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Social Regulation of Learning During Collaborative Inquiry Learning in Science: How does it emerge and what are its functions?

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Students' ability to regulate their learning is considered important for the quality of collaborative inquiry learning. However, there is still limited understanding about how students engage in social forms of regulation processes and what roles these regulatory processes may play during collaborative learning. The purpose of this study was to identify when and how co- and shared regulation of metacognitive, emotional and motivational processes emerge and function during collaborative inquiry learning in science. Two groups of three students (aged 12) from a private primary school in Turkey were videotaped during collaborative inquiry activities in a naturalistic classroom setting over a seven-week period, and the transcripts were analysed in order to identify their use of regulation processes. Moreover, this was combined with the analysis of stimulated-recall interviews with the student groups. Results indicated that co- and shared regulation processes were often initiated by particular events and played a crucial role in the success of students' collaborative inquiry learning. Co-regulation of metacognitive processes had the function of stimulating students to reflect upon and clarify their thinking, as well as facilitating the construction of new scientific understanding. Shared regulation of metacognitive processes helped students to build a shared understanding of the task, clarify and justify their shared perspective, and sustain the ongoing knowledge co-construction. Moreover, the use of shared emotional and motivational regulation was identified as important for sustaining reciprocal interactions and creating a positive socio-emotional atmosphere within the groups. In addition, the findings revealed links between the positive quality of group interactions and the emergence of co- and shared regulation of metacognitive processes. This study highlights the importance of fostering students' acquisition and use of regulation processes during collaborative inquiry learning.

Keywords: *Collaborative inquiry learning; Social regulation of learning; Knowledge co-construction*

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Introduction

Collaborative inquiry learning has received considerable attention in many science curricula around the world and is widely advocated for use in today's science classrooms. However, it is also commonly acknowledged that collaborative inquiry learning is a challenging process and does not happen automatically. Instead, recent research shows that a successful interaction that enables collaborative learning depends on a range of factors, including group composition (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010), relational and communication skills (Kutnick & Blatchford, 2014), as well as students' regulation of their individual and shared learning (Grau & Whitebread, 2012; Järvelä & Hadwin, 2013; Volet, Vauras, Khosa, & Iiskala, 2013). In this paper, which is based on a detailed study of students' self- and social regulation of learning during science activities, we examine when and how social forms of metacognitive, emotional and motivational regulation processes emerge and function during collaborative inquiry learning.

In collaborative inquiry learning, students are expected to explore scientific phenomena by utilising various inquiry processes (e.g. formulating scientific questions and hypotheses, collecting and interpreting data, constructing explanations) and collaborate in small groups in which they are encouraged to share and discuss plans, ideas, questions and explanations with each other by means of mutual interactions (Bell, Urhahne, Schanze, & Ploetzner, 2010). It is suggested that collaborative inquiry learning can have a positive impact on student learning and achievement, because it provides students with the opportunity to come across new ideas or ways of thinking, clarify and justify their perspectives, build on or refine one another's ideas by comparing multiple viewpoints, as well as co-construct new scientific knowledge (Gijlers & de Jong, 2013; Sampson & Clark, 2009).

Research shows that students do not always readily engage in the productive interactions necessary for effective collaboration, such as developing shared understanding of the task, negotiating multiple perspectives, or sharing and maintaining a joint focus of attention (Barron, 2003; Slof, Erkens, Kirschner, Jaspers, & Janssen, 2010). While collaborating with each other, students may also experience a variety of emotional and motivational challenges which can negatively influence a group's collaborative interactions and engagement (Järvenoja & Järvelä, 2009). Recent research has indicated that in order to achieve success in collaborative learning situations, it is important for students to engage in self and social forms of regulation of learning processes (i.e. self-regulation, co-regulation and shared regulation). In one recent study, for example, Järvelä et al. (2013) identified a positive relationship between Finnish university students' use of social regulation (e.g. planning, monitoring) and the degree of their collaborative success as measured by the quality of a collaborative product. In a study with upper elementary students (aged 10) from the USA, Rogat and Linnenbrink-Garcia (2011) found students' use of social regulation processes (i.e. (meta)cognitive planning and monitoring, and behavioural engagement) critical for achieving deeper mathematics understanding during collaborative learning tasks. Another study conducted with secondary school students showed that social regulation

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processes (i.e. planning the collaboration, monitoring and evaluations of the group process) predicted the performance of student groups in the context of a collaborative historical inquiry task (Janssen, Erkens, Kirschner, & Kanselaar, 2012).

In the current literature, detailed empirical evidence of the nature of social forms of regulation processes in collaborative learning situations is still scarce and insufficient, as the majority of previous work has focused only on students' self-regulation of learning (SRL) rather than also taking account of the importance of social aspects of regulation (Hadwin, Järvelä, & Miller, 2011). In particular, there has been limited research in relation to collaborative science inquiry learning. Although, some studies have examined how students' SRL processes (e.g. planning, monitoring) are related to their learning and achievement (e.g. Greene & Azevedo, 2009, Winters & Alexander, 2011) and how their regulatory processes could be supported during science inquiry learning (e.g. Ben-David & Zohar, 2009; Sandi-Urena, Cooper, & Stevens, 2011; Thomas, 2013), this research has mostly focused on students' metacognitive regulation from an individualistic perspective, while neglecting the emotional, motivational and social aspects of regulation of learning. Therefore, there is still limited understanding about how students engage in social forms of regulation processes and what roles these regulatory processes may play during collaborative science inquiry activities.

In the following two sections, we review existing literature on current theories and models of self- and social regulation of learning and then existing evidence of the emergence and function of regulation of learning before presenting the current study.

Conceptualisations of Self- and Social Regulation of Learning

SRL is perceived as playing a key role in influencing student learning and achievement in and beyond schools (Zimmerman & Schunk, 2011). It refers to an active, constructive process in which students intentionally set learning goals and then attempt to plan, monitor and regulate their cognitive, behavioural, emotional and motivational processes in the service of those goals in order to achieve optimal learning (Pintrich, 2004).

While the extant literature includes various conceptualisations and models of SRL, most of them characterise SRL as involving multiple components and phases (Butler, 2011). In particular, it is assumed that self-regulated learners have the potential to engage in continuous and concurrent regulation of metacognitive, emotional and motivational processes through following a series of phases (or processes) while performing the learning task. Across most models, metacognitive regulation is described as a recursive activity which usually involves planning, monitoring and evaluation processes. Regarding the foremost, students usually analyse the learning situation, set learning goals, create plans for the task and decide which learning strategies to utilise (Pintrich, 2004). Next, while implementing the plans and strategies, they engage in a monitoring process in which they become aware of and monitor their emerging understanding or progress towards goals or task standards (Pintrich, 2004; Winne & Hadwin, 2008). Further, the evaluation process involves the reaction and reflection of students on their content understanding and task performance in

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relation to the entire task (Pintrich, 2004). With regard to the regulation of emotional and motivational processes, students monitor their own level of motivation, feelings and emotions during their learning and, when necessary, apply a variety of strategies to purposefully control their motivational state or emotional experience in order to sustain their engagement, willingness and goal-oriented actions (Järvenoja & Järvenoja, 2009; Pintrich, 2004).

