' affective states that were made visible in the socio-emotional interaction episodes. Accordingly, 30 seconds was deemed long enough to enable valid judgements of group members' behavior (Porayska-Pomsta et al., 2013), and it was also reasonable in terms of EDA data analysis.

In the second step, segments including socio-emotional interaction were located based on criteria from earlier literature, considering both group members' verbal and non-verbal expressions of emotions and related actions from group members (Kreijns et al., 2013; Kwon et al., 2014). In the third step, the valence of the groups' affective state in each segment was coded into four categories (positive, negative, mixed, neutral) based on the group members' emotional expressions. The framework of academic emotions (Pekrun et al., 2002) and the affective circumplex model (Russell & Barrett, 1999) were used as a theoretical basis to separate expressions of positive and negative affect. In addition, the study of Linnenbrink-Garcia et al. (2011) was utilized as an example when building the video coding scheme for emotional expressions. The coding scheme was applied also for Data II. However, the fit of the coding scheme to the new data set was first confirmed by preliminary coding. The detailed coding schemes of groups' emotional valence together with data examples are presented in the Articles I, II, and IV.

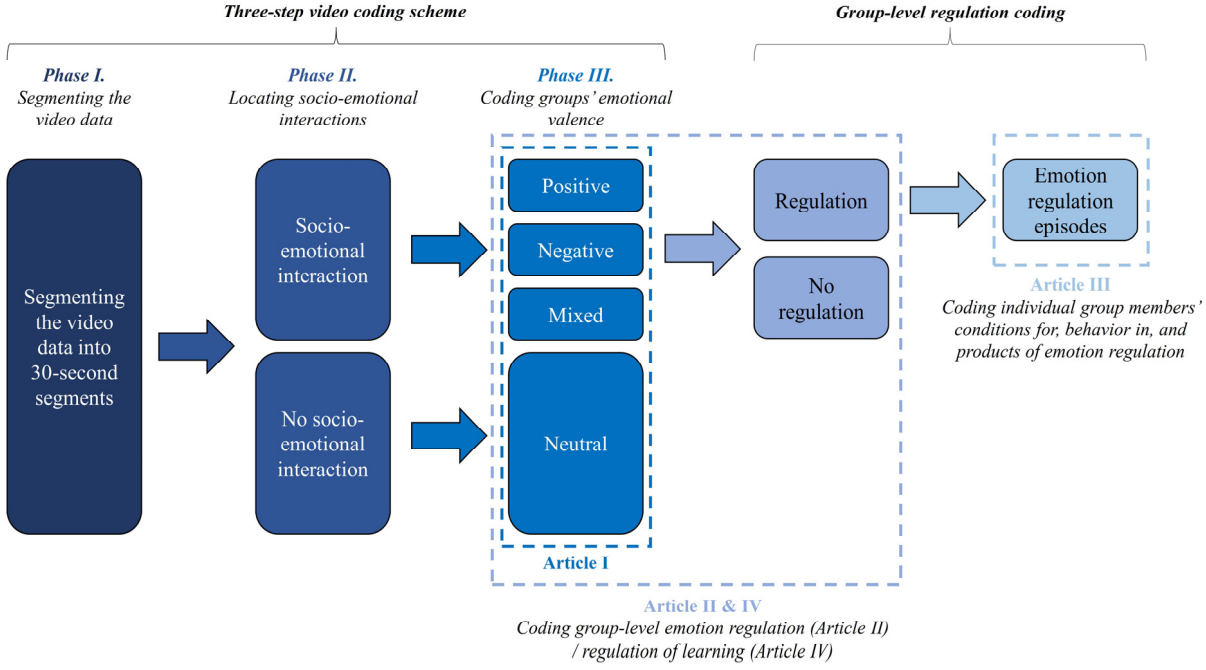

Fig. 5. Video coding procedure using the three-step coding scheme of emotional valence together with group-level regulation coding.

Coding of group-level regulation

After the three steps, the video coding continued in alignment with the focus of each article. In Article I, emotional valence codes resulting from the three-step video coding were used in the analysis. In Article II, the video analysis went on to code group-level emotion regulation in each socio-emotional interaction segment. Coded emotion regulation activities were derived from theories and prior research on emotion regulation (Gross, 2014; Järvenoja et al., 2019). The detailed coding scheme with example interactions of group-level emotion regulation are presented in Appendix 1 in Article II.

In Article IV, video analysis was extended from only emotion regulation into coding of group-level regulation of learning in general. The coding covered CoRL and SSRL activities addressing group members' cognition, motivation, affect, and behaviors (Hadwin et al., 2018). A detailed coding scheme for the regulation of learning is presented in Article IV.

Coding of individual group members' conditions for, behavior in, and products of emotion regulation

In Article III, the focus moved from the 30-second segment level into the episodes of emotion regulation, and from the group to the individual level. That is, emotion regulation situations located in Article II were selected and further coded in more detail in Article III. First, the 30-second segment coding was adapted into emotion regulation episodes. From these episodes it was analyzed which of the group members initiated or contributed to emotion regulation. Students were coded as observers if they did not take any regulatory actions during the episode. Finally, if the regulatory actions were targeted toward a specific student who was not contributing to the regulation as such, that student was coded as a target for emotion regulation.

Furthermore, group members' conditions during a one-minute period before and products during a one-minute period after regulation were observed from the video in terms of emotional valence and participation in collaborative task execution. The one-minute period was chosen so that it would align with the EDA data used to define students' emotional activation, which was also used as a variable for defining students' conditions and products (see Sub-chapter 4.4.2). In addition, based on the preliminary coding of socio-emotional interactions (see Article I), one

minute was considered as a long enough time window to capture the students' emotional expressions prior to and after the emotion regulation episode. The valence of the group members during the one-minute period before and after the episode was coded into three categories (positive, negative, neutral). The valence coding categorization along with examples of emotional expressions is presented in detail in the supplementary file of Article III. Participation in collaborative task execution was coded with a binary variable (participating/not participating). More detailed criteria for participation coding are presented in Article III.

4.3.2 Electrodermal activity data analysis

In both studies, NS-SCR peaks in EDA were selected as the component used in the analysis, since this was considered the most suitable for measuring emotional responses in the research context of this dissertation study. Collaborative learning contexts include continuous stimuli, and separating SCR and NS-SCR peaks from each other is challenging. However, in situations with continuous stimuli, the frequency of NS-SCRs can be used to indicate the current arousal state (Braithwaite et al., 2013). This approach was used with both data sets.

In Data I, EDA data processing was done using the Python programming language. In Data II, a MySQL database was constructed to organize the EDA data. In both data sets, filtering was used first to remove movement artifacts from the signal. Then, NS-SCR peaks with a minimum amplitude of 0.05μS were identified in each student's signal using the trough-to-peak method (Boucsein, 2012; Dawson et al., 2007). More detailed information on the EDA data pre-processing is provided in the Articles. Each group member's individual EDA recordings were synchronized based on the timestamps, after which the EDA data sets were synchronized with the groups' video data coding. In Article III, individual-level emotional activation was used in the analysis, whereas in Articles II, II, and IV individual group members' emotional activations were aggregated into a group-level emotional activation variable. Fig. 6 presents an overview of the EDA data processing and aggregation.

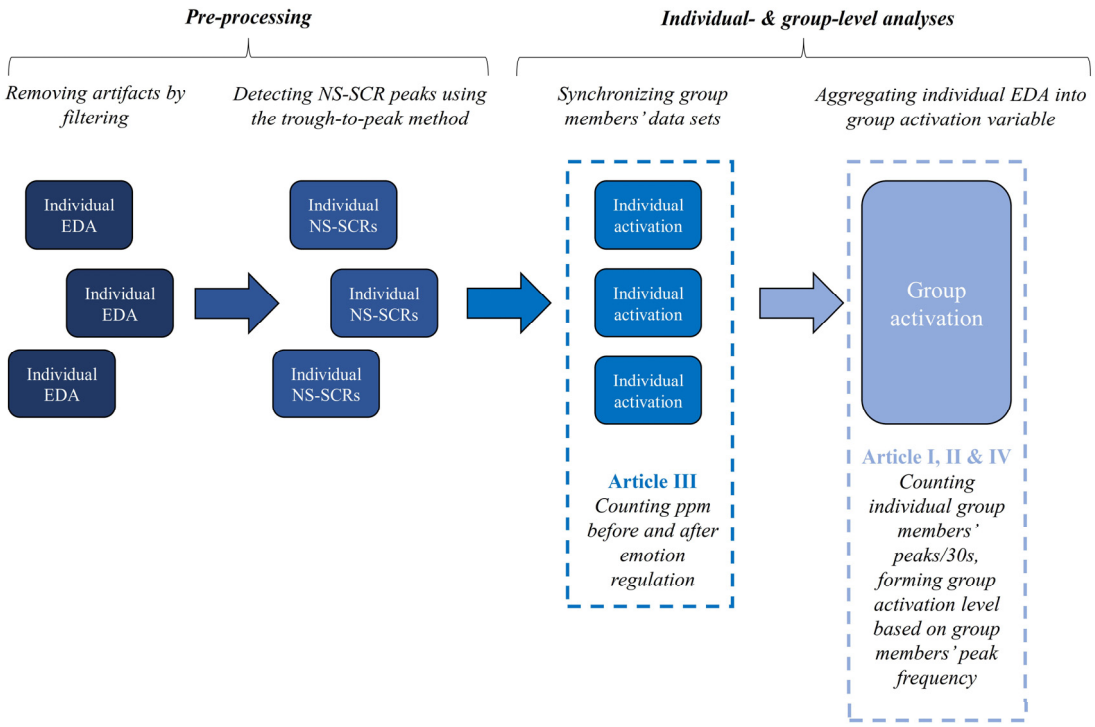

Fig. 6. Overview of EDA data processing and aggregation.

