# Identifying regulation profiles during computer-supported collaborative learning and examining their relation with students' performance, motivation, and self-efficacy for learning

Abstract

The present study unravels profiles of regulators, based on online measures of collaborative learners' adoption of individual-oriented and socially shared metacognitive regulation (SSMR) during asynchronous computer-supported collaborative learning (CSCL). Additionally, it investigates how the regulation profiles are related to students' conceptual understanding after CSCL and to their motivation and self-efficacy for learning. 196 university students participated in the study. Hierarchical and *k*-means cluster analysis are adopted to identify the regulation profiles, whereas ANCOVA and MANOVA are run to study how the regulation profiles are related to respectively students' performance and learner characteristics. The results revealed three regulation profiles, labelled as 'all-round-oriented and affirming regulator' (AOAR), 'social-oriented and elaborating regulator' (SOER), and 'individual-oriented and passive regulator' (IOPR). The regulation profiles differed significantly in their conceptual understanding, motivation for learning, and self-efficacy beliefs. The current results serve as a stepping stone for lecturers and researchers to design customized metacognitive scaffolds in CSCL-environments and to examine their effectiveness in future intervention studies, advancing both the emerging literature on SSMR and educational practice.

*Key words: shared regulation, regulation profiles, performance, learner characteristics, higher education*

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## 1. Introduction

The COVID-19 pandemic has put digital learning high on the educational agenda and has made blended learning or distance learning by means of computer-supported instruction common practice in higher education (Järvelä & Rosé, 2020). Lecturers often opt for computer-supported collaborative learning (CSCL), aiming at fostering interaction between students and enabling them to learn from peers when constructing knowledge. For CSCL to be successful students need technical, communicative, socioemotional and cognitive competence, which enables them to negotiate and compromise on alternative ideas on how and what to learn (Wang et al., 2017; Yilmaz & Yilmaz, 2019). Uniting students' divergent perspectives additionally implies controlling and monitoring students' understanding and regulating the group's progress, requiring the adoption of metacognitive regulation at both the individual student and the group level (Kim & Lim, 2018; Panadero & Järvelä, 2015). Students are responsible for regulating their personal learning and for aligning the latter with the collaborative learning process taking place, implying the adoption of metacognitive regulation at the individual student level. Simultaneously, they are expected to interact with peers to collectively regulate the course of collaborative learning, implying the adoption of shared metacognitive regulation at the group level (Hadwin et al., 2017). Taking into account this complexity of regulating at multiple levels, it should not be surprising that students benefit from being provided with support mechanisms to adequately regulate their own and/or the group's learning during CSCL (Hadwin et al., 2018; Wang et al., 2017; Yilmaz & Yilmaz, 2019). The educational technology that is embedded in many learning management systems (e.g. online quizzes with automated feedback, learning analytic tools to capture log patterns, … ) holds promising opportunities for tracking students' learning and for foreseeing adaptive scaffolding (Sedrakyan et al., 2020; Wise et al., 2021), which can optimize students' metacognitive regulation at both the individual and group level. Nevertheless, it remains unclear how students' (shared) metacognitive regulation during CSCL can best be supported (Kim & Lim, 2018; Schnaubert & Bodemer, 2019; Splichal et al., 2018). Further, although it can be assumed that collaborative learners particularly benefit from customized regulative support (Miller & Hadwin, 2015), little is known about interindividual differences in collaborative learners' shared metacognitive regulation behaviour. Whereas some previous studies focussed on inter-group variety in the occurrence of self-, co- and shared regulation (e.g. Author et al., 20xx; Järvelä et al., 2016; Malmberg et al., 2017), others examined how students' self-regulation capacity influences the adoption of shared regulation strategies in the group (e.g. Author et al., 20XX; Li et al, 2020). However, interindividual differences in students' (shared) regulation behaviour during CSCL still remain underexplored in the emerging literature on shared regulation (Iiskala et al., 2021).