Earlier definitions conventionally portrayed and studied SRL as an individual process influenced by social context (see Zimmerman, 2012 for a review). However, drawing from a variety of theoretical perspectives (e.g. sociocognitive, sociocultural and situative), more recent research increasingly considers the regulation of learning also as a social process at the interpersonal level (Hadwin et al., 2011). In this regard, there is currently an emerging consensus among a number of researchers in the field that in collaborative learning situations, group members can engage in three types of regulation processes, namely self-regulation, co-regulation and (socially) shared regulation of learning (Chan, 2012; Grau & Whitebread, 2012; Hadwin et al., 2011; Volet et al., 2013). Thus, besides self-regulating their own metacognitive, emotional and motivational processes, group members can engage in co-regulation in which they guide, support, shape or influence one another's regulation of the learning process via momentary interpersonal interactions (Hadwin et al., 2011). In collaborative situations, for instance, a teacher or peer(s) can co-regulate the learning process of another student who may need assistance with some aspect of the learning task, or a student can request or prompt a teacher or peer(s) to co-regulate his/her own learning processes (Hadwin et al., 2011; Iiskala, Vauras, & Lehtinen, 2004; Whitebread et al., 2009). In each instance, the regulation process is shared between the student and other(s) (usually a more capable other), and is directed at influencing the student's cognitive, emotional or motivational processes in order to support and guide his/her learning.

Shared regulation of learning refers to the process by which multiple group members regulate their joint learning process in order to achieve a shared goal (Hadwin et al., 2011). It is described as collective regulation in which group members 'develop shared awareness of goals, progress and task toward co-constructed regulatory processes, thereby sharing regulation processes together as a collective process' (Järvelä & Järvenoja, 2011, p. 353). Shared regulation of learning occurs in collaborative learning situations and requires a high level of mutuality within the group, as it occurs and is expressed when multiple group members equally share and socially co-construct regulation processes towards a shared goal (Hadwin et al., 2011). Shared regulation of learning is seen as crucial for successful collaborative learning together with self- and co-regulation (Perry & Winne, 2013).

The literature increasingly acknowledges that self-, co- and shared regulation of learning processes (i.e. metacognitive, emotional and motivational) can occur simultaneously in a collaborative learning task, and hence it is important to take into consideration both social and individual aspects of regulation in order to obtain a comprehensive understanding of students' engagement and participation in the learning process (Chan, 2012; Järvelä & Hadwin, 2013; Volet et al., 2013).

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However, despite this recent increasing research interest and development of theory, the examination of self-, co- and shared regulation of learning in collaborative learning situations is still in its infancy (Iiskala, Vauras, Lehtinen, & Salonen, 2011; Järvelä & Hadwin, 2013). In particular, there is a lack of research that examines how co- and shared regulation processes emerge and function during collaborative learning activities.

Evidence of the Emergence and Function of Regulation of Learning

The few studies conducted recently have begun to suggest some of the factors that are important in the emergence and function of co- and shared regulation processes. For example, in one Australian study of university students' collaborative problem-solving activities, Volet, Summers, and Thurman (2009) investigated students' collaborative problem-solving activities and identified certain features of interactions (e.g. question-asking, tentativeness, background knowledge, shared positive emotions) as possible contributors to the emergence and maintenance of high-level socially shared metacognitive regulation. Rogat and Linnenbrink-Garcia (2011) investigated socially shared regulation processes in small groups of upper elementary students (aged 10) from the USA. Through qualitative analysis of videotaped observations of the student groups across a series of three collaborative mathematics tasks, the researchers identified positive socio-emotional interactions and collaboration within the groups as playing an important role in facilitating the groups' engagement in high-quality shared (meta)cognitive and behavioural regulation (Rogat & Linnenbrink-Garcia, 2011). Their findings also suggested links between the processes of planning, monitoring and behavioural engagement, and students' achievement of deeper mathematical understanding. Particularly, monitoring the group's content understanding was found to be crucial in terms of providing students with opportunities to receive feedback, support and explanation which promoted elaboration and revision to task responses (Rogat & Linnenbrink-Garcia, 2011). Iiskala et al. (2011) examined the focus and function of socially shared metacognitive regulation and their relations with Finnish primary school students' (aged 10) metacognitive experiences in the context of mathematical word-problem-solving activities. They identified that shared metacognitive regulation processes affected dyads' problem solving through (1) activating a new construct in line with the previous direction of problem solving (2) confirming the previous direction of the activity as correct or (3) slowing down, changing or stopping the direction of a dyad's previous activity (Iiskala et al., 2011). These third type effects were found most commonly in the more difficult tasks.

Moreover, some of the studies focused specifically on the regulation of emotional and motivational processes. For example, Järvenoja and Järvelä (2009) investigated how Finnish teacher education students regulated their emotions while learning collaboratively. Their findings showed that the students experienced different kinds of socio-emotional challenges during group learning, and engaged in self-, co- and shared regulation in order to control their emotions. In another study, of how

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college students jointly regulated group motivation during collaborative learning in an educational psychology class, Järvelä and Järvenoja (2011) found that student groups experienced a number of social challenges and subsequently activated a variety of shared motivational regulation strategies (such as social reinforcement, task structuring, socially shared goal-oriented talk, efficacy management) in order to increase or sustain the level of group motivation.

In summary, the previous studies discussed here provide evidence for the importance of co- and shared regulation of learning processes for collaborative learning and point to some of the features that may contribute to the emergence and maintenance of social forms of regulation processes. However, none of these studies focused on collaborative science inquiry learning which is under consideration in this paper. Furthermore, these studies focused on investigating metacognitive, emotional and motivational aspects of regulation separately, without paying attention to how different types of regulation processes may influence and interact with each other.

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Current Study

The study on which this paper is based aimed to explore self-, co- and shared regulation of metacognitive, emotional and motivational processes utilised by Turkish upper primary students in the context of collaborative science inquiry activities. The research questions guiding this study were:

(1) When and how do co- and shared regulation of metacognitive, emotional and motivational processes emerge in the context of collaborative science inquiry learning?
(2) In which ways do these regulation processes function and influence students' collaborative science inquiry learning?

This study extended the existing research on self and social forms of regulation in collaborative learning in several ways. First, unlike most previous research, we examined self-, co- and shared regulation of metacognitive, emotional and motivational processes simultaneously while occurring within a collaborative learning context. This allowed for us to examine influences and interactions among different types of regulation processes. Second, by providing a detailed analysis of the emergence and functions of co- and shared regulation of learning engaged in by students while learning collaboratively, this study aimed to further explicate social forms of regulation processes in collaborative learning settings. Third, in line with the recent calls for studying the regulation of learning as an ongoing dynamic and recursive process occurring in real time and real contexts (Butler, 2011), the case study explored self-, co- and shared regulation processes within a naturalistic classroom setting. This naturalistic setting together with the analyses of multiple sources of evidence and detailed description accounted for the credibility of the study (Creswell, 1998; Lincoln & Guba, 1985).

Methods

Participants and Setting

Two groups of three students (aged 12) belonging to a seventh grade class and their science teacher, Mrs Celin, from a private primary school located in the city centre of Ankara, Turkey, volunteered to participate in this study. In line with the purposeful sampling strategy, the student groups were selected from among eight groups in their class by the teacher using criteria that we decided upon together, including willingness to be video-recorded and interviewed, having good group work skills as well as good attendance of all members. Choosing students with good group work skills was necessary for the current study because our aim was to examine the emergence and function of social forms of regulation processes during collaborative inquiry tasks, and hence we wanted students who were more likely to engage in this activity. Both groups were self-formed and heterogeneous in terms of gender and science achievement level.

The students worked together in their groups throughout the first unit of the science and technology curriculum on human body systems. During this unit of 17 lessons over seven weeks the students studied three topics: the digestive system, the nervous system and the excretory system. Each topic began with an introductory session in which the teacher aimed to probe the students' preconceptions, and create interest and curiosity via a whole class discussion. Subsequently, the students engaged in collaborative activities, planned by the teacher, in which they carried out observations and investigated a set of inquiry questions collectively. According to the teacher, the group tasks were linked to students' everyday lives, encouraged seeking more than one answer or idea, and were designed to become progressively more difficult towards the end of the unit (see the Appendix for descriptions of each task). Following each collaborative session, the students participated in a whole class discussion where they were encouraged to explain and extend their understanding of the scientific concepts and topics. The data and analyses presented in this article focused on the collaborative activities of which there were five.