Individual emotional activation

In Article III, individuals' emotional activation one minute before (conditions) and one minute after (products) the regulatory episode were determined based on their frequency of NS-SCR peaks. The one-minute time window derived from the traditional peaks per minute (ppm) variable used in the EDA data analysis (Braithwaite et al., 2013; Dawson et al., 2007). The ppm values were used to define the students' individual emotional activation (activated/deactivated) during episodes of conditions and products. The binary categorization was chosen to align the EDA data categorization with the valence coding based on the affective circumplex approach (Linnenbrink, 2007; Russell & Barrett, 1999). More details on defining the individual emotional activation are provided in Article III.

Group emotional activation

In Articles I, II, and IV, a group emotional activation variable was defined for each 30-second segment of collaboration. First, the number of NS-SCR peaks per each 30-second segment was counted for each student in the group, and then an activation level for each student in each segment was categorized. In Data I, it was categorized as low, medium, or high arousal (see Article I and II for more details; Dawson et al., 2007; Boucsein, 2012). Subsequently, the group level variable of emotional activation (activating/deactivating) was formed based on the number of group members with medium or high arousal during the segment. Segments, in which two or more students were in medium/high arousal were considered as activating and other segments as deactivating.

In Data II (see Article IV), a group emotional activation variable accounted for three categories of group activation level: high, divergent, and low. This categorization was chosen since in Article I and II it was noticed that group members were rarely in high arousal simultaneously, which indicated a need to also account for the divergent activation situations. If all group members were in a state of deactivation, group-level activation was categorized as low; if some group members were in a state of activation, group-level activation was categorized as divergent; and if all group members were in a state of activation, group-level activation was categorized as high. More details on how the individual group members' activation levels were defined are provided in Article IV.

4.3.3 Multichannel data analysis

Various statistical and process-oriented methods were used to analyze the multichannel data, that is, the integrated data set of video and EDA. Based on the focus of the analysis, the analysis methods can be divided into 1) variable-centered methods for analyzing the characteristics of individual- and group-level affective states, 2) sequence analysis methods for studying the sequential relations between the variables, and 3) process mining methods for identifying the processes of regulation in socio-emotional interactions (see Table 1 for a summary).

Table 1. Summary of the methods used for the multichannel data analysis.

Analysis	Article	Focus	Methods
Variable-centered	I	Characteristics of group-level affective states	Chi-square statistics
	III	Characteristics of individual-level affective states	Two-step clustering
	II	Relations between affective states and regulation	Chi-square statistics
Sequence analysis	I	Triggering factors for activating affective states	Inductive qualitative content analysis
	III	Sequential relations between individual conditions and group-level regulation	Lag sequential analysis
Process mining	III	Process of emotion regulation	Disco process models
	IV	Process of regulation in socio-emotional interactions	Clustering by MHMMs

Variable-centered methods for analyzing the characteristics of individual- and group-level affective states

The affective states were analyzed first on a group level with variable-centered methods by studying the relations between the different affective dimensions, emotional valence (video) and activation (EDA) (see Article I). The unit of analysis was one 30-second segment. Next, the relations between valence, activation, and group-level emotion regulation (video) were explored (see Article II). Since all variables were categorical in nature, non-parametric tests were considered applicable to test the relationships between emotional valence, activation, and emotion regulation. The relationships between the different variables were explored with a chi-square test of independence. In addition to significance of observed differences, chi-square provides information on which categories account

for the differences found (McHugh, 2013). Accordingly, significant relationships found were further explored with significant z scores from adjusted residuals with an alpha level 0.01 ($z < 2.58$).[6] Cramer's V was used to test the strength of the significant results (McHugh, 2013).

Clustering was used to identify different compositions of affective states as conditions for regulation. This was done on an individual level prior to emotion regulation (see Article III). The analysis used a 'case' as the unit of analysis, referring here to one condition/emotion regulation/products episode. Variables of emotional valence (video), activation (EDA), and participation in collaborative task execution (video) were used to define the conditions for regulation. To find the similarities among condition cases, the cases were clustered with an IBM SPSS two-step cluster analysis. Two-step cluster analysis was chosen since it can handle categorical variables and includes automatic selection of the number of clusters. The analysis yielded four clusters that differed in terms of affective conditions of valence and activation as well as participation.

Sequence analysis methods for studying the sequential relations between the variables

After discovering the characteristics of affective states as conditions for collaboration (see Article I) and regulation (see Article II), the analysis adopted process-oriented methods to account for the temporal relations between the different variables of interest (Molenaar & Järvelä, 2014). In Article I, possible triggers for group-level physiological emotional activation were explored with qualitative content analysis (Elo & Kyngäs, 2008). The analysis focused on the situational factors that seemed to provoke students' emotional expressions. Two categories of factors emerged from the qualitative content analysis: task-related and socially-related factors. The analysis then moved on to explore whether there was a sequential relationship between the triggering factors for activation and the following video-observed emotional valence. The relationship was tested with a chi-square test of independence (McHugh, 2013). Significant relations were further explored with significant z scores from adjusted residuals with alpha level 0.01 ($z < 2.58$) and Cramer's V was used to test the strength of the significant results.

In Article III, the analysis moved from the group-level to the individual-level. The sequences from the different individual level conditions (resulting from the

[6] In Article I, alpha level is incorrectly typed as 0.001.

two-step cluster analysis) to students' emotion regulation behavior (video) were discovered. The sequential relations were studied using the Observer XT state lag sequential analysis function with lag order 1. State lags with lag order 1 consider the transitions between events that directly follow each other (in this case, the transitions from conditions to regulatory behaviors). After the frequencies of different sequences were identified, chi-square statistics were calculated for the results. The significant associations between conditions and regulatory behaviors were further explored with significant z scores from adjusted residuals with alpha levels 0.05 ($z > 1.96$) and 0.01 ($z > 2.58$),[7] along with Cramer's V tests of the strength of the significant results

Process mining methods for identifying the processes of regulation in socio-emotional interactions

To account for the assumption that processes of regulation generate sequences of events, the analysis was expanded to utilize process mining (Bannert et al., 2014). Process mining methods can identify process models from event data, and thus are suited for visualizing and investigating process patterns between different conditions, emotion regulation behaviors, and products (see Article III). Fluxicon's Disco analysis software (https://fluxicon.com/disco/) was used to create process models of different sequences, and the process patterns were explored separately for each condition cluster. To execute the process models, the products were divided into the same clusters that resulted from the two-step cluster analysis of conditions. To simplify the complex illustration of each possible sequence and their interconnections (Bannert et al., 2014), the process models were restricted to show only the strongest (i.e., the most frequent) paths of interconnectivity (although 100% of the activities were included). The strongest paths were explored further using qualitative case examples that demonstrated individual students' emotional expressions and regulatory behavior in relation to the group's socio-emotional interaction. The case examples were selected so that they would represent the typical flow of the path.

Next, the focus of the analysis moved from the individual and case levels to identifying longer episodes of socio-emotional interaction and affective states as a part of the regulation of the learning process. The socio-emotional interaction episodes were identified using multichannel sequence mining and clustering by

[7] In Article III, alpha level is incorrectly typed as 0.001.

mixture hidden Markov models (MHMMs) (Helske & Helske, 2019). In general, a sequence mining process includes constructing a sequence according to a time scheme and then identifying sequences or patterns that form homogeneous subgroups of behaviors (Abbott & Tsay, 2000), but do not account for the (latent) processes (Bannert et al., 2014). However, when combined with hidden Markov models (HMMs) that can also discover the underlying hidden states, they can be considered comparable to process models (Bannert et al., 2014; Helske & Helske, 2019). Using clustering by MHMMs, the socio-emotional interaction episodes were clustered into homogeneous subgroups based on three data channels: emotional valence (video), activation (EDA), and regulation of learning (video). Further information on the MHMM analysis process is provided in Article IV.

To investigate the differences between the clusters with statistical methods, fluctuations in valence and activation as dimensions of these affective states were measured in terms of Shannon's entropy (Gabadinho et al., 2011). Initially, Shannon's entropy quantifies the unevenness in the probability distribution (Lesne, 2014). In terms of affective states, it can be applied to quantify the randomness of affective states where larger entropy values indicate larger fluctuations in affective states (Lesne, 2014; Li et al., 2021). Furthermore, proportions of positive valence and divergent activation among the group was calculated for each cluster. Finally, the differences between the clusters were explored using the Kruskal-Wallis test and the Dunn-Bonferroni post hoc test with Holm adjustment. The Kruskal-Wallis test was chosen since it is a non-parametric test suitable for assessing the differences among multiple groups on a non-normally distributed continuous variable (McKight & Najab, 2010).