The contribution of the present study is twofold. First, it aims at extending available insights on individual differences in collaborative learners' regulation behaviour. It more specifically answers the current call for person-oriented analyses of regulation (Li et al., 2020; Zheng et al., 2020), aiming at profiling students based on their adopted metacognitive regulation strategies during asynchronous CSCL. To deepen current understandings of interindividual differences in the regulation behaviour of collaborative learners even more, the study also investigates whether the identified regulation profiles differ in their understanding of the learning content, motivation for learning, and self-efficacy beliefs. These innovative insights directly advance the current literature on interindividual variety in shared (metacognitive) regulation (Iiskala et al., 2021; Panadero & Järvelä, 2015). Second, by identifying profiles of regulators during CSCL, the present study serves as an important starting point for designing customized metacognitive support, adapted to the characteristics and regulative needs that typify each regulation profile. As such, the study's findings might facilitate more personalised (regulative) support in educational practice, which is likely to benefit CSCL-participants' learning outcomes (Miller & Hadwin, 2015).

## 2. Theoretical framework

### 2.1 The focus of metacognitive regulation situated at diverse levels of social interaction

Successful CSCL requires students with varying levels of domain-specific knowledge, willingness to collaborate, technical and socio-communicative expertise to interact and agree on how to organise CSCL and how to interpret the learning content addressed (Li et al., 2020; Melzner et al., 2020). This implies students' activation of regulation strategies in order to coordinate, modify, or reinforce their ideas, learning activities taking place, and the progress made towards learning objectives put forward (Hadwin et al., 2018). These regulation activities can be directed at cognitive, motivational, or behavioural aspects of collaboration (Hadwin et al., 2017; Järvelä et al., 2019). The present study investigates metacognitive regulation in particular, referring to the regulation of cognitive activities within the CSCL-group (Iiskala et al., 2015). As depicted in the model of Nelson (1996), shown in Figure 1, metacognitive regulation acts as a meta-level of learning that is continuously in interaction with an object-level of learning (i.e. cognitive activities dealing with the content of learning). Through the monitoring function, the meta-level is informed about the state of a student's cognition (e.g. content is being misinterpreted). Through the control function, the meta-level instructs the object-level about which step to take next during learning (e.g. rereading learning content in order to modify the misinterpretation).

*<Insert Figure 1 about here>*

Although metacognitive regulation has traditionally been studied from an individual student's perspective, the increased implementation of CSCL over the past years pushed the attention towards social forms of regulation, demonstrated at the interpersonal level (Hadwin et al., 2017; Panadero &

Järvelä). In general, metacognitive regulation can be focussed at three levels of interaction during collaborative learning (see Figure 2). It can concern (1) individual-oriented metacognitive regulation[1] of a student's personal cognition (no interaction); (2) co-regulation of a peer's or the group's cognitive processing by one group member (one-way interaction); or (3) socially shared regulation of each other's cognition in which multiple peers actively contribute (mutual interaction) (Iiskala et al., 2015).

*<Insert Figure 2 about here>*

Co-constructing knowledge during CSCL requires students first of all to regulate their personal cognition (e.g. activating their prior knowledge, planning when and how to contribute to an asynchronous group discussion, checking their conceptual understanding, or evaluating their input when solving the group assignment) as well as to align their personal learning with the collective learning process that unfolds within the CSCL-group (Järvelä et al., 2019; Li et al., 2020). In other words, despite an emphasis on collaboration inherent to the social nature of CSCL, each group member is expected to activate individual-oriented metacognitive regulation strategies at the individual student level, aimed at optimizing his/her personal understanding and progress.

Second, a collaborative learner can decide to regulate peers' cognition, by instructing them to adopt regulation strategies, eliciting co-regulation of cognition (Iiskala et al., 2015). Although co-regulation is situated at the interpersonal level, it is characterised by an asymmetrical involvement of two or more collaborative learners in metacognitive regulation: guided by intra-individual goals, one student takes responsibility to sustain/correct another student's or the group's cognitive processing (Grau & Whitebread, 2012; Panadero & Järvelä, 2015).