Data Collection Procedure

The student groups were observed and video-recorded (approximately 170 minutes of recording for each group) as they engaged in collaborative inquiry activities. In addition, stimulated-recall interviews were conducted with the student groups, using selected video clips (14 in total) that indicated metacognitive, emotional or motivational regulation processes based on our preliminary analysis, half way through and at the end of the data collection period. These sessions of 25–35 minutes were audio-recorded and transcribed. Students were asked open-ended questions such as 'OK, let's talk about what's happening here?', 'What were you thinking at this point?', 'How did you feel at that moment?'. The stimulated-recall interview data were triangulated with the video observations to enhance the credibility and validity of the data analysis. That is, eliciting students' own perceptions of their thinking, feelings and intentions during collaborative inquiry activities in their own words provided an

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opportunity to see if our interpretations of video observation data clearly reflected the participants' perspectives and actions.

Data Analysis

A multi-step analysis design was used to explore when and how social forms of metacognitive, emotional and motivational regulation processes emerged and functioned during collaborative inquiry learning (Table 1). The students' and teacher's verbal discourses were first transcribed verbatim and their nonverbal actions (e.g. eye contact, body language, hand speed, facial expression and tone of voice) were noted.

In Step 1, all the utterances and nonverbal actions were analysed through an iterative process to see if they constituted evidence of belonging to any a priori category of the initial scheme developed based on Pintrich's widely used conceptual framework of SRL (2004) and the schemes of Winters and Azevedo (2005) and Whitebread et al. (2009), or needed to be constituted into a new specific code. The coding schemes of Winters and Azevedo (2005) and Whitebread et al. (2009) were chosen as they were particularly relevant to our research questions because the former was developed for investigating students' regulation of their learning in a collaborative scientific inquiry context, and the latter was used to assess simultaneously both metacognitive and emotional and motivational regulation processes of pre-school students. Through reading the transcriptions and viewing the video recordings in these iterative cycles, we identified incidents which indicated evidence for metacognitive, emotional and motivational regulation processes and then tested and refined the codes into the final coding scheme (Table 2). The coding scheme included two main categories (1) metacognitive and (2) emotional and motivational regulation, and several sub-categories. Table 2 presents descriptions of each of the categories together with examples from the data. Given that self and social forms of regulation of learning processes (i.e. metacognitive, emotional and motivational) can occur simultaneously in a collaborative learning situation (Järvelä & Hadwin, 2013), in order to have a comprehensive analysis of data, the categories of this coding scheme were neither mutually exclusive (more than one code could be associated with a particular utterance(s) and/or nonverbal action(s)) nor exhaustive (there was no code for every utterance and nonverbal action in the video data) (see Bakeman & Gottman, 1997).

For the second analysis step we examined the focus of each regulatory utterance and nonverbal action within the sequence of an interaction based on previous coding schemes (Iiskala et al., 2011; Whitebread et al., 2009) (Table 3). Here the unit of analysis was at the episodic level, since co- and shared regulation of learning always comprised at least two turns or more.

The third step examined students' own perspectives (Table 1). In Step 4 we analysed all the co- and shared regulation episodes thematically based on approaches by Braun and Clarke (2006) and Volet et al. (2009) by first identifying and describing the utterance(s) and/or nonverbal action(s) which appeared to be the initiating moment of each social form of regulation episode. We also described the features of group interactions which appeared to be associated with the emergence of co- and

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Table 1. Outline of a multi-step analysis

Step	Purpose	Analysis approach	Unit of analysis	Data
1	Identify and characterise incidents that indicated evidence of regulation processes	Utilising a coding scheme derived from Pintrich's (2004) conceptual framework of SRL and the coding schemes of Winters and Azevedo (2005) and Whitebread et al. (2009)	Turns (i.e. an utterance(s) and/or nonverbal action(s))	Transcripts and video recordings (2,347 turns in total)
2	Identify and analyse episodes indicating a self-, co- or shared focus of the regulation processes	Utilising a coding scheme derived from operational definitions used by Iiskala et al. (2004, 2011) and Whitebread et al. (2009)	Episodes	Transcripts and video recordings (informed by field notes, student worksheets and lesson plans)
3	Identify and analyse students' reflections and interpretations, which were indicative of their regulation processes	Utilising the categories of the coding schemes used in Step 1 and Step 2	Turns (i.e. an utterance(s)) and episodes	Students' responses (275 turns) from the stimulated-recall interviews
4	Explore how and when co- and shared regulation of learning processes emerged	Thematic analysis: (1) Inductive coding to identify and describe the utterance (s) and/or nonverbal action(s) which initiated each social form of regulation episode (2) Sorting and analysing emerging codes into themes, reviewing and refining	Episodes	Co- and shared regulation episodes
5	Explore the functions of co- and shared regulation of learning processes	Describing how the social forms of regulation episodes influenced or played a role in students' collaborative learning process	Episodes	Co- and shared regulation episodes

Table 2. Coding scheme for the students' regulation of learning processes

Categories and sub-categories	Description of behaviour	Examples
Metacognitive regulation		
Planning		
Any utterance, nonverbal action, interpretations and/or appraisals concerning the understanding of task goals or the procedural aspects of the task (MP)	Setting goals or subgoals in relation to the task (GS)[a]	L: Now, we will write about the journey of these nutrients in our body and explain in which sections of the digestive system they are digested chemically as well as physically. So, should we write a story for this activity or explain everything separately (*looking at her partners*)? (PT)
	Clarifying and coordinating conditions about the task (CC)[b]	Ay: Let's look at this diagram too.
	Asking or deciding on how to proceed with the task (PT)[b]	L: OK.
	Assigning individual roles or negotiating responsibilities concerning the task (AN)[b]	K: Can I, can I explain this one? Ay: Yes, go ahead. (AN)
Monitoring		
Any utterance, nonverbal action, interpretations and/or appraisals associated with the ongoing assessment of understanding of the task content or actual performance of the task (MM)	Making an assessment or judgement of own or other's or their mutual understanding or learning (AU)[a]	'B: But, I am not sure if it is going to the brain' (AU)
	Monitoring actual progress to assess if any learning goal has been achieved (MAP)[c]	E: Now, we have answered only one question. We have explained the duty of the pituitary gland and so on. V: OK, let's look at the next question (MAP)
	Asking a question in order to check, assess or improve the level of understanding or learning (QfU)[c]	B: Are you sure that this [explanation] is true (*speaks with an uncertain voice tone*)? (QfU)
	Realising a mistake or misjudgement made by him/herself or as a group (SC)[c]	K: Sorry, I put this arrow into a wrong place. (SC)
Evaluation		
Any utterance, nonverbal action, interpretations and/or appraisals related to reviewing overall learning process and outcomes, usually towards the end of task completion (ME)	Reviewing the group's overall learning process or progress (RLP)[b]	'L: Now, let's talk from the beginning (*glances at her partners*). For the first question, we suggested three types of events, for which we can give different examples when considering our daily lives' (RLP)