4.4 Evaluation of the research

Instead of creating generalizable results to represent the total population, this dissertation seeks to understand how affective states and regulation unfold in context-specific settings (Golafshani, 2003; Johnson & Onwuegbuzie, 2007). Therefore, the data used in this dissertation derives primarily from qualitative video data triangulated and complemented (Greene et al., 1989) with EDA data that are analyzed with various statistical and process-oriented methods.

In qualitatively based research, reliability can be evaluated through the quality and fit of the research data as well as through trustworthiness, which can be supported by transparently reporting the analytical methods, procedures, and results (Elo et al., 2014). In this study, the quality and consistency of both data sets

were ensured by careful planning, testing, and piloting as well as by controlling and monitoring the data collection equipment before, during, and after the data collections. The video data quality was confirmed by using multiple high-quality 360° cameras situated in different locations of the classroom. For example, if one camera malfunctioned, learning situations could also be later observed from the recordings of other cameras. To ensure the quality of audio, in addition to the cameras' own microphones the audio was recorded with separate microphones. Physiological data was collected with Empatica E4 and Shimmer3 GSR+ sensors that both produce EDA data with high granularity. Before each data collection session, the functioning and synchronization between cameras, microphones and sensors were confirmed. After each data collection session, the quality of each data source was checked to detect possible malfunctioning. To ensure the quality of the physiological data, possible artifacts were removed before the analysis. The data collection procedures of both studies were piloted. In Data I, the procedure and equipment were piloted first by university students to get systematic feedback from the different phases and then with a group of primary school students to test its suitability for the age group. In Data II, the procedure was piloted with the participating students during one week of science studies before the actual data collection period.

Regarding trustworthiness, in the articles of this study the video (coding schemes) and EDA (details of data processing) analysis procedures as well as their integration are described in detail, including the reasoning behind the different analytical decisions. Furthermore, attention has been paid to the clear presentation and interpretability of the results as well as to providing qualitative data examples demonstrating the results. The reliability of the video analysis can be evaluated through interrater reliability (Derry et al., 2010; McHugh, 2012), which was also assessed in this study. In each step of the video coding, the coding schemes were first developed and adjusted through data examples and discussions between the two researchers. The two researchers then coded part of the data (10–40%, depending on the total amount of the data, see Table 2) to calculate Cohen's kappa values to indicate the interrater reliability. Finally, the disagreements between the two coders were discussed to agree on the final codes.

In addition to reliability, the validity of the research should also be evaluated. One of the main methodological principles of this study was to ensure the ecological validity of the data. That is, both data sets were collected in authentic learning situations with unobtrusive equipment, which can be considered a strength of this study. Another strength is the triangulation and complementation of the two

different data channels providing both explicit (video) and implicit (EDA) information of the phenomenon. This is considered to improve the validity by offering corroboration (or revealing the inconsistency) of the results from the different methods (triangulation) and by increasing the interpretability and meaningfulness by elaborating and clarifying the results from one method with the results from the other (complementarity; Greene et al., 1989). By complementing video observations with EDA data, this study was able to increase the level of explanation regarding the interplay between affect and regulation of learning in groups' socio-emotional interactions.

As it pertains to the validity of the measurements used, the variables of interest as well as how they were operationalized were derived from the theoretical standpoints of regulation in learning (Hadwin et al., 2018) and the affective circumplex model (Linnenbrink, 2007; Russell & Barrett, 1999). In research performed in collaborative learning contexts, both affect and regulation have also been previously studied through video observations of group members' interactions (see e.g., Järvelä, Järvenoja, et al., 2016; Jones et al., 2021), and this study followed this valid line of research. Affective states were operationalized through the two dimensions traditionally used, emotional valence and activation (Pekrun, 2006; Russell & Barrett, 1999). Valence was determined based on groups' visible emotional expressions with a coding scheme that was carefully developed to suit the purpose of the study and was based on previous studies that have coded valence of affect from the video data (for a review, see Jones et al., 2021). Emotional activation was detected through sympathetic arousal, to which EDA provides a sole link (Braithwaite et al., 2013; Dawson et al., 2007). This approach is also supported by previous research linking sympathetic arousal to students' affect in learning situations (e.g., Ahonen et al., 2018; Harley, Jarrell, & Lajoie, 2019; Malmberg et al., 2019). Furthermore, previous research has indicated that EDA can also reflect regulatory processes in learning (Järvelä, Malmberg, et al., 2021; Winne, 2019) and thus offered a suitable complementary data source to study the variables of interest in this study.

Table 2. Cohen's kappa values for interrater reliability analyses of each variable in Data I and II.

Data	Variable	Percentage of coded videos (%)	Kappa value (κ)	Agreement (Landis & Koch, 1977)
I	Socio-emotional interaction	40	0.69	Substantial
	Group emotional valence	40	0.72	Substantial
	Emotion regulation	30	0.71	Substantial
	Regulatory behavior	30	0.82	Almost perfect
	Emotional valence as individual condition	30	0.75	Substantial
	Participation	30	0.85	Almost perfect
	Triggers for emotional activation	30	0.87	Almost perfect
II	Socio-emotional interaction	10	0.77	Substantial
	Group emotional valence	10	0.68	Substantial
	Regulation of learning	10	0.79	Substantial

4.5 Ethical issues

This study follows the ethical guidelines of the Finnish National Board on Research Integrity (Finnish National Board on Research Integrity, 2012) and the European Code of Conduct for Research Integrity (All European Academies, 2017). The data management plan was made to address the management of both data sets according to the relevant laws and regulations. Participation in both data collections was voluntary. Before asking for consent to participate, the researchers visited the participants' school to inform the community about the study and the guardians received a written information letter. Written consent was required separately from both students and their guardians after both parties had been informed of the study details and personal data management. Consent was also asked from teachers and the participating school. In addition, the participants were asked to indicate whether they allow pictures or recorded videos of them to be used when presenting the results of the studies. For the parts of the study addressing students' physical integrity (physiological measures), a statement on research ethics from the University of Oulu ethics committee of human sciences (https://www.oulu.fi/en/university/faculties-and-units/eudaimonia-institute/ethics-committee-human-sciences) was obtained for both data collections.

Because both data collections were conducted as a part of the students' normal school activities, steps were taken to ensure that participating/not participating in the study did not cause any drawbacks for the students' schoolwork. In Data I, the

students who did not take part in the research studied the same topic in their own classroom with their classroom teacher. In Data II, the not-participating students studied simultaneously in the other classroom with another science teacher and followed the same collaborative learning design, or room dividers were used to crop these students from the video recordings. The topic and structure of the lessons/tasks that students worked with during the data collections were planned in collaboration with science teachers to ensure that the topics, tasks, and ways of working followed the Finnish curriculum of basic education (Opetushallitus, 2016).

After the data collection, physiological data were stored in the secured server of the University of Oulu, which was secured by the University IT services. The video and audio data were combined and moved to the LeaForum (University of Oulu) secured server. During the data management, all the data were pseudonymized and the students' names were replaced with ID numbers. A separate document (code key) with students' ID numbers were made to ensure connections between different data sources. When the results were reported, fictional names for students were used. Access to the research data was given only to the members of the research group. The data sets were not made openly available due to the sensitive nature of the data. However, FAIR (Wilkinson et al., 2016) principles were followed to make metadata of both studies findable and accessible for others. Metadata was created through Fairdata national services (Qvain; https://qvain.fairdata.fi/). Both sets of metadata are available online with assigned persistent identifiers (see Järvelä, Järvenoja, & Malmberg, 2021; Järvenoja et al., 2021) and findable through the *Etsin* (https://etsin.fairdata.fi/) research data finder. Metadata descriptions were provided respecting the research ethics related to the sensitive data.

5 Overview of the original articles

This dissertation consists of four empirical articles based on collaborative efforts of several researchers. The author of this dissertation was the first author in Articles I, III, and IV. In Article II, the author of this dissertation was the second author, but had the main responsibility for the data analysis and contributed actively to the writing process. All articles zoom in on group members' socio-emotional interactions in collaborative learning in order to study individuals' and groups' affective states in relation to the regulation of learning.

Article I focuses on the relations between the group's video-observed affective states and their physiological emotional activation. Furthermore, Article I examines the situational factors in collaborative learning that trigger activated affective states in groups. Article II expands on this investigation by exploring how the different kinds of group-level affective states are related to group-level emotion regulation. Article III focuses on the episodes of group-level emotion regulation and explores the individual students' affective states as conditions for and products of regulation. It examines how affective conditions are related to students' behavior in emotion regulation situations, and whether emotion regulation makes a difference in students' affective products after regulation. In Article IV, the interplay between affective states and regulation of learning is studied across longer episodes of socio-emotional interaction to reveal how these processes are continuously intertwined. Table 3 presents the overall aims of the articles and the author's contribution.

Table 3. Aim of the articles and the author's contribution.