Third, CSCL requires students to engage in joint goal setting, to control the interpretations put forward as a group, as well as to collectively modify or reinforce the course of ongoing interaction. This implies the adoption of socially shared metacognitive regulation (SSMR), which is also focussed at the interpersonal level but characterised by a mutual and symmetrical regulative involvement of collaborative learners (Iiskala et al., 2015; Kim & Lim, 2018). SSMR is embedded in interactions and occurs when multiple CSCL-participants reciprocally react upon each other's activated regulation strategies in order to orient on, plan, monitor, or evaluate the group's cognitive processes or products (Iiskala et al., 2015). It is expressed when students collectively set forward learning objectives, jointly question the adequateness of the problem solving approach, collectively evaluate the group's solution for the presented assignment, or mutually reflect upon alternate learning strategies to optimize future CSCL. SSMR starts with the expression of metacognitive regulation by one student, which is picked up

[1] We opt for the term "individual-oriented metacognitive regulation" to stress the focus on metacognitive regulation of individual students' cognition in the present study. This should, however, not be interpreted as self-regulated learning (SRL). SRL is conceptualized as a student's deliberate monitoring, regulation, and control of one's cognition, motivation, and behaviour towards completing an academic goal (Hadwin et al., 2017), and consequently encompasses a metacognitive, cognitive, and motivational component.

by group members who engage themselves in a chain reaction of activating metacognitive regulation (Author, 20xxa).

Compared to the abundant literature on self-regulated learning (SRL) and individual metacognition, the research on SSMR (and shared regulation in general) has only recently gained momentum (Hadwin et al., 2017; Järvelä et al., 2019). It is assumed that a joint engagement of students in regulation can foster the depth and outcomes of CSCL, in line with the added value of SRL for the quality of individual learning (Li et al., 2020). Empirical evidence in this respect is, however, scarce (e.g. Kim & Lim, 2018; Li et al., 2020; Paans et al., 2019; Zheng et al., 2019). Recent studies moreover unravelled the heterogenous character of shared (metacognitive) regulation and demonstrated that not all of its utterances are equally effective. Based on the characteristics of the (shared) metacognitive regulation behaviour students engage in, a differential relation with collaborative learners' outcomes was revealed (Author, 20xxa; Iiskala et al., 2021; Isohätälä et al., 2019; Paans et al., 2019). The present study takes an interest in the functions of SSMR as potential expressions of this heterogeneity within SSMR.

**2.2 The functions of SSMR**

Students' involvement in specific functions of SSMR, referring to alternate consequences that SSMR can generate on the course of the collaborative learning process (Iiskala et al., 2015), determines what students pick up from collaborating with peers (Author, 20xxa). In the current study, we conceptualise the functions of SSMR based on the framework of Iiskala and colleagues (2015), who discern five potential functions. First, SSMR can *confirm* ongoing interaction, implying that previous activity is continued (e.g. students agree with the problem solving approach suggested by a group member). Second, SSMR can *activate* a new direction for ongoing interaction elaborating upon previous activity (e.g. after evaluating the group's final answer students start evaluating the strengths and weaknesses of their collaboration). Third, SSMR can *slow down* the course of collaborative learning by initially questioning but subsequently confirming its current direction (e.g. a student can criticise the planned problem solving approach, leading the group to discuss alternatives but ultimately to decide to tackle the assignment as was initially planned). Fourth, SSMR can *change* the direction of ongoing interaction by critically questioning current activity and moving forward in a different direction (e.g. students criticise the learning strategies adopted hitherto to solve the assignment, to the extent that the group decides to restart problem solving using an alternate strategy). Fifth, SSMR can briefly *stop* ongoing interaction without meaningful consequences for the continuation of collaborative learning (e.g. some students' questions regarding peers' activated prior knowledge are not picked up and the group continues discussing and activating comparable content-related prior knowledge). Especially students' engagement in SSMR that changes collaborative learning and SSMR that activates a new direction for ongoing interaction appeared beneficial for students' learning outcomes (Author, 20xxa).