Emotional and motivational regulation		
Monitoring		
Any utterance, nonverbal action, interpretations and/or appraisals related to the assessment of current motivational and emotional states during the task (EMM)	Expressing awareness of own or his/her negative emotional experience, such as annoyance, embarrassment, boredom (AE)[b]	'B: Actually (*looking at the partners*), I have had a lot of questions at the beginning, but I have learnt almost everything. Now, I don't really wonder about anything.' (Expression of lack of interest—AM)
	Expressing awareness of own or his/her motivational experiences, such as enthusiasm, lack of interest, wonder (AM)[a]	'V: Oof, Brus! We cannot read the question because of you (*looks with a frowning face*)' (Expression of boredom—AE)
Control		
Any utterance, nonverbal action, interpretations and/or appraisals associated with the regulation and control of emotional and motivational experiences during the task (EMC)	Encouraging him/herself or others or the group (EH)[a]	'T: Why don't you discuss with each other, I think you can find the answer yourself.' (EH)
	Controlling attention (CA)[b]	'B: A really nice explanation (*speaks to Ezgi*)' (PC)
	Praising or giving compliments (PC)[d]	T: But we are talking about systems not cells.
	Attention shifting (AS)[d]	K: Yes, right, skeleton system (*looks confused and displeased. He touches his chin with his left hand and puts his pen into his mouth*).
	Promoting a sense of tolerance and respect within the group (PTR)[d]	T: (*she leaves the group*)
	Interest enhancement (IE)[c]	K: So, which one is performing the mental events (*turns back and checks if the teacher is still listening to them*)? (AS)

[a]Pintrich (2004).
[b]Whitebread et al. (2009).
[c]Winters and Azevedo (2005).
[d]Derived from our data.

Table 3. Coding scheme for the focus of regulation processes

Categories	Definitions
Self-regulation	An episode was considered as self-regulation when a student regulated their own learning process, without any clear intention of influencing others' metacognition, motivation or emotion. This form of regulation was always specific to one student and located only in this student's turn. Such an episode usually comprised a single turn *Example*: V: One second, but I still don't understand the previous question. (AU—Self-regulation)
Co-regulation	Co-regulation represented episodes in which the regulation processes aimed at influencing other's metacognition, motivation or emotion in order to assist and guide his/her learning. This interpersonal interaction was always in an asymmetrical form in which an unbalanced contribution and low-level reciprocity in the dialogue was visible among the students (and teacher). This type of episode usually started with a student or teacher's utterance or nonverbal action which appeared to be the initiating point for co-regulation and finished with another turn that indicated its end *Example*: T: Are you sure that the oxygen is burnt? It [*oxygen*] must be a caustic substance … (AU—Co-regulation)
Shared regulation	An episode was classified as shared regulation when multiple students regulated their collective activity in order to achieve a shared goal. In this type of episode, at least two group members' balanced regulatory involvement was essential, as they had to regulate jointly the group's metacognitive, motivational or emotional processes towards a shared goal with a high level of reciprocity. This type of episode always began with a turn which appeared to be the starting point of the group's collective regulation and finished with another turn in which the joint regulation ended *Example*: E: But let's think together, let's force our imagination. And the most interesting questions always come from Vural, let's first listen to him. He may stimulate our mind too … (EH—Shared regulation)

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shared regulation processes. We started this coding process inductively and then sorted codes into potential themes. We then reviewed and refined all the themes by checking them in relation to all the coded episodes as well as the entire data set (see Table 5 for the list of themes). Step 5 explored the functions of co- and shared regulation of learning by identifying and describing how the social forms of regulation episodes influenced or played a role in students' collaborative inquiry learning process.

Inter-Coder Agreement

In order to reduce the risk of bias, created by dependence on one researcher, and thus enhance the reliability of the data analysis, another researcher coded independently 15% of the transcribed video data by using the two coding schemes explained above. Since these coding schemes were not exhaustive, this process was carried out in two phases in line with the recommendation of Bakeman and Gottman (1997)

and the procedure utilised by Whitebread et al. (2009). During the first phase, agreement on unitising was sought (i.e. agreement about which utterance and/or nonverbal action should constitute a unit of coding in the selected data). The second phase involved the calculation of absolute levels of agreement (i.e. agreement about which categories of the coding schemes should be ascribed to the agreed units of coding). Regarding the level of unitising, we reached 63% agreement, a value which is considered acceptable for this type of study involving categories that include higher levels of inference (Bakeman & Gottman, 1997). For the application of the first coding scheme the percentage of absolute agreement was 90% (Cohen's Kappa = 0.86). Additionally, we achieved an acceptable Cohen's Kappa coefficient on the sub-category level apart from the evaluation category[1] (Planning, $K = 1$; Monitoring, $K = 0.9$; Evaluation, $K = 0$; Monitoring (emotional and motivational), $K = 0.72$; Control, $K = 0.84$). For the second coding scheme, the percentage of absolute agreement was found to be 89% (Cohen's Kappa = 0.76), and satisfactory Cohen's Kappa coefficients were achieved on the sub-category levels (Self-regulation, $K = 0.68$; Co-regulation, $K = 0.89$; Shared regulation, $K = 0.74$).

Results

Our analysis provided evidence of self-, co- and shared regulation of learning engaged in during collaborative inquiry activities. Table 4 shows the variation across the regulation categories of the different forms of regulation processes. During planning, the students in both groups mostly engaged in co- and shared planning episodes, while no clear evidence of self-regulation processes was identified. The students in both groups engaged in all three forms of metacognitive monitoring regulation, while for the evaluation category, only a few shared regulation episodes were identified. In terms of emotional and motivational regulation, our analysis only showed evidence of self- and shared monitoring and control processes. In the following sections, we explore the emergence and functions of each social form of regulation processes identified within our analysis along with illustrative example episodes.

Co-regulation of Metacognitive Processes

Our thematic analysis showed that co-regulation of metacognitive processes commonly emerged when the group members (a) articulated a misconception or (b) made explicit their lack of understanding (Table 5). During these episodes, the students either requested or received assistance or guidance from their partners or the teacher while externalising their perspectives and opinions to each other by means of a variety of types of questions, prompts and explanations. In most cases, the co-regulation processes had the function of stimulating the group members to reflect upon and clarify their thinking as well as facilitating the construction of new scientific understanding by enabling them to modify their initial conceptions.

Also, the analysis indicated that the students in both groups usually were supportive and respectful of one another in almost all the co-regulation episodes, politely asking

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Table 4. Frequency of use of regulation episodes across the student groups

	Group A			Group B		
	Self-regulation	Co-regulation	Shared regulation	Self-regulation	Co-regulation	Shared regulation
Metacognitive regulation						
Planning	–	3	22	–	2	25
Monitoring	30	12	31	29	8	33
Evaluation	–	–	4	–	–	–
Emotional and motivational regulation						
Monitoring	6	–	4	5	–	5
Control	3	–	7	3	–	8

Note: The frequencies shown in this table are a count of regulation episodes and do not refer to a measure of time spent on each type of regulation.

Table 5. Frequency and percentages of occurrence of the themes regarding the emergence of social forms of regulation

		Group A		Group B	
Type of regulation episodes	Themes	(*F*)	(%)	(*F*)	(%)
Co-regulation of metacognitive processes	Articulating a misconception	3	20	2	20
	Making explicit his/her lack of understanding	6	40	2	20
Shared metacognitive regulation processes	Experiencing conflicting viewpoints	8	14	4	6.9
	Expressing tentativeness concerning the group's shared idea	3	5.3	5	8.6
	Seeking consensus about a conceptual idea or a shared plan	12	21	11	19
Shared emotional and motivational regulation processes	Experiencing different priorities in relation to the task	0	0	2	15.4
	Failing to reach a consensus on a shared understanding	1	9.1	2	15.4
	Displaying disruptive behaviour during the activity	3	27.3	0	0

Note: The frequencies and corresponding percentages are out of the total number of each social form of regulation episodes.

for or responding to help, listening to each other's ideas attentively and mostly making eye contact. This positive quality of group interactions appeared to contribute to the emergence of co-regulation processes by creating a positive social climate in which the group members usually seemed to feel comfortable in monitoring their partner's comprehension or requesting an assessment of their own understanding from their partners or teacher.