Article	Aim	Author's contribution
I	To explore the relations between video-observed group-level affective states and physiological emotional activation. To understand what type of factors in collaborative learning are related with the physiological emotional activation of group members.	1st author; theoretical grounding, data collection, data analysis, reporting
II	To investigate the two dimensions of group-level affective states, valence and activation, in relation with group-level emotion regulation.	2nd author; data collection, data analysis, reporting the methods and results
III	To explore the interplay between individual students' group-level emotion regulation behavior and affective states as conditions and products of regulation.	1st author; theoretical grounding, data collection, data analysis, reporting
IV	To identify the episodes of socio-emotional interaction during collaborative learning and examine how group-level affective states fluctuate with regulation of learning.	1st author; theoretical grounding, data collection, video data analysis, EDA data aggregation, reporting

5.1 Exploring groups' affective states during collaborative learning: What triggers activating affect on a group level?

When engaging in collaborative learning, it is probable that individual group members converge in their affective states, which leads to synchronous and interactive experiences of group-level affect. The group's affective state can be seen as a condition that influences how the group engages in learning and collaboration, but can also fluctuate along with different learning activities occurring during collaboration. Even though the emergence and importance of group-level affect has been recognized in theories, only few previous studies have addressed the group-level affective processes in the context of collaborative learning. This study focused on this understudied phenomenon by exploring groups' affective states during a collaborative learning process.

The aim of this study was to explore the different affective states found in groups' learning processes. The first research question focused on studying the relations between the groups' video-observed affective state and physiological emotional activation. Furthermore, the study aimed to understand what type of learning situations trigger activated affective states in collaborative groups, which was addressed in the second research question. The participants were 12-year-old primary school students (N = 31, 10 groups) who performed a collaborative science

task in small groups. The groups' collaboration was video-recorded to observe the valence of group members' emotional expressions (positive/negative/mixed/neutral) emerging in their socio-emotional interaction. To indicate group members' emotional activation (activated/de-activated), their sympathetic arousal was measured with EDA. In the statistical analysis, the relations between observed emotional valence and physiological emotional activation was examined on a group level with a chi-square test of independence. Inductive qualitative content analysis was used to identify the situational social or task-related factors triggering the affective states including simultaneous emotional activation among group members.

The results revealed that group-level affective states can have various compositions in terms of emotional valence; group members can converge in positive or negative affect, or they can react differently, leading to a mixed affective state among the group members. In terms of emotional activation, situations with group members' simultaneous high emotional activation were rare compared with the video-observed emotional expressions. However, when group members indicated emotional activation simultaneously, they also showed observable emotional expressions more often than in deactivating situations. Moreover, the results showed that socially-related factors were more likely to trigger emotional activation in interactions with mixed group-level valence. In contrast, task-related factors were more likely to trigger emotional activation in interactions with neutral group-level valence. The results of this study suggest that by combining different process data modalities that reveal the different components of affect, it might be possible to track emotionally meaningful situations that shape the course of the collaborative learning process.

5.2 Affective conditions for collaborative learning: When do groups engage in emotion regulation?

In collaborative learning, group members can experience shared positive affect, such as enjoyment of learning, but can also face socio-emotional challenges leading to negative emotional experiences. When these shared experiences occur, group members can strengthen the favorable positive affective state or restore more positive grounds for collaboration through group-level emotion regulation. While affect as a condition for learning has been studied before, there is still a research gap concerning the relations between affective states and the emergence of group-level regulation.

Accordingly, this study focused on the groups' affective states as conditions for regulation and explored the relations between different kinds of group-level affective states and actualized group-level emotion regulation. The participants were 12-year-old primary school students (N = 31, 10 groups) and video and EDA data were collected while they performed a collaborative science task. The affective states were operationalized with two dimensions, namely emotional valence and activation. Valence (positive/negative/mixed) was continuously captured from the video-observed emotional expressions, and activation (activated/de-activated) was derived from physiological EDA data. In the first and second research questions, valence and activation were treated as separate dimensions and their relations with emotion regulation were studied separately with a chi-square test of independence. The third research question combined these two dimensions into six affective states to study how the dimensions of valence and activation together are associated with the manifestation of group-level emotion regulation.

The results indicated that both emotional valence and activation are valid dimensions of affect experienced by collaborative groups. That is, this study provided evidence that both can be associated with the initiation of group-level emotion regulation. However, the results revealed that the groups engaged in emotion regulation quite rarely, although their affective state was calling for it. Emotion regulation was most likely to occur when the group was in a negative activated condition. In turn, mixed emotional valence without emotional activation rarely prompted emotion regulation within the groups. This indicates that emotion regulation is most likely to emerge when there is a clear need for regulation, which in this study was identified through visible signs of negative valence. The need for regulation was also visible in group members' physiological emotional activation as specified through the sympathetic arousal level. To conclude, combining process-oriented data channels that reveal different emotional dimensions can be useful in understanding the circumstances in which collaborative groups are able to activate CoRL and SSRL or, alternatively, explain the lack of it.

5.3 All for one and one for all – How are students' affective states and group-level emotion regulation interconnected in collaborative learning?

When a group of learners interact, individual affective states have an impact on the socio-emotional interactions taking place in a group, which in turn plays a role in how individual group members' perceptions of the group's affective state are

constituted. When group-level emotion regulation occurs, it can serve as a means for influencing individual group members' self-regulation, and hence make an impact on individual affective states. However, there is a lack of empirical research examining how this interplay between individual- and group-level emotional processes takes place in authentic collaborative learning situations.

This study aimed to fill this gap by empirically exploring how individual group members' affective states and participation in collaborative task execution are interrelated with their behavior in group-level emotion regulation situations. This was pursued through three research questions addressing 1) the combinations of affective states and participation that serve as conditions for students' group-level emotion regulation, 2) the relations between students' conditions and emotion regulation behavior, and 3) the process patterns between conditions, emotion regulation behavior, and products of regulation. The participants were 12-year-old students (N = 31, 10 groups) performing a collaborative science task. Students' individual emotional valence (positive/negative/neutral) and participation (participating/not participating) as conditions prior to regulation, their emotion regulation behavior (initiator, contributor, target, observer) in regulation situations, and products (valence, activation, participation) after regulation were captured from video observations and EDA data. In the statistical analysis, the different kinds of conditions before regulation were identified through two-step cluster analysis, and the associations between students' conditions and emotion regulation behavior were revealed through lag sequential analysis. Finally, the process patterns between conditions, emotion regulation behavior, and products of regulation were revealed through process models.

The results revealed four types of conditions for emotion regulation (activated, positive/neutral de-activated, negative de-activated, not participating), and these conditions were related to students' regulatory behavior. Students were more likely to initiate group-level emotion regulation when they were in a negative de-activated condition, and hence indicated a personal need to restore emotional grounds. Moreover, emotion regulation was used to restore students' participation by targeting regulation to non-participating students. While group-level emotion regulation did not always change individual conditions for collaboration, the results indicate that it was more influential for students who either initiated or were targets for regulation. The results support the purposeful and agentic role of the individual learner, which is emphasized in SRL theories, in group-level regulation as well; if there is no personal need for regulation, the student might not engage as actively in CoRL and SSRL. The results offer novel empirical insights to strengthen theories

of emotion regulation during collaborative learning by dissecting the interplay between individual- and group-level emotional processes. Furthermore, the results demonstrate the potential of novel process-oriented approaches for studying the role of emotions for academic learning.

5.4 Affective states and regulation of learning during socio-emotional interactions in secondary school collaborative groups

The previous research targeting students' socio-emotional interactions during a collaborative learning process has indicated that these interactions are related to students' self-reported affect and emotional experiences. However, there is a lack of evidence showing how affective states form conditions for collaboration during longer episodes of socio-emotional interaction, and how this sets the stage for the regulation of learning. To address this gap in the research, appropriate methods are needed to track the relationships between affective states and regulation of learning occurring in group members' interactions.

Accordingly, this study sought first to identify various episodes of socio-emotional interaction during collaborative learning, and second to examine how group-level affective states (operationalized as emotional valence and activation) fluctuate during these episodes with the regulation of learning. Multichannel process data were collected in an authentic classroom while 54 secondary school students (aged ~13 years) collaborated in 18 small groups to study a topic of light and sound across four sequential lessons. Groups' emotional valence (positive/negative/mixed) was captured on video, and activation levels (high/divergent/low) were captured as sympathetic arousal measured by EDA. Group-level regulation of learning (regulation/no regulation) was observed from the videotaped interactions. Multichannel sequence mining and clustering using MHMMs was used to identify the various kinds of socio-emotional interaction episodes. Fluctuations of emotional valence and activation during these episodes were explored with Shannon's entropy as well as with the proportions of positive valence and divergent activation.

The study disclosed four types of socio-emotional interaction episodes (positive, negative, occasional regulation, frequent regulation) that differed in terms of the fluctuation of affective states and the regulation of learning. These clustered episodes confirmed how affective states are constantly reset by socio-emotional interactions and regulation of learning. The results suggested that the

groups can use regulation of learning strategically to alter the group's affective states during the learning process. In occasional regulation episodes, groups activated regulation when positive affective states were temporarily endangered. Episodes of frequent regulation were rare compared to the other types of episodes. In these episodes, negative states recurred, but the groups were able to activate regulation frequently to overcome them. The results also showed that affective states that call for the regulation of learning do not often lead to its activation, as it was detected in only two of the four clusters. In the positive episodes, groups' affective states remained positive throughout, and regulation might not have been needed. However, regulation was not detected in negative episodes either, although it would be presumably have been needed. To conclude, for the collaborative groups in this study, maintaining a positive affective state seemed easier than engaging in strategic regulation of learning to overcome the accumulating negative states. The results can be utilized in advancing existing understanding of how group level socio-emotional processes contribute to the regulation of learning.