The rationale behind the functions of SSMR is in line with more general literature on the importance of interactivity in CSCL-communities (Kent et al., 2016), dialogic argumentation during online learning (Stegmann et al., 2012), and transactive discourse as facilitator of shared understanding within and enhanced learning of CSCL-groups (Noroozi et al., 2013; Popov et al., 2017). All three frameworks emphasize that knowledge construction results from the interactive exchange of information. The flow of communication that is being established in this way appears particularly instructive when peers actively relate to each other's thinking, by asking questions, providing extra information to support their viewpoints, and negotiating conflicting ideas aimed at shared understanding (Kent et al., 2016). Especially contributing to transactive discussions, in which students build upon peers' reasoning about the learning content, is likely to foster individual CSCL-participants' cognitive learning gains (Noroozi et al., 2013). The way students build on each other's comments can, nevertheless, be carried out at varying levels of transactivity (Popov et al., 2017). At a lower level, CSCL-participants can simply reach consensus by accepting what is being said or written in an online forum, whereas a higher level of transactivity implies that peers jointly decide on the interpretation of learning content, after incorporating conceptual (dis)agreements that were previously expressed by the group members (Noroozi et al., 2013; Stegmann et al., 2012). Highly transactive discourse not only assumes a more intensive engagement in the collaboration process, it has shown to be more beneficial for CSCL-participants' learning outcomes as well, especially when peers critically respond to each other's contributions (Popov et al., 2017).

Taking the functions of SSMR into consideration, it becomes clear that interindividual differences can arise in students' adoption of metacognitive regulation during CSCL. Previous studies confirmed that the frequency of individual group members' contributions to regulating the collaborative learning process, differ considerably (Author, 20xxa; Isohätälä et al., 2017; Li et al., 2020). Also differences in what individual group members pick up from CSCL are reported (Noroozi et al., 2011). More in-depth investigations of interindividual variety in regulation and its impact on students' learning outcomes is needed, for it will allow to design more customized instruction in regulation and to foresee adaptive regulative support during CSCL, which can in its turn optimize the effectiveness of CSCL for all group members (Schnaubert & Bodemer, 2019; Wang et al., 2017; Yilmaz & Yilmaz, 2019). To compromise on personalised instructive support for learners and manageable instructive support by instructors, it is recommended to start from a person-oriented analysis, since the latter is directed at exposing natural subgroups of students who demonstrate comparable learning or regulation (Bergman & Wangby, 2014).

### 2.3 A person-centred approach of studying CSCL-participants' metacognitive regulation

There is a recent call for shifting from a variable-centred to a person-centred approach when studying differences in students' adoption of regulation strategies (Co-author, 20xx; Li et al., 2020; Zheng et al., 2020). A variable-centred perspective puts the focus on frequency measures of students' adoption of regulation and how these relate to other variables (e.g. gender, academic achievement). Alternatively, a person-centred perspective allows to investigate how individuals or subgroups of students combine regulation strategies in a particular way (Bergman & Wangby, 2014). This enables researchers first of all to unravel naturally occurring profiles in students' regulation behaviour and to design custom-made instructional practices, matched to the variation in students' regulative needs and actual competences, afterwards (Vansteenkiste et al., 2009). Some previous studies adopted a person-centred approach to explore the presence of motivational and SRL-profiles (e.g. Co-author, 20xx; Li et al., 2020; Vandevelde, 2015; Zheng et al., 2020). They demonstrated that subgroups of students regulate their individual learning by combining specific regulation and motivation strategies and that some profiles are more successful than others (Dörrenbächer & Perels, 2016; Liu et al., 2014).

Whether similar regulation profiles can be revealed during CSCL remains unclear. Given that collaborative learners can activate regulation at both the individual and interpersonal level and that regulation strategies can differ in depth (Author, 20xxa; Isohätälä et al., 2017; Järvelä et al., 2019), it seems likely that CSCL-participants' regulation behaviour can be typified based on combinations of adopted regulation strategies. The present study aims at shedding more light in this respect by taking a person-centred perspective for analysing students' metacognitive regulation during asynchronous CSCL. Unlike most other studies that unravel motivational or SRL-profiles based on differences in self-reported strategy use, the current study takes online measures (i.e. systematic observation) of CSCL-participants' metacognitive regulation as a starting point. Online measures are conducted concurrently during learning and capture students' actual adoption of regulation more easily, through their micro-analytical focus on learning and regulation processes (Veenman, 2011). Although they are very time-consuming, they are less vulnerable to students' memory distortion as compared to self-report questionnaires, in which students are asked to recall their regulation behaviour. Whereas self-report questionnaires hardly correspond to students' actual adoption of regulation strategies, online measures are assumed to be more accurate (Järvelä et al., 2019).