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The following episode from the 'poisonous plant' small-group activity exemplifies an episode of co-regulation initiated due to articulation of a misconception (Table 6). In this activity, the students watched a three-minute video clip about children playing football and noted down their observations regarding the neural events happening in the goalkeeper's nervous system. In Episode 1 (below), Group B is trying to identify the responses created by the nervous system while playing football by discussing their observations. At the beginning of this episode, Ezgi reads the inquiry question out aloud (turn 1) and Brus states his opinion which reveals his misconception about the conditioned reflex (turn 2). Next, Ezgi glances at Brus with raised eyebrows and challenges his misconception, which prompts Brus to reconsider his initial idea (turns 3 and 5). Then, in turn 6, Brus shows that he has become aware of his misunderstanding and puts forward a new idea in the form of an implied question in which he requests a judgement of his current understanding from his peers. In response, Ezgi glances at Brus again and affirms his perspective (turn 7). Towards the end of the episode, after Brus completes his explanation, Ezgi and Vural provide a judgement regarding his understanding by elaborating upon his idea (turns 9 and 10).

In this episode, Brus made explicit his misconception while externalising his thinking. This led to a co-regulation process by which Ezgi and Vural assisted Brus in clarifying his misconception and constructing a new scientific understanding. During this

Table 6. Episode 1—small-group activity 4 (Group B)

Turns	Transcript	Regulation	Focus
1	E (female): 'What are the events which the child's nervous system creates responses to during the match?' (*reads the question*)		Co-regulation and MM
2	B (male): Responses nervous system creates, which means only the conditioned reflexes (*looks at his partners*)		
3	E: I think (*glances at B with raised eye brows*), the responses created by the nervous system means that it can be any response to any event, not just the conditioned reflex	AU	
4	B: What (*gazes at E with a confused look*)?		
5	E: Something like for instance, any response the brain creates (*glances at B*)	AU	
6	B: Oh, yeah. Um (*thinking for a second*), it is like a player's reaction to the ball (*his tone of voice indicates indirect questioning*)?	QfU	
7	E: Yes, as a goalkeeper (*glances at B*)	AU	
8	B: When he misses the ball, the brain tells him to take the ball (*looking at his partners*)		
9	E: Yes, so this is a response which the brain is involved in (*writing*)	AU	
10	V (male): Yes, this can be one of the responses	AU	

Note: All the names used in this paper are pseudonyms. AU, assessment of understanding or learning; QfU, questioning to assess the level of understanding or learning and MM, metacognitive monitoring.

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asymmetrical interaction, they monitored Brus's understanding and responded coherently to changes in his thinking (turns 3, 5, 7, 9 and 10). Supportive interactions were also visible in this episode in the form of the group members mutually respecting and listening attentively to each other by making eye contact, paying close attention and responding to ideas put forward.

Shared Regulation of Metacognitive Processes

Three themes that emerged from the analysis of data show that shared regulation of metacognitive processes were commonly initiated when the students (a) experienced conflicting viewpoints, (b) expressed tentativeness or uncertainty concerning their ideas or (c) sought consensus about a new conceptual idea or a shared plan within the group (Table 5). The shared regulation processes always influenced the flow of group discussion. Shared planning processes played an important role in building a shared understanding of the task among the group members, while shared monitoring processes usually facilitated and simultaneously occurred during the knowledge co-construction process within the groups. In particular, our analysis suggested that the shared monitoring processes stimulated the students to reflect on, clarify and justify their shared understanding, as well as sustaining the ongoing co-construction of knowledge by enabling a continual co-elaboration and expansion of ideas during the group discussion. In addition, in a few instances, some of the shared monitoring processes also slowed down the continuation of the ongoing group discussion especially when the group members experienced divergent ideas.

Moreover, similar to the co-regulation episodes, our analysis showed evidence of the positive quality of group interactions in almost all the shared regulation episodes, with the groups creating an inclusive space for discussion and group cohesion by taking into consideration each other's perspectives, listening attentively and constructively responding to ideas shared, showing mutual participation and remaining open to negotiating their mutual understanding via elaborations, justifications and questions. These features of group interactions played a key role in supporting and sustaining the emergence of shared regulation of metacognitive processes. For instance, their mutual respect and habit of listening attentively to each other appeared to support their confidence in articulating ideas, as well as monitoring and negotiating their mutual understanding. Even in cases of emergence of conflicting ideas within the group, the positive aspects of students' interactions supported and sustained the ongoing dialogue and shared regulation process.

Episode 2 (Table 7) from the 'poisonous plant' small-group activity exemplifies a shared regulation episode which emerged after the group members experienced conflicting viewpoints. At the beginning, the group members are sharing ideas about how the nervous system functions while a goalkeeper attempts to catch a ball and Kutay presents his view about which neurons are stimulated during this incident (turn 4). Next, Leman glances at Kutay and expresses disagreement with him by suggesting an opposing idea (turn 5). Subsequently, while the latter attempts to clarify his perspective (turn 6), the former insists on her claim and challenges him by asking for

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justification of his standpoint (turn 7). In response, Ayse and Kutay provide a rationale for their perspective (turns 8 and 9), but Leman remains unconvinced and asks them another question (turn 10). In response, Kutay stands up and elaborates upon their perspective by using his body language (turn 11), which Ayse affirms and builds on (turn12). Next, following these elaborations, Leman remains silent, and Ayse asks her group to reflect on what they have been discussing (turn14). Subsequently, Kutay paraphrases their joint idea and seeks agreement from his partners (turn 15). Then, Leman and Ayse express agreement with him and the group continues to share and co-elaborate upon their ideas (turns 16–20).

As this dialogue reveals, after experiencing conflicting ideas, the students assessed and negotiated the group's mutual understanding which facilitated the knowledge co-construction process. During this process, the students shared ideas and prompted each other to justify and clarify their understanding, which is evidence of a shared metacognitive process. For example, in turns 5–12, after recognising there were conflicting ideas, the group members prompted each other to reflect on their ideas through statements and questions, which indicates a shared monitoring process. Furthermore, in turns 14–17, they checked and assessed their shared understanding through a shared monitoring process. During these symmetrical interactions, they were able to build a consensus on a mutual understanding within their group which then sustained the knowledge co-construction process. Positive and supportive interactions were also apparent in this episode, where the members of Group A showed mutual respect, listened to each other attentively and constructively responded to the ideas shared with a sense of mutual purpose. Thus our analysis suggested that these features of interactions played a role in sustaining and facilitating the dialogue among the students and their shared metacognitive processes.

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Shared Emotional and Motivational Regulation

Our analysis showed that shared regulation of emotional and motivational processes often emerged when the group members (a) experienced different priorities in relation to the inquiry task, (b) failed to reach a consensus on a shared understanding or (c) displayed disruptive behaviour during the activity (Table 5). There was also evidence of links between self- and shared regulation of emotional and motivational processes. In some instances, the analysis suggested that shared regulation processes emerged due to an emotional and motivational self-regulation engaged in by an individual group member. Moreover, in a few cases, co- and shared regulation of metacognitive processes engaged in by Group A were observed to activate a negative emotional reaction within the group which then led its members to engage in a shared emotional and motivational control process.