6 Main findings and discussion

The aim of this dissertation was to investigate the interplay of affect and regulation of learning in a collaborative learning context. For this purpose the study focused on exploring individuals' and groups' affective states and the triggering factors for these states, and implemented a set of analyses to study the interconnections between affective states and group-level regulation (i.e., CoRL and SSRL). Furthermore, this study aimed to utilize novel data channels to explore the potential of multichannel process data in this endeavor. The main findings and related discussion are presented next in relation to the study's four objectives.

6.1 Individuals' and groups' affective states in collaborative learning

The first empirical objective of this study was to examine how individual- and group-level affective states manifest during socio-emotional interactions of collaborative learning. By disclosing the different kinds of group-level affect, this study demonstrated the complex manifestation of affect in collaborative groups: it is constructed of both individual- and group-level components in interactions between the group members, situational factors, and the learning context (Järvenoja et al., 2015; Kelly & Barsade, 2001). Overall, the results identified various kinds of frequently occurring individual- and group-level affective states showing that *learning in small groups is, indeed, very emotional* (Järvenoja & Järvelä, 2013; Linnenbrink-Garcia et al., 2011), and that *affective states vary frequently and situationally along with the collaborative learning activities.* On the one hand, it was discovered that *group members can converge in their affective states, leading to negative or positive affective state within the group*. On the other hand, it was demonstrated that *individuals in the group can respond differently to the learning situations, which leads to a mixed affective state within the group.* To sum up, affect in collaborative groups is multifaceted and can include various compositions, which should be considered when studying affect in small group learning.

So far, there are not many empirical studies in the field of collaborative learning that would focus on the group-level affect (however, see Pietarinen et al., 2019, 2020). Previous research in the field of collaborative learning has mainly focused on individual affective experiences (Linnenbrink-Garcia et al., 2011; Mänty et al., 2020; Zschocke et al., 2016) or studied groups' affective processes through group members' socio-emotional interactions, dynamics, or challenges

(Jones et al., 2021). By focusing explicitly on affective states on a group level, this study extended the previous collaborative learning research and found evidence that group members tend to converge in their affect in these learning situations (Barsade & Knight, 2015; Pietarinen et al., 2020): The affective states of the group were mostly uniformly either negative or positive. When the valence dimension of affect is supplemented with the activation dimension, the results draw a more thorough picture of the groups' affective structures. The results supported the previous findings by indicating that the physiologically activating affective states during learning are rare compared with the deactivating affective states (Harley, Jarrell, & Lajoie, 2019; Malmberg et al., 2019; Pijeira-Díaz et al., 2018).

Interestingly, both activating and deactivating negative states were more common than the positive states within the group, which in the light of previous research findings is alarming. Prior research has recognized that a negative de-activated condition, such as boredom, can be linked to students' disengagement and social loafing (Linnenbrink-Garcia et al., 2011). Thus, those states require regulation to restore students' active participation and neutral or positive emotional grounds for collaboration (Järvenoja & Järvelä, 2009; Näykki et al., 2014). Moreover, when combined with emotional activation, negative valence may indicate negative activating emotions such as anxiety (Pekrun et al., 2002; Roos et al., 2020), which has been found to be harmful for individual learning and performance when not controlled (Zeidner, 2014). It can be further assumed that in a collaborative context, negative activating emotions can challenge groups' joint learning processes such as co-construction of knowledge and shared understandings, and call for regulation (Järvenoja et al., 2019). Mänty et al. (2020) explored the relations between groups' negative socio-emotional interactions and individual students' emotional experiences, and found that negative group interactions occurring during group work negatively influenced students' emotional experiences after the task. These negative experiences, in turn, may have a negative influence on how the students approach future collaborative learning tasks. Nonetheless, too much emphasis should not be ascribed to the frequencies of different affective states compared to each other, since these states are very situation- and context-specific (Järvenoja et al., 2015). For example, in a high school context, Pietarinen et al. (2020) explored affect in small groups using both self-reports and video observations of affect. In contrast to this dissertation, in their study positive affective states were prevalent in both self-reports and observations (Pietarinen et al., 2020).

Actually, previous research focusing on individuals' affect has shown that learning situations involve a multiplicity of individual differences in students' emotions (Ganotice et al., 2016; Karamarkovich & Rutherford, 2021; Robinson et al., 2017). Studies have indicated that compared to students with a positive emotional profile, negative profile students are more disengaged and display lower achievement (Karamarkovich & Rutherford, 2021; Robinson et al., 2017). By observing emotional expressions in groups' socio-emotional interactions, this study expanded prior research by adding a group-level perspective on the different kinds of affective states during the learning process. When this study explored how affect is composed on a group level, it was able to discover situations where individual group members diverged in their affective state, and surprisingly, these mixed states were even more common than the positive states. This type of group-level affect has previously been identified among teams in work organizations (Barsade & Gibson, 2012) but has not been systematically studied in collaborative learning contexts. However, these situations might hamper groups' coordinated learning efforts and lead to reduced performance (Barsade & Gibson, 2012; Pietarinen et al., 2020).

Since affect arises in relation to the student's appraisal of the situation, one reason for the emergence of mixed states might be individual group members' diverse emotional appraisals and thus diverse responses to the learning situations (Gross, 2014; Lobczowski, 2020). These diverse appraisals could derive from the group members' diverse individual characteristics or other internal conditions shaping their learning-related interpretations (Gross, 2014; Winne & Hadwin, 2008). Furthermore, because mixed affective states occurred relatively often, it might be speculated that the students of this study did not share their goals and standards for collaborative learning, and as a result had diverse interpretations of the learning situations (Järvenoja, Malmberg, et al., 2018; Winne & Hadwin, 2008). Alternatively, during relatively short periods of collaborative learning the students might not have strongly identified themselves as members of the group and thus might not have experienced group-based emotions that much (Delvaux et al., 2015; Smith & Mackie, 2016). The divergent affective states were also visible when individuals' affective states were analyzed as conditions for group-level emotion regulation. The results revealed four different types of individual affective conditions that can occur prior to regulation (activated, positive/neutral de-activated, negative de-activated, and not participating).

To conclude, collaborative learning research still lacks evidence of mixed affect within small groups, even though the research-based evidence has started to

accumulate for the existence of mixed affect within individuals in learning situations (Ganotice et al., 2016; Karamarkovich & Rutherford, 2021; Robinson et al., 2017). Collaborative learning contexts present a more complex setting for research compared to individual learning, leading to more various affective conditions, as the results of this study demonstrate. Although this complex phenomenon of group-level affect has been recognized in discussions of the social nature of regulation (Hadwin et al., 2018; Lobczowski, 2020), collaborative learning research has not yet systemically studied it. The results of this study pose a clear *need for more empirical research exploring different compositions of group members' affective states on both the individual and the group level to reveal the complex interrelations between affect and group learning processes*.

6.2 Collaborative learning as an antecedent for groups' affective states

The results related to the first objective revealed that simultaneous high arousal between group members (i.e., activated affective states) occurred very rarely and negative and mixed states were more prevalent than positive states. These findings gave rise the second objective of this study, which sought to identify what kinds of factors during collaborative learning trigger physiologically activating affective states within groups. It was assumed that even though, or because of, their rare occurrence, these situations might reveal the critical moments during the collaborative learning process. Therefore, they would be relevant moments to track and study (Horvers et al., 2021; Järvenoja et al., 2019). To follow up this assumption, the episodes with group-level activated affective states were explored qualitatively. The results indicated that *collaborative groups' activated affective states are triggered by factors deriving from the learning task and context as well as from various social aspects of collaboration.* In this study, convergent positive and negative activating affect were triggered equally by task- and by socially-related factors. However, when the group members' affective states diverged in valence (i.e., group's affective state was mixed), social factors emerged as a trigger. That is, *social aspects of collaboration seem to play a vital role in the likelihood that the affective grounds of the group will diverge.*

Previously, Zschocke et al. (2016) studied individuals' group work appraisals in relation to emotions arising in the group work. They found that appraisals of the cognitive benefits of group work were a significant predictor of positive activating emotions. In turn, negative activating and deactivating affect were mostly

associated with task management and group assessment aspects (Zschocke et al., 2016). The task-related factors found also in this dissertation were mostly related to the task management or achievement, that is, monitoring and reflecting on the activity or outcome, or facing a challenge. It can be assumed that the shared goals and standards of the learning task prompted the students to make similar appraisals, which resulted in either positive or negative convergent emotional responses within the group (Gross, 2014; Winne & Hadwin, 2008). In turn, this study indicated that in terms of socially-related factors, the goals and standards might have been more various. When socially-related factors are interpreted, differences among the group members' social goals or priorities can result in conflicting views or experiences that produce further differences in group members' appraisals of the situation (Järvenoja & Järvelä, 2009). In this study, socially-related factors often involved squabbling between the group members. Squabbles can also stem from peer relationships and group dynamics, and for example lead to the exclusion or withdrawal of a group member (Barron, 2003; Näykki et al., 2014). Furthermore, emotional standards deriving from the cultural norms and social structures influence the students' views on how affect should be experienced and expressed in the group work situations (Lively & Weed, 2016). That is why affect triggered by those interactions might be expressed in more covert ways and, thus, be more difficult to interpret for other group members and not lead to emotional contagion in the group (Barsade et al., 2018; Duffy et al., 2015).