Further, the present study aims at contributing to the growing research on the effectiveness of shared (metacognitive) regulation. Although actively being engaged in SSMR is assumed to advance the learning outcomes of the collaborative learners involved, empirical evidence in this respect is scarce and rarely acknowledges the potential heterogeneity within SSMR (Iiskala et al., 2021; Isohätälä et al., 2019; Paans et al., 2019). The current study therefore investigates whether the identified regulation profiles show a differential understanding of the learning content addressed during CSCL.

### 2.4 Student characteristics related to CSCL-participants' learning

To deepen our understanding of identified profiles and to further justify their delineation, a person-centred study is often extended with between-group analyses directed at unravelling differential relations of the identified profiles with other variables (e.g. whether one profile is more effective or shows another relation with a dependent variable as compared to another profile) (Bergman & Wangby, 2014). These variables have often been put forward as influential factors in variables-centred analyses. To better comprehend interindividual differences in students' (shared) metacognitive regulation, the current study therefore investigates whether and how regulation profiles relate to individual learner characteristics. It more specifically takes an interest in students' motivation and self-efficacy for learning. Both have shown to be predictive for learners' level of engagement in learning and regulation as well as for students' performance in response to learning (e.g. Baars et al., 2017; Dörrenbächer & Perels, 2016; Liu et al., 2014).

In the present study, motivation for learning is conceptualised from the Self-Determination Theory (SDT) (Ryan & Deci, 2000). SDT distinguishes types of motivation based on varying levels of autonomy, introducing a continuum from autonomous to controlled motives for learning. Autonomously motivated students engage in learning because they enjoy it (i.e. intrinsic regulation, e.g. participating in CSCL because of the satisfactory nature of exploring learning content with peers) or because they perceive it as personally relevant (i.e. identified regulation, e.g. joining discussions because it is assumed to be important for one's own and the CSCL-group's academic success). Controlled motivated students involve themselves in learning because of external pressure (i.e. external regulation, e.g. contributing to CSCL for being rewarded with good grades) or internal pressure (i.e. introjected regulation, e.g. feeling ashamed or guilty when not participating in discussions during CSCL). Previous research particularly stressed the importance of autonomous motivation for learning. Autonomous motives are associated more frequently with positive learning outcomes, such as the adoption of profound learning strategies, deeper insights in content-knowledge, showing persistence when encountering challenges during learning, higher grades, and enlarged adoption of regulation strategies (Baars et al., 2017; Co-author, 20xx; Dörrenbächer & Perels, 2016; Liu et al., 2014; Vansteenkiste et al., 2009).

Self-efficacy for learning refers to a student's belief in one's ability to successfully learn or to effectively perform academic tasks (Pajares, 2008). Students with high levels of self-efficacy for learning apply more cognitive and metacognitive strategies, are more strategic learners, work harder, and show more perseverance during academic challenges, as compared to students doubting their ability to learn (Vandevelde, 2015; Wilson & Narayan, 2016). Additionally, self-efficacy for learning is associated with students' perceived responsibility for learning (Wilson & Narayan, 2016), which might particularly be at play during CSCL. Students with strong confidence in their learning ability, feel more responsible for the course of collaborative learning, which encourages them to participate in ongoing interaction.

Whereas previous research on SRL-profiles of individual students demonstrated that subgroups of self-regulators revealed qualitative differences in their motivation and self-efficacy for learning (e.g. Co-author, 20xx; Liu et al., 2014), it remains unclear whether both student characteristics are equally related to person-centred differences in CSCL-participants' metacognitive regulation.