During the shared regulation episodes, the students expressed awareness of a negative emotional (e.g. annoyance, embarrassment, boredom or disappointment) or motivational (e.g. lack of interest or wonder towards the task, facing distraction while engaging with the task) experience, and controlled their shared emotional and motivational states collectively by using a variety of strategies, such as controlling attention,

Table 7. Episode 2—small-group activity four (Group A)

Turns	Transcript	Regulation	Focus
1	Ay (female): The ball comes and he sees where the ball is going. Here (*pointing at the nervous system diagram*), the message goes to the brain and the brain responds through the nerves		Shared regulation and MM
2	L (female): The nerves go to the legs		
3	Ay: They stimulate the muscles		
4	K (male): I think it's like this. It [message] first comes from our eyes to the brain, then from the brain to the cerebellum (*explaining on the diagram*), the spinal bulb, the spinal cord and all of the neurons in the whole body		
5	L: OK, but it doesn't have to go to all of the neurons (*glances at K*)	AU	
6	K: It [message] needs to go to all of the neurons (*glances at L*), because he cannot know where the ball is going	AU	
7	L: It is enough if it only goes to the legs. Why should it also go to the hands (*raises her eye brows*)?	QfU	
8	Ay: Because he is the goalkeeper		
9	K: Perhaps, he is going to react to the ball with his hands if it comes from up high (*using a hand gesture*)		
10	L: Well, OK, but in the video, isn't the ball going to his feet (*looks at her partners*)?	QfU	
11	K: Look, he gets into position like this in the middle of the goal (*stands up and uses body language pretending like a goalkeeper*). So taking this position means that he is ready for everything		
12	Ay: Yes, that means the brain sends a message to everywhere in the body	AU	
13	L: (*Thinking without responding*)		
14	Ay: Now, let's start from the beginning (*looks at her partners*)	MAP	
15	K: OK, so it [neural message] is sent to the whole body by the brain and then when the ball comes, the relevant organ responds (*explaining by using the diagram*). Is that OK (*glances at his partners*)?	QfU	
16	Ay: Yes (*nodding*)	AU	
17	L: Yes, then, he cannot keep the ball and the ball goes near the poisonous plant. When he touches the poisonous plant	AU	
18	Ay: When touching		
19	L: When he touches it, the needle is broken		
20	Ay: Poisoned toxins make contact with his hand. So, he is stimulated here immediately		

Notes: AU, assessment of understanding or learning; QfU, questioning to assess the level of understanding or learning; MAP, monitoring actual progress; and MM, metacognitive monitoring.

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promoting a sense of tolerance and respect within the group, and encouraging or giving compliments to each other. These shared regulation processes were identified as crucial for effective group functioning. In most cases, they played an important role in sustaining reciprocal interactions among the group members, increasing group motivation and cohesion as well as creating and sustaining a positive socio-emotional atmosphere of the groups.

An example of a shared regulation process is illustrated in Episode 3 (Table 8) taken from the 'football match' small-group activity. Prior to this episode, while Group A engaged in a shared metacognitive monitoring process in which they negotiated each other's perspectives of the events occurring around and inside a footballer's body, the discussion was ineffective in terms of building a consensus on a shared understanding due to the contradictory ideas expressed by the group members. In the beginning of this episode, after Kutay asks his partners to move to the next inquiry question, Leman disagrees with him and attempts to revise what they have previously discussed (turns 1–2). While taking notes in relation to their discussion, Kutay looks confused about a word written in Leman's notebook and asks if it is neural or digestive (turn 4). At this point, Leman replies to Kutay's question in an unkind way, while her tone of voice and gesture also suggest an expression of boredom (turn 5) and her reaction challenges the positive emotional atmosphere of the group. After this incident, Kutay attempts to defend the necessity of asking his question with a negative facial expression and tone of voice which indicates his awareness of a negative emotional experience (turns 6 and 8). Next, Leman points out how inappropriate Kutay's question is, as he must know that 'neural' is the word written in her notebook as they are currently working on the nervous system (turn 9). However, Kutay teases Leman by claiming that she has mistakenly written 'neural' instead of 'reflex' (turn 10). He also tries to provide a justification for his claim in response to Ayse's question (turn 12).

In the second half of this episode, the socio-emotional challenge the group is facing also triggers another challenge within the group. That is, while staring at Kutay with a sad face, Leman reminds her partners that still none of them has a clear idea of the correct answer and also points out the complexity of the inquiry question (turn 13). Next, Kutay stares at Leman with a negative facial expression and makes a critical comment about her perceived status within the group (turn 14). Then, both Leman and Kutay engage in an argument which leads to them deciding to study independently from each other (turns 15–18). At this point, Ayse reminds Leman that they are studying collaboratively as a group where they should acknowledge the significance of the ideas that each of them puts forward (turns 19 and 21). Ayse's reaction can be seen as a process of controlling the group's emotional and motivational states. After this, Kutay and Leman also try to explain how they value each other's ideas too, joining Ayse in controlling their negative emotions (turns 22–23). In the end, Leman attempts to encourage her group to engage in the task again, which slowly results in the restoration of a positive learning atmosphere in the group. Following this episode, Group A carried on with their discussion, while Kutay showed less participation, but only for a short time.

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Table 8. Episode 3—small-group activity three (Group A)

Turns	Transcript	Regulation	Focus
1	K: Should we look at the next question?		Shared regulation and EMC
2	L: No, Kutay (*with a loud sound*). Now, we have talked about three types of events, neural, physical and mental		
3	All: (*continue to take notes*)		
4	K: But, um, what is this [word], neural or digestive? (*pointing at Leman's notebook while looking confused*) {*In Turkish, 'sindirim' means digestive and 'sinirsel' means neural, so the initial letters of these words are the same and hence could be confused*}		
5	L: Don't be silly, Kutay! (*taking a deep breath while leaning back and forward and speaking in a bored tone of voice*)	AE	
6	K: Leman, I can't read it! (*eyebrows are lowered and the pitch of his voice rises while leaning back away from the desk*)	AE	
7	L: How can it be '*digestive*'? (*stares at Kutay*)		
8	K: But it starts with an 'S', what else can it be? (*looks upset*)	AE	
9	L: Of course it is '*neural*', we are working on the nervous system now (*speaking in a bored tone of voice*).	AE	
10	K: There is no such thing as neural, it is called reflex (*looks at both Leman and Ayse with a sad facial expression*).	AE	
11	Ay: Neural? Are we really going to say neural is reflex (*confused look*)?		
12	K: Yes, you will write reflex. Look, Leman, when we think about neural events, we refer to the nervous system, but only reflex is involved here (*staring at Leman with a negative frowning expression and playing with his pen constantly*)	AS	
13	L: Kutay, at the moment, none of us know the correct answer, anyway (*looks at K and speaks with a furious tone of voice*)	AE	
14	K: OK, Leman, humph! You are always the right one, anyway (*raises his shoulders while looking at his notebook and speaking in a low tone of voice*) (*glances at L*)	AE	
15	L: I want to do this way (*stares at K*)		
16	K: OK, I want to do my own way too *(pointing at his notebook*)		
17	L: So, don't interfere with me (*starts writing*)		
18	K: OK (*looks very upset*)	AE	
19	Ay: Leman, but we are working as a group (*looks at L and speaks in a calm tone of voice*)	PTR	

(*Continued*)

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Table 8. Continued

Turns	Transcript	Regulation	Focus
20	L: Ok, but didn't we agree on neural events at the beginning? (*speaks in a calm tone of voice*)		
21	Ay: But Kutay is also talking about reflex too. I am writing his idea in parenthesis now	PTR	
22	K: I am writing it in parenthesis too (*speaks in a calm tone of voice*) (*writing*)	PTR	
23	L: When I say neural events, I also think about reflex. That's why I have said so (*looking at K*)		
24	L: (*After a few seconds of silence*) let's give an example for mental events too (*looking at Ay*)	EH	
25	Ay: Something like defending. Can we call it mental?		
26	K + L: (*no response from either of them*)		
27	L: Should we read the next question?		
28	Ay: Yeah		

Notes: AE, expressing awareness of a negative emotional experience; AS, attention shifting; PTR, promoting a sense of tolerance and respect within the group; EH, encouraging him/herself or others or the group; and EMC, control of emotional or motivational experience.