When the findings are considered in the light of other studies that view mixed affective states and social conflicts as particularly harmful for the groups' coordinated functioning and performance (Barsade & Gibson, 2012; De Dreu & Weingart, 2003), it might be concluded that the groups could benefit from support targeting especially the socio-emotional aspects of group learning. Currently, the instruments supporting students' regulation of learning focus mainly on cognitive aspects, neglecting the support for emotional and motivational aspects (Koivuniemi et al., 2021). This reveals the need to develop more support instruments targeting emotional aspects of learning. The results of this study suggest that support targeting socially-related aspects of group work could be particularly effective for supporting group members' emotional consistency as a foundation for learning together.

6.3 Interrelations between affective states and group-level regulation

The third empirical objective of this study was to investigate how affective states are interrelated with group-level regulation of learning. Overall, while the results indicated that group learning is very emotional, they also showed that group-level emotion regulation is an inherent part of groups' collaborative interactions (Järvenoja & Järvelä, 2013; Kwon et al., 2014). The results showed that *groups utilize emotion regulation not only to overcome negative and mixed affect but also to strengthen positive affect within the group*. This highlights the role of strategic emotion regulation as a part of the more general regulation of collaborative learning: It can be activated not only in relation to socio-emotional challenges, but also to create and maintain a positive socio-emotional atmosphere that also fosters regulation of cognitive learning processes (Isohätälä et al., 2018; Järvelä, Järvenoja, et al., 2016). If we broaden the scope from solely emotion regulation to regulation in collaborative learning in general, the results demonstrated how affective states can either facilitate or hinder group members' ability to regulate their learning together, but also how regulation of learning can change affective states as the learning situation changes. The results showcase the different functions of socio-emotional interaction and regulation in maintaining and restoring emotional grounds for collaboration: *Socio-emotional interaction can be sufficient to maintain positive affective states, but strategic regulation of learning is needed to address socio-emotional challenges before the negative and mixed states start accumulating* (Bakhtiar et al., 2018; Näykki et al., 2014). In terms of the interplay between SRL, CoRL, and SSRL, the results support the purposeful and agentic role of the individual learner, which is emphasized in SRL theories (for a review, see Panadero, 2017). For group-level regulation, this study implies that *if there is no personal need or awareness of the need for regulation, the student might not engage as actively in or be influenced by group-level regulation.*

Based on the results, the 6th and 7th grade students seem to have intermediate capabilities to regulate their emotions together in a group learning context. Although this study was performed with a relatively small sample size, and thus generalizable conclusions cannot be drawn, the results seem to reflect well the adolescents' developmental stage in terms of affect and regulation. Adolescents tend to have exaggerated responses to emotional situations, experience negative and mixed emotions more often, fluctuate more rapidly in their affective states, and social environments (like collaborative learning) in particular can be very emotion-

eliciting for them (Riediger & Klipker, 2014; Somerville, 2016). At their age they still have an intermediate regulatory capacity as the prefrontal cortex, which has a key function in emotion regulation, is continually developing (Somerville, 2016). In practice, although emotion regulation was present in the groups' collaborative interactions of this study, in line with the previous findings it was relatively rare (Järvenoja, Järvelä, & Malmberg, 2020): It was activated as a response only in a minority of negative and mixed affective states. This finding was also supported when longer episodes of socio-emotional interaction were explored. For example, in negative socio-emotional interaction episodes, negative affective states were recurring, but regulation was not commonly detected.

Although emotion regulation was not very common, it was discovered that particularly the group-level negative activated affective state seemed to trigger the groups to initiate regulation. This is in line with theoretical assumptions that for group-level regulation to emerge, there is a need for a challenge or trigger that invites the groups to initiate regulation (Hadwin et al., 2018). In contrast, this study showed that when negative states recurred, it seemed that groups' ability to initiate regulation was hindered. Previous studies have also shown that when negative interactions are recurring, they can hinder the group's ability to actualize regulation (Bakhtiar et al., 2018; Rogat & Adams-Wiggins, 2015). Only in a minority of the longer socio-emotional interaction episodes were the groups able to engage in frequent regulation when the negative states recurrently challenged their collaboration. Another challenging situation for initiating regulation seemed to be when the group-level affective state was mixed and did not include physiological emotional activation of group members. This supports the notion that mixed affective states among groups are, indeed, hampering the groups' coordinated efforts in learning situations, which is particularly required for group-level regulation to occur (Barsade & Knight, 2015; Hadwin et al., 2018; Isohätälä et al., 2017). These findings highlight that when studying the relations between affect and learning processes, it is not enough to consider only the negative or positive affective states within the group; there is also a need to recognize the (in)consistency between the group members' states.

The groups also actualized regulation in relation to positive affective states. Although this was not that common, it still demonstrates the nature of regulation targeted to emotions and motivation: It can be activated not only to restore, but also to maintain and strengthen the positive emotional and motivational grounds for collaboration (Järvenoja et al., 2019; Wolters, 2003). The results also showcase the role of recurrent positive socio-emotional interactions, which can be used to

maintain the already positive affective state; thus, strategic regulation targeting the affective state as such might not be frequently needed. Furthermore, when the socio-emotional atmosphere remains positive, it can facilitate group-level regulation when needed in the face of challenges (Bakhtiar et al., 2018; Rogat & Adams-Wiggins, 2015). This was demonstrated in the socio-emotional interaction episodes of occasional regulation where the groups were able to successfully activate regulation when their stable positive affective grounds were temporarily endangered by mixed states. However, sometimes positive affect, such as fooling around and having fun, may also distract collaborative learning processes and thus might need to be regulated to keep the focus on the learning task (Tomas et al., 2016).

The studies on emotion regulation in collaborative groups are still scarce. While this study contributes to this body of research, it posed a need to study emotion regulation emerging in groups in more detail to account also for the interconnections between individual and group processes. The results showed that group members' individual affective conditions are constantly intertwined with group-level learning processes. In particular, group members' individual affective responses serve as conditions for how they contribute to their groups' learning processes, which in this study comprised group-level emotion regulation situations (Törmänen et al., 2022). Moreover, the learning processes students engage in can cause different types of individual changes leading to diverse affective products (Lobczowski, 2020). For example, in this study regulation could change the students' unfavorable conditions for further collaboration, but this was not guaranteed. This is in line with previous findings that group-level regulation can change the negative valence of students' interaction, but regulation attempts do not always succeed (Mänty et al., 2020). In this study, the students' active role in group-level emotion regulation seemed to make a difference on how the students' states changed. Regulation seemed to be more influential if the need to regulate arose from the self-regulatory metacognitive awareness of the need for regulation, which prompted the student to initiate regulation (Haataja et al., 2022). This is in line with the findings of Mänty et al. (2022), which demonstrated the interplay of SRL and SSRL: Group-level emotion regulation often starts by individual group members sharing awareness of the emotional trigger to the group, and the shared awareness enables the initiation of SSRL. The findings of this dissertation also highlight the importance of timely and targeted co-regulation and its support of students' SRL (Bakhtiar & Hadwin, 2020; DiDonato, 2013): If the student was a target of CoRL, it often enabled the students to change their conditions for collaboration.

6.4 Detecting individuals' and groups' affective states during collaborative learning with video and electrodermal activity data

The methodological objective of this study was to explore how affect as a part collaborative learning can be investigated with different process-oriented measures. The dissertation targeted the two dimensions of affective states, namely valence and activation, and detected them using multichannel process data. In practice, this exploration was done by observing the emotional valence of group members' emotional expressions from video data and detecting emotional activation from sympathetic arousal tracked with EDA. Overall, this study confirms that *both emotional valence and activation are valid dimensions of group members' affective responses during collaboration and trackable during the authentic learning process. Capturing them by separate process data channels can provide further insights on individuals' and groups' emotional and regulatory processes during collaboration*.

In particular, the results showed that high physiological activation was more likely to emerge on a group level when the group members also showed visible emotional expressions in the video. However, as a separate affective dimension (Kuppens et al., 2013), activation alone could not reveal the valence of the expressed affect. This study provided preliminary evidence that emotional valence and activation are separate dimensions, which however when used together to categorize different kinds of affective states can be associated with the actualization of group-level regulation. The effect size particularly for the activation alone remained small, and thus to draw any proper conclusions it seems necessary to combine it with the dimension of valence. This is reasonable, though, and highlights that activation alone only indicates a physiological state and should not be considered to reveal a certain affective state without supplementation with other, more contextualized data sources (Eteläpelto et al., 2018; Järvelä, Malmberg, et al., 2021).