## 3. Objectives and research questions

The present study aims at unravelling profiles of collaborative learners, based on their adoption of metacognitive regulation during asynchronous CSCL. The identification of regulation profiles is more specifically based on students' activation of individual-oriented metacognitive regulation strategies and their engagement in SSMR that either confirms, activates, changes, or stops collaborative learning[2]. In other words, both the focus of regulation and the function of SSMR are taken into consideration. Second, the study aims at investigating the relationship between the regulation profiles and students' understanding of the learning content after CSCL, measured by means of a cued-recall knowledge test. Third, it aims at examining the relationship between the regulation profiles and individual learner characteristics, more particularly students' motivation for learning and self-efficacy beliefs. The study objectives put forward allow lecturers and researchers to develop differentiated instruction in and scaffolding of metacognitive regulation during CSCL, as well as to better comprehend individual differences in CSCL-participants' (shared) regulation behaviour.

The research questions were as follows:

(1) Which regulation profiles can be discerned based on students' adoption of individual-oriented metacognitive regulation and their involvement in the functions of SSMR (i.e. confirm, activate, change, or stop CSCL) during asynchronous CSCL?

(2) How are regulation profiles related to students' performance on a knowledge test assessing their understanding of the learning content addressed during CSCL, after controlling for students' prior knowledge?

(3) How are regulation profiles related to students' motivation and self-efficacy for learning?

## 4. Method

### 4.1 Procedures

[2] It should be noted that 'SSMR slowing down CSCL' (Iiskala et al., 2015) was not taken into account as a function of SSMR in the current study, since it remained covered when coding the collected video data. When SSMR slows down CSCL, students reflect on the course of ongoing interaction and continue in the same direction. Given that the function of SSMR was coded based on the episode of the discussion transcript following an event of SSMR (see infra), only a confirmation of ongoing interaction was observable, while the function 'slowing down' as such remained covert.

**4.1.1 Participants and data collection.** All first-year Educational Sciences students (*n*=214, 18.88% male and 81.12% female) participated in an obligatory asynchronous CSCL-intervention as part of the course 'Instructional Sciences'. Students were randomly divided over 36 small groups of six students[3] and conducted four online group assignments in order to discuss and construct domain-specific knowledge. The discussion transcripts of the last CSCL-session (i.e. fourth group assignment) was collected from all groups to obtain data on students' metacognitive regulation during CSCL. Additionally, 196 students (16.84% male and 83.16% female students) administered a questionnaire on their motivation for learning and self-efficacy beliefs[4]. Only students who completed all aspects of the data collection (see Figure 3) were included in the present study. In accordance with the guidelines outlined in the General Ethical Protocol of the Ethical Committee of the Faculty of [blinded for review purposes], active informed consent for participation in the study was obtained from all students.

*<Insert Figure 3 about here>*

**4.1.2 CLCS-intervention.** The CSCL-intervention was asynchronous and comprised of a prior training and four content-related group assignments during 10 successive weeks. Students processed the learning content of a particular theme within the course Instructional Sciences (e.g. cognitivist didactical approaches, curriculum development, assessment) by working together to solve the respective group assignment. The assignments were presented at the learning management system adopted by the lecturer of the course. In this learning management system, a discussion forum and Google docs (i.e. a shared online Microsoft Word document) were integrated in the digital space provided to each group, enabling them to discuss the learning content, share solutions, and modify each other's input when solving the assignment. Each group assignment took two weeks and consisted of an individual component during the first week and a group component during the second week (see Figure 3). Given the asynchronous nature of the sessions, students could work at their own pace on both components.

Given students' limited prior content knowledge, they were instructed to thoroughly read the handbook chapter that corresponded to the CSCL-session's theme, as a first step. In a second step, each group member was provided with two theoretical statements (e.g. "Explain whether and why the following statements are true or false: (a) Problem-based learning is an illustration of discovery learning, (b) Fading implies that an instructor operates within a learner's zone of proximal development") and an instructional case (e.g. "Which didactical guidelines from instructional constructivism do you recognize in the case of community service learning below?") that addressed

[3] The 214 CSCL-participants were divided over 34 groups of six students and two groups of five students.