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The stimulated-recall group interview also presents evidence supporting this interpretation through revealing how and why the negative emotional experiences emerged as a result of the students' reciprocal interactions, and the ways in which they attempted to socially regulate them in order to maintain their level of motivated engagement with the group work high (Table 9). When asked to reflect on what happened during this incident, Leman explained why she reacted to Kutay's question in a way which created a challenging situation for their group (turns 2 and 4). Kutay also explained how he attempted to control his motivational and emotional state individually. In his comments, he explained that he wanted to defend himself against Leman by disregarding the word 'neural', even though he actually acknowledged the correctness of this word (turns 6 and 8). Also, he explained that Leman's disagreement led him to comment negatively about how she was seen within the group, which then caused the emergence of another socio-emotional challenge (turns 16–23). Furthermore, when Ayse was asked about why she reminded Leman about working as a group and valued Kutay's idea, she explained that she knew how the latter was feeling during this incident as she had also been on the receiving end of similar encounters with Leman previously (turns 25–29). In the interview, Kutay also explained how he was feeling in response to Leman's reaction after he misread the word 'neural' and how good he felt as a result of Ayse's emotional support (turns 30 and 32).

In this example, as the analyses of video and stimulated-recall interview data reveal, the students experienced a negative emotional experience and attempted to control

Table 9. Stimulated-recall interview—Group A

Turns	Transcript	Regulation	Focus
1	I: So what happened here?		Shared regulation
2	L: Kutay tried to read my notebook upside down, but he read 'neural' as 'digestive'. And then I said 'what are you saying?', and then I began to defend myself		
3	Ay: No, you said 'don't be silly Kutay!'		
4	L: Yeah, but we were in the subject of nervous system		
5	I: For instance, Kutay, I am just wondering, when you said that there is nothing called neural, did you really believe that there was not something like neural or there was something else behind your response?		
6	K: Of course it was a counter-attack (*laughing*). I mean there is of course something called neural		
7	I: Yes, can you explain this a little bit more?		
8	K: There is something called neural actually. Certainly, I just told this, don't know why. It was against Leman to defend myself, I guess. I was looking at her notebook, but could not see very well because of her small handwriting	EMC	
9	L: Is it small?		
10	K: Yes		
11	I: OK, the rest of your conversation is so funny. Let's look at it		
12	All: (*laughing and watching*)		
13	I: Yes, what's happening here?		
14	K: Me?		
15	I: Yes, when you say that 'you are right all the time'		
16	K: I don't know. Leman knows everything perhaps that's why		
17	I: But, she may not know everything really		
18	L: Yeah		
19	K: But I thought that was the case		
20	I: Here, Leman		
21	K: Here, Leman did not support my idea, that's why I have said she was right all the time		
22	L: Yeah but you didn't intend to say it to praise me		
23	K: I was showing a bad attitude towards her and the reason for this was that she didn't support my idea		
24	I: So, why did you talk like that, Ayse?		
25	Ay: Because, Leman sometimes, I really realise that sometimes she criticises Kutay's ideas in an insensitive manner		
26	K: Yes, she does		
27	Ay: Even though we always work together in other lessons, because I want that. But she sometimes does the same thing to me too, so I wanted to help Kutay here because I knew how he was feeling	AE EMC	
28	I: Also in order to maintain working as a group?		

(*Continued*)

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Table 9. Continued

Turns	Transcript	Regulation	Focus
29	Ay: Yes		
30	K: Yes, she was really helpful	EMC	
31	I: Kutay here you seem a little bit upset, what were you feeling?		
32	K: Of course, I was angry with her, because she rebuked me during this incident. I didn't really feel very good, but Ayse supported me, this was good. But Eventually, Leman was proved right and this made me also feel sad	AE	

Notes: AE, expressing awareness of a negative emotional experience and EMC, control of emotional or motivational experience.

their emotional and motivational states individually as well as socially. For instance, in turns 6–14, Kutay's utterances, facial expressions, voice tone and gestures in the video data indicated his awareness and control of a negative socio-emotional experience which challenged his own as well as the group's motivational engagement subsequently. In addition, the students' utterances, eye contacts and voice tone in turns 19–27 showed evidence of controlling their group's emotional and motivational states by means of emphasising a sense of tolerance and togetherness as well as valuing and encouraging respect for each other's feelings and ideas. As a result of this shared regulation, the group was successful in terms of increasing group cohesion and maintaining the group's shared motivational engagement in relation to carrying out their task.

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Discussion and Conclusions

In summary, the findings presented in this paper show ways in which co- and shared regulation processes are activated and suggest how they influence students' collaborative learning during science inquiry activities. Our analysis revealed that co- and shared regulation processes were often initiated by particular types of events and played a central role in the success of students' collaborative inquiry learning. For instance, group members' expression of a misconception or a lack of understanding about a scientific idea often led to the emergence of co-regulation of metacognitive processes. In addition, expressing tentativeness about a shared idea, experiencing contradictory viewpoints or seeking consensus about a conceptual idea or a shared plan were commonly observed to initiate shared regulation of metacognitive processes within the groups.

While our study aimed to understand this regulation of learning in small groups and did not attempt to measure the students' actual learning, our observations of students' performance in whole class interaction as well as small-group discussion suggested that the particular groups that we studied did learn well during these activities and that the activities were well designed to gradually build their understanding.

Specifically we identified examples of their overcoming misconceptions and co-constructing knowledge. Informal discussions with the teacher supported this observation and the teacher explained that because these groups were functioning well it was not necessary for her to intervene with them as often as for other groups.

Our findings showed how co- and shared regulation of metacognitive processes contributed to the success of collaborative inquiry activity. More specifically, co-regulatory monitoring processes were usually observed to stimulate students to reflect upon and clarify their thinking, and facilitate the construction of new scientific understanding. Shared planning processes helped students to build a shared understanding of the task among the group members, while shared monitoring processes helped students to clarify and justify their shared understanding, as well as sustain the ongoing knowledge co-construction process. These findings support previous research studies in other subject contexts that have started to identify relationships between social forms of regulation processes (e.g. planning, monitoring) and effective collaborative learning (e.g. Janssen et al., 2012; Järvelä et al., 2013; Rogat & Linnenbrink-Garcia, 2011). These findings are also consistent with those of a systematic review by Bennett et al. (2010) of small-group discussions in secondary science learning in which they found that a key factor that contributed to enhancement of understanding in several studies was dissimilarity or conflict in understanding or views between group members. Our findings showed how co- and shared regulation of metacognitive processes, triggered by such dissimilarities, can contribute to the success of collaborative learning. In a few instances, shared monitoring processes were also observed to slow down the ongoing group discussion. This finding concurs with a study in mathematics education by Iiskala et al. (2011), in which they identified the functions of shared metacognitive regulation as both facilitating and inhibiting dyads' collaborative problem-solving process. These instances of 'slowing down' have not been discussed in detail here because they were relatively rare in the current study so we have not been able to examine their importance. In line with a hypothesis of Iiskala et al. (2011), we suspect that slowing down the collaborative problem-solving process by shared regulation may be an important factor contributing to success where tasks are relatively difficult and thus need careful consideration and time for thinking. While the importance for learning of setting tasks of an appropriate level of difficulty is a well-known challenge for teachers, relatively little research has examined metacognition and shared regulation at different task difficulty levels in collaborative contexts (see Iiskala et al. 2011 for a review of such research in the context of mathematics) and this is an issue that merits further research.