This study was one of the first to capture the dimensions of valence and activation with separate process-data channels in an authentic context. However, there is prior evidence provided for example by Eteläpelto et al. (2018) that studying emotional valence and activation through different emotional components and data channels can provide complementary information on emotions experienced during a learning process. When zooming in on the activation dimension alone, previous research has shown that regulation efforts and

subsequent changes in affective states or learning actions may be reflected in fluctuations in the physiological activation level (Matejka et al., 2013; Pizzie & Kraemer, 2021). In this study, this was demonstrated for example with high activation entropy (i.e., a high fluctuation in the physiological activation state of the groups), which occurred in the socio-emotional interaction episodes including frequent regulation. The interplay between emotional activation and regulation was also studied on an individual level, and the results supported the indications that were made based on the group-level analyses. First, if a student was in a physiologically activated state prior to regulation, they were more likely to contribute to the group's regulatory actions. Second, students' activated state most often remained after emotion regulation. In some cases, emotion regulation calmed students' arousal or led to an activated product of regulation if the student had not been activated before emotion regulation. This supports the notion that both increases and decreases in sympathetic arousal can reflect regulation processes (Kinner et al., 2017; Matejka et al., 2013).

However, it should be noted that the results of this study that were gained through several process analyses showcased that the associations between valence, activation, and regulation are by no means simple or linear and should not be studied as such. This naturally influences the methodological decisions as well as analysis methods used when combining other sources of data with physiological data. For example, in this study it was revealed that physiological activation can be triggered by various task- and socially-related factors that should be taken into account when studying the effects of arousal on learning and performance. When utilizing the new opportunities that multichannel process data together with advanced analysis methods can provide, it is important to properly consider the underlying theoretical perspectives behind the methodological choices (Azevedo & Gašević, 2019; Järvelä & Bannert, 2021; Järvenoja, Järvelä, et al., 2018; Winne, 2019). In this study, the dimensions of valence and activation derived from the theoretical standpoints of emotion research (Linnenbrink-Garcia et al., 2016; Pekrun, 2016a; Russell & Barrett, 1999), and they were operationalized for empirical research by acknowledging the multicomponent nature of emotional responses (Shuman & Scherer, 2014). Furthermore, the nature of the data channels aligned well with the process-oriented approach by providing process data quite unobtrusively and with commensurable granularity sizes (Järvenoja, Järvelä, et al., 2018; Järvenoja, Malmberg, et al., 2020).

When considering that the development of the theory has been traditionally based on static self-report measures, it is not surprising that challenges emerged

when observing and analyzing these two components in authentic learning contexts. For example, the physiological activation component was not always aligned with the student's expressive behavior: Group-level physiological activation could also occur without visible emotional expressions from the group members. Then again, this could be considered an advantage of multichannel process data as the complementary data channels can reveal such a misalignment between the different components and inform the development of the current theoretical understanding (Johnson & Onwuegbuzie, 2007). As another example, the qualitative analysis showed that relating high activation solely to experienced affect is not straightforward. In this study, it was particularly task-related factors that were more likely to trigger physiological activation with neutral valence. The most frequent task-related factors involved some type of monitoring and reflecting activities, which supports the assumption that the group-level analysis of EDA data might also reveal relevant cognitive learning processes such as shared monitoring events (Haataja et al., 2018, 2021; Taub et al., 2019).

To conclude, the results of this study encourage further exploration of how students' physiological activation can be utilized to understand the complexity of affective states and regulation in groups. When integrated with more contextualized data channels such as video, it may provide new insights into emotional and regulation processes in relation to the overall learning process (Horvers et al., 2021; Järvelä, Malmberg, et al., 2021). Based on this study, *the strength of the multimodal approach utilizing physiological data seems to be its potential to increase the level of explanation regarding the multifaceted role of affect in collaborative learning.* In this case, adding the physiological component of affect enabled us to reveal the temporal and changing markers of affect in relation to the regulation of learning that could not have been captured with other process measures. *The results encourage further research to explore how physiological measures can be utilized to understand the complexity of affect in SSRL* both on a micro-level, which was the focus of this study, but also on a more macro-level revealing the longitudinal trajectories of the groups' regulatory behavior in relation to the development of the socio-emotional atmosphere.

6.5 Limitations

Despite the many advantages of using multichannel data together with the process-oriented analytical approach, this dissertation has limitations that warrant discussion. First, the sample size in terms of the number of participants was

relatively small, and thus generalizable conclusions from the findings should be made with caution. The sample size was further limited due to poor quality EDA data from some students: Since the analyses were mostly performed on a group level, problems with only one individual's data excluded the whole group from the study. Given that this study collected data in authentic collaborative learning contexts and was one of the first to do so, some loss of the sensor data is understandable. Data loss has been documented also in prior research implementing physiological sensor measures in authentic learning contexts (e.g., Pijeira-Díaz et al., 2018). However, as the analysis of this study focused on moments and episodes within the groups' collaboration rather than for example comparing individual students' or groups' processes, in this sense the amount of final analysis units can be considered relatively high, despite data loss. Overall, the data included in the study enabled the reliable analysis of the selected groups with good data quality.

Second, since the exploration was mainly done on a group level, individual-level EDA data needed to be aggregated on a group level, which left more subtle changes in individual students' EDA mostly undisclosed. The same can also be said of the application of 30-s segments to integrate the EDA data with the video data coding. However, this was a necessary choice to find a commensurable granularity size for combining the two data channels. With the manual video coding, it was not reasonable to code valence using, for example, a second-by-second moving window. Furthermore, the traditional trough-to-peak method was used for the peak detection, which does not account for the superimposition of SCRs, and thus, may have caused an underestimation of the SCR amplitude (Benedek & Kaernbach, 2010). However, instead of amplitude this study used the frequency of NS-SCRs, which is not that much influenced by the superimposition.

Third, while video coding addressed the chosen variables of emotional valence and group-level regulation, ongoing learning activities related to the socio-emotional interaction episodes were not systematically explored; that is, group task progress during the socio-emotional interactions could only be assumed. Furthermore, although video data observations provide unique opportunities to capture the social as well as the temporally fluctuating nature of affect in the group work context, group members' own interpretations and reasons behind their behaviors remain unknown. This study focused on affect as expressed, which is a different focus compared to affect as an experienced feeling state (Jones et al., 2021). Still, combining these perspectives would have provided an even more

thorough picture of the relations between affect, regulation, and the collaborative learning process.

7 Conclusions

The findings of this study have many theoretical, empirical, and methodological implications, which will be discussed next. Furthermore, this dissertation contributes to the discussion about educational practices by highlighting the role of affect and emotional regulation as a part of students' learning skills, especially in the collaborative learning situations. Finally, directions for future research will be discussed.

7.1 Theoretical, empirical, and methodological implications

This study offers novel empirical evidence of the interconnections between affect and emotion regulation, contributing to the theoretical development of the SSRL framework (Hadwin et al., 2018). In particular, this study demonstrated the importance of conceptualizing affect in collaborative learning as a condition that sets the stage for learning and regulating together, but also as a product continuously reformed by students' learning activities and interactions (Bakhtiar et al., 2018; Hadwin et al., 2018; Winne & Hadwin, 1998, 2008). Furthermore, by exploring the interrelations between affective states and emotion regulation on a micro-level, this study brought together research on affect in academic contexts (Linnenbrink-Garcia et al., 2016; Pekrun et al., 2011) and SSRL (Hadwin et al., 2018; Järvelä, Malmberg, et al., 2021). By combining theoretically and empirically the dimension of valence and activation with the actualization of emotion regulation, this study produced new empirical evidence on the initiation of emotion regulation. Furthermore, it uncovered how individual students' active role in group-level regulation can make a difference in their continuing learning conditions. That is, SRL plays an important role for recognizing the situational need and initiating the regulation, but in order to reach the group-level contributions, building a shared awareness within the group is needed (Järvenoja et al., 2019; Mänty et al., 2022).

This dissertation took a novel approach in collaborative learning research by studying affect as a group-level phenomenon constituted in group members' socio-emotional interactions and setting a stage for SSRL. The findings align with the emerging overall trend in emotion research to study affect as more multifaceted and fluctuating within and between individual learners and groups (Goetz et al., 2016; Harley, 2015; Karamarkovich & Rutherford, 2021; Zembylas & Schutz, 2016). Moreover, this dissertation evidences that expanding the investigation from

individual-level to group-level affect can shed light on group members' shared conditions for SSRL.

Methodologically, this study contributed to developing and exploring the potential of multichannel process data in detecting affect and regulation in collaborative learning (Horvers et al., 2021; Noroozi et al., 2020). This study applied various process-oriented methods to analyze the multichannel data. In doing so, the study showcased the significance of understanding affect in learning as multi-componential and dimensional (Linnenbrink, 2007; Shuman & Scherer, 2014). It provides the field new insights in capturing especially the expressive and physiological components of affect during the learning process and thus contributes to the growing body of online process measures of affect (Azevedo et al., 2010; Harley, 2015; Horvers et al., 2021). Furthermore, when learning-related data is derived from multiple sources, analysis methods such as the multi-channel sequence mining used in this study can make a valuable contribution to our understanding of the multifaceted and dynamic nature of regulation. For example, recent implementations showcase the potential of for example MHMM for predicting individual students' trajectories or behavioral profiles (Helske & Helske, 2019); it has been utilized to identify students with different kinds of socio-emotional interaction profiles across a collaborative learning period, and to show how these profiles are related with the group-level process of SSRL (Törmänen et al., 2022).