Creating and maintaining a positive socio-emotional atmosphere within groups is well recognised as a challenge for teachers. Our analysis suggested that the student groups often activated shared emotional and motivational regulation processes when they experienced a variety of socially challenging situations, such as having different priorities in relation to the task, failing to reach a consensus on a shared understanding or exhibiting disruptive behaviour during the group activity. Our evidence suggested that these regulation processes were important in sustaining reciprocal interactions among students, increasing group motivation and creating a positive socio-emotional

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atmosphere within the groups. Consistent with the studies of Järvelä and Järvenoja (2009, 2011), this finding indicates that students not only engage in metacognitive regulation processes, but can also actively self- and socially regulate emotional and motivational states which help them to maintain effective group functioning during collaborative learning situations.

Our analysis identified links between the emergence of social forms of metacognitive regulation processes and the quality of group interactions. Evidence of positive and supportive interactions was always visible in both co- and shared regulation episodes in which the students were supportive and respectful to one another. For example, the group members usually took into consideration each other's perspectives, listened attentively and constructively responded to one another's ideas, and remained open to negotiating their shared understanding, rather than displaying negative group behaviours (e.g. ignoring or rejecting each other's suggestion, using excess criticism) which have been identified by previous studies as having an unfavourable effect on the quality of group functioning and learning (e.g. Barron, 2003; Webb, Ing, Kersting, & Nemer, 2006). In this study, the presence of these positive and supportive interactions was observed to create a favourable social climate within the groups, which, in turn, seemed to facilitate and sustain the emergence of co-regulation and shared regulation processes. This finding supports findings from the study by Rogat and Linnenbrink- Garcia (2011) that identified positive socio-emotional interactions as facilitating a high quality of social regulation processes of upper elementary students during small-group mathematics tasks. Considering this finding, we can hypothesise that by increasing and fostering positive quality of interactions among students, it may be possible to promote social forms of metacognitive regulation processes during collaborative inquiry learning.

An important implication of the current study is that students need to learn how to employ both self and social forms of regulation processes during collaborative inquiry learning in science. The existing literature includes a number of instructional intervention programmes aiming to support students' acquisition and use of regulation processes during science inquiry activities (e.g. Sandi-Urena et al., 2011). However, they mostly target individual aspects of metacognitive regulation, whereas our findings suggest that teachers and curriculum designers should design and implement new instructional programmes which also include social, emotional and motivational aspects of regulation processes.

In the literature, whereas it is commonly stated that some students struggle with effectively self-regulating their learning in science classrooms (e.g. Winters & Alexander, 2011), the student groups in this current study appeared to regulate their learning processes successfully, which consequently had a positive impact on their collaborative inquiry. This may be attributed to the practices of the teacher during the inquiry group activities. In this study, at the beginning of each group work session, the teacher promoted collaborative dialogue for the group work through emphasising the shared responsibility of the students and the value of collaboration for effective learning, as well as providing the students with written instructions about the objectives and rules of the group activities. During the activities, she also visited each of the groups

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and when necessary provided help and often praised those who were actively performing their tasks appropriately. While we did not research the role of teacher in this study, we believe that these pedagogical interactions by the teacher before and during the study were important in enabling effective collaboration among students as well as encouraging the emergence of self and social forms of regulation processes. However, it should be noted that the groups chosen for this study were those who had already been found to be able to work well together and that the teacher still found it necessary to support other groups in developing their skills in regulation. Previous research also points towards the importance of teachers' pedagogical interactions in supporting students' use of regulation processes. For instance, in one study carried out with pre-school children in a mathematical learning context, Whitebread and Coltman (2010) identified that teachers' pedagogical interactions which provided students with emotionally contingent support gave them feelings of autonomy and control, provided them with the opportunity to share their understanding and had the potential to initiate and support self-regulatory processes of students. Therefore, it would be valuable for future studies to explore how teachers play a role in students' acquisition and use of regulation processes. Such research has the potential to help us find ways of designing inquiry science curricula that can support students becoming successful self- and socially regulated learners.

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Methodological Considerations and Future Research

The naturalistic case-study approach adopted for this research together with the multi-step analysis of the classroom video observational data was successful in identifying verbal and nonverbal behaviours of students, indicating evidence of self and social forms of regulation processes during the collaborative inquiry science activities. Furthermore, the students' interpretations and appraisals explicated during the stimulated-recall interviews provided an additional insight into elucidating and understanding students' self- and social regulation of their learning processes by revealing how, why and what the students were thinking or feeling while engaging in collaborative inquiry activities. This supported and complemented the analysis of video data through allowing for an understanding of the video observations from students' own perspectives in their own words. For example, in the interviews, the students were able to articulate and describe their individual as well as their group's thinking at the metacognitive level. They were also able to describe and interpret why and how they felt when facing emotional and motivational experiences, as well as how they attempted to control these individually and socially in order to maintain engagement with the task.

We acknowledge that an important limitation of this study is that it involved only two student groups and their science teacher. Also, the participants were from a private fee-paying primary school, in which almost all of the students were from higher socio-economic backgrounds. While the results of this study may not be generalisable to other schools and classrooms in Turkey or beyond, it can enable 'naturalistic generalisation' by the readers who can assess the relevance of the research

findings to new circumstances or 'analytic generalisation' in which the findings can be used to inform, build or elaborate upon the theoretical concepts and propositions under consideration in this paper (Yin, 2011). Overall, we anticipate that the multi-step analysis and coding processes used in this study (Tables 1–3) could be adopted and if necessary adapted to further research collaborative science inquiry learning in order to identify whether or not the emergence and functions of regulatory processes vary in different cultural contexts and with students from different backgrounds.

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Note

1. While the first author of this paper did not identify any evaluation episodes in the data that were subjected to the inter-coding agreement, the other coder considered two regulation processes as evaluation episodes (the first author considered them to be monitoring processes). Although the percentage of episodes which both coders agreed not to code as an evaluation episode was 95%, the Kappa score was 0 for this category.

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Appendix. Description of the small group tasks

Task 1: 'Why do we eat?'

The groups examined a digestive system diagram and noted down their ideas about the digestive system process. In this activity, the students were expected to explain the relationship between nutrients and the energy produced and used in the human body.

Task 2: 'Journey of food'

The groups watched a short video clip about the digestive system process and noted down their observations. Then, they were asked to select two types of food as a group and describe how they are digested in the human body through answering a set of questions.

Task 3: 'Football match'

The groups were asked to watch a short video clip of a football match and write down their observations about the events that occur around and inside a footballer's body. The aim was to engage the groups in exploring the importance of the nervous system for the functioning of other human body systems and the coordination which exists among all the systems in the human body.

Task 4: 'The poisonous plant'

The students watched a video clip about children playing football near a shrubbery and a goalkeeper accidently touching a poisonous plant while trying to keep the ball and subsequently pulling his hand away as a reflex and then screaming. The students were instructed to note down their observations regarding the neural events happening in the goalkeeper's nervous system, and explore a set of inquiry questions collaboratively.

Task 5: 'Water content of our body'

In order to understand the importance of the nervous system, endocrine glands and kidneys in the regulation of body conditions, the groups were asked to investigate how the water level in human body is adjusted and what processes occur during the filtration of blood in the kidneys.

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