To conclude, when studies utilizing multichannel data together with the process-oriented approach accumulate, they can offer new insights into changes in both emotional and cognitive processes, as well as how they intertwine during learning (Sharma & Giannakos, 2020; Taub et al., 2019). Furthermore, these types of methodologies can enable this investigation on micro- and macro-levels, but also from individual and group perspectives (Law et al., 2021; Molenaar & Järvelä, 2014; Törmänen et al., 2022). This dissertation deepened the understanding of how multichannel data together with novel analysis methods can be used to detect various kinds of states and episodes during collaboration that could for example indicate a need for regulation support. That is, these types of analyses methods could be used when developing adaptive technologies and artificial intelligence to give appropriate and proactive support for the groups' regulation (Järvelä, Kirschner, et al., 2016; Kwon, 2020; Lavoué et al., 2020).

7.2 Practical implications

Emotions are central to human life. As emotions set the conditions for our everyday life, they should not be undermined either in education. At best, they can facilitate our cognitive processing and learning, and create a foundation for our shared positive learning experiences and collaboration when externalized and regulated in socio-emotional interactions (Glazer, 2021; Järvelä, Järvenoja, et al., 2016; Kwon et al., 2014; Pekrun, 2016a). In this study, the SSRL framework offered a theoretical grounding to view affect as a part of the learning process (Hadwin et al., 2018; Winne & Hadwin, 1998, 2008). Affective states in learning are neither static nor unchangeable; instead, they can be regulated in many ways to facilitate the progress towards our learning goals (Harley, Pekrun, et al., 2019). Thus, emotion regulation can be considered an important skill that can be learned and practiced when facing emotional learning situations at school (Boekaerts & Pekrun, 2016; Harley, Pekrun, et al., 2019; Kurki et al., 2016). Emotion regulation is also the main mechanism for changing our affective conditions for life in general: It is a central socio-emotional skill that is needed to respond to everyday challenges (Gross, 2014; OECD, 2015). Socio-emotional skills play an important role for children's positive lifepaths and future working life success (Chernyshenko et al., 2018; OECD, 2015; World Economic Forum, 2016). The importance of these skills has been taken into account in the Finnish curriculum for basic education (Opetushallitus, 2016), which states that teachers should guide and support the development of students' emotion regulation skills. However, emotion regulation has not been systematically studied in an authentic elementary school context, which makes producing research-based knowledge on the topic highly important.

The findings of this dissertation can be utilized by teachers to better understand as well as support elementary school students' emotions and their regulation, and thus to manage emotional problems in the classroom and help their students to cope with emotional burdens. The results can also benefit learners themselves by helping them to become agentic, self-regulated learners who take responsibility for their own cognitive and emotional learning processes to guarantee motivation, coping, and well-being (Wolters, 2003; Zimmerman, 2002), but also to identify the moments where they need help and social support in managing them (Karabenick & Dembo, 2011; Nolen-Hoeksema & Aldao, 2011). This study showed that collaborative learning is a very emotional context, which makes it a great venue for students to practice their skills for emotion regulation, and for teachers to support these important, still developing skills (Somerville, 2016; Tolmie et al., 2010).

The results of this study align with arguments that to reach the full potential of collaborative learning, the students need more knowledge and support in how to apply appropriate emotion regulation strategies to overcome the socio-emotional challenges and enable the change in their learning conditions (Gross, 2014; Lobczowski et al., 2021; Wolters, 2003). The results also highlight the importance of increasing group members' awareness of affective states in the actual learning situation, especially at the beginning of the collaborative learning process, before socio-emotional issues begin to accumulate (Näykki et al., 2021; Reis et al., 2018). In addition to peers in the group, teachers have a key role as co-regulators of their students' emotions: When emotional challenges occur in everyday learning situations, teachers can provide support and guidance in how to apply appropriate emotion regulation strategies supporting the student's progress towards the learning goals (Kurki et al., 2016; Meyer & Turner, 2007; Silkenbeumer et al., 2018), but also guide the collaborative groups to jointly discuss and solve their emotional challenges together through SSRL (Järvenoja et al., 2019; Lobczowski et al., 2021). Moreover, based on this study and also indicated by prior research (Bakhtiar et al., 2018; Järvelä, Järvenoja, et al., 2016), recurrent positive affective states built up in socio-emotional interactions seem to facilitate the group's ability to maintain positive emotional grounds, but also to initiate regulation when needed in the face of challenges. Thus, supporting groups' ability to build a positive socio-emotional atmosphere at the beginning of their collaboration could also support their ability to regulate their learning across the collaboration process. In practice, this could be taken into account for example when supporting students' collaborative learning through scripting: In addition to the scripting of cognitive group learning processes, the scripts could also create a space for positive socio-emotional interaction between the group members to support group formation and cohesion, sense of belonginess, and mutual trust (Kreijns et al., 2003; Kwon et al., 2014; Miller & Hadwin, 2015; Näykki et al., 2021; Rojas et al., 2022).

However, it can be challenging for both teachers and students to recognize socio-emotionally critical episodes in everyday classroom learning, where with appropriate support, emotion regulation skills could be practiced and learned (Koivuniemi et al., 2018). This is especially the case when novel learning technologies offer alternative contexts for collaboration, some of which do not enable face-to-face interaction between students and teachers. In addition to the support provided by the teacher, novel learning technologies can be harnessed to provide co-regulatory support through for example awareness tools and prompts (Bodemer et al., 2018; Järvelä, Kirschner, et al., 2016; Kwon, 2020; Lavoué et al.,

2020). Thus, it can be argued that by providing information on the data channels and novel methodologies that can be harnessed to indicate the need for support, this research can also benefit educational technology developers. They can utilize the results deriving from the different indicators of multichannel data in designing more appropriate and adaptive support for learners and teachers, and as a result promote timely regulation. Finally, this study provides important information for policymakers and other experts in the field of education about the vital role of socio-emotional processes in learning and collaboration, which can be utilized when developing schools and curricula and providing further training for classroom teachers.

7.3 Future directions

Future research is needed to produce more systematic empirical evidence to advance the theories on how affect is constituted in a collaborative learning context and furthermore, how affect and emotion regulation play a role for SSRL both on a micro- and macro-level. Micro-level inspections would be needed to uncover 1) the different implicit and explicit as well as individual- and group-level processes in the formation of affect in collaborative groups as well as 2) the contribution of emotion regulation in the process of SSRL. That is, instead of studying emotion regulation as a separate process, it could be systematically studied as intertwined in the regulation of learning process. These investigations are needed to advance the theories considering the relations between socio-emotional and cognitive processes of collaboration and how individual and group levels interact within these processes. Furthermore, future studies utilizing multichannel data are needed to reveal 3) the relevant indicators, patterns, and combinations of the different data channels that can be linked to actualized regulation of learning, or alternatively, to signal the need for regulation support. This type of information would be needed especially when aiming to develop adaptive support systems with artificial intelligence that could offer timely support for the groups on the fly (Järvelä & Bannert, 2021; Law et al., 2021).

Macro-level investigations, in turn, are needed to track 4) the longitudinal trajectories in the formation of groups' socio-emotional atmosphere in relation to SSLR and 5) the longitudinal development of students' emotion regulation skills that would also account the group-level modes of regulation. This information would be needed when planning and implementing systematic support for the development of students' socio-emotional and collaboration skills throughout their

basic education (Weissberg et al., 2015). Systematic support will help to equip learners with the skills they need in the future to respond to and tackle the megatrend challenges together, as proactive and responsible citizens, who know how to reach the full potential of collaboration (OECD, 2022).

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Original publications

I Törmänen, T., Järvenoja, H., & Mänty, K. (2021). Exploring groups' affective states during collaborative learning: What triggers activating affect on a group level? *Educational Technology Research and Development, 69*, 2523–2545. https://doi.org/10.1007/s11423-021-10037-0

II Järvenoja, H., Törmänen, T., & Mänty, K. (2022). *Affective conditions for collaborative learning: When do groups engage in emotion regulation?* Manuscript submitted for publication.

III Törmänen, T., Järvenoja, H., & Mänty, K. (2021). All for one and one for all – How are students' affective states and group-level emotion regulation interconnected in collaborative learning? *International Journal of Educational Research, 109*(September), Article 101861. https://doi.org/10.1016/j.ijer.2021.101861

IV Törmänen, T., Järvenoja, H., Saqr, M., Malmberg, J., & Järvelä, S. (2022). Affective states and regulation of learning during socio-emotional interactions in secondary school collaborative groups. *British Journal of Educational Psychology,* 1–23. https://doi.org/10.1111/bjep.12525

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204. Saari, Maria Helena (2021) Animals as stakeholders in education : towards an educational reform for interspecies sustainability

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206. Moilanen, Antti (2022) Sivistys ja emansipaatio : sivistävä ja yhteiskuntakriittinen opetus kriittis-konstruktiivisessa didaktiikassa

207. Kekki, Minna-Kerttu (2022) Educational possibilities of media-based public discussion : a phenomenological-philosophical analysis of the givenness of others

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