[4] Seven students dropped out from the course before the end of the semester while eleven students completed the CSCL-intervention but did not fill in the questionnaire. The input from these students in the discussion transcripts was removed after coding.

terminology regarding the central theme. The statements and cases varied among group members. All group members were instructed to individually provide an answer for each theoretical statement and illustrative case by the end of the first week. Individual group members uploaded their answers on the individual component of the assignment in a Google Docs that was accessible for all group members. The Google Docs bundling all individual answers provided insight in students' initial conceptual understanding and served as a starting point for the group component of the assignment in the second week. During this second week, the group discussed (on the discussion forum) each individual group member's input on the Google Docs, focusing on the correctness, elaborateness, and the degree of integrating multiple insights. Based on the peer discussions, the group members could correct, modify or extend the initial answers in the Google Docs. By the end of the second week, the group was expected to provide a final group answer to all theoretical statements and instructional cases that were provided in the first week of the CSCL-session.

Despite the rather tight schedule and clear learning objectives put forward, the groups were free and responsible for organising and monitoring their personal and collaborative learning process during each CSCL-session, implying their adoption of metacognitive regulation.

**4.1.3 The quality of implementation of the CSCL-intervention.** Two trained research assistants screened the discussion fora and Google Docs of all CSCL-groups for each CSCL-session, using a scoring rubric, to check treatment fidelity. The rubric focussed on both the structure of the CSCL-session (i.e. individual problem solving, discussion, collective problem solving, and evaluation) and students' activity in the group discussion (i.e. discussing the learning content, asking questions, providing explanations, giving feedback, and reporting on the group's answers). It adopted a five-point Likert-scale, ranging from 'not observed' to 'observed systematically'. Table 1 shows that the global quality was sufficiently high for all critical elements.

*<insert Table 1 about here>*

**4.2 Measures**

**4.2.1 Metacognitive regulation.** CSCL-participants' metacognitive regulation was measured concurrently during learning by means of discourse analysis on the transcripts of peers' discussions during the fourth content-related CSCL-session. The coding procedure that was adopted to transform the discussion transcripts into meaningful data on CSCL-participants' metacognitive regulation is outlined below (see section 4.3.1).

**4.2.2 Prior knowledge.** To enable controlling for students' prior knowledge when examining how the regulation profiles affected students' conceptual understanding, all students individually conducted an online prior knowledge test before starting the fourth group assignment. Students were asked to type everything they knew about five central concepts from the session-specific theme. The scoring of students' prior knowledge was based on the correctness and elaborateness of each of their answers: 0 was given to incorrect answers, 1 to correct but basic answers, and 2 to correct and elaborate answers. In this respect, students could obtain a maximum score of 30. Prior knowledge test scores varied between 3.00 and 18.00, with a mean score of 8.36 (*SD*=2.85).

**4.2.3 Understanding of the learning content addressed during CSCL.** One day after the CSCL-intervention, students took an individual cued recall knowledge test that mapped their understanding of the theory addressed during the last CSCL-session. The test was provided on the same platform where students had worked together on the group assignments. It encompassed fifteen open questions instructing students to recall concepts (e.g. "What is the difference between scripting and scaffolding?") or to analyse instructional cases (e.g. "Read the article on interactive book reading and outline which constructivist didactical guidelines are applied."). In accordance with the prior knowledge test, a predefined answer key was used to score students' answers, taking into account the correctness and level of elaboration. Test scores varied between 10.00 and 28.00 out of 30, with a mean score of 17.95 (*SD*=3.39).

**4.2.4 Motivation for learning.** Students administered a questionnaire on their motivation for learning one day after the CSCL-intervention (see Figure 3). Motivation for learning was mapped by means of the Learning Self-Regulation Questionnaire (SRQ-L) (Black & Deci, 2000). The SRQ-L consists of twelve items that inquire about students' motives to engage in learning in a particular setting and that are subdivided into two scales: controlled motivation (e.g. *"I actively participate during CSCL… because others might think badly of me if I didn't; … because I would feel proud of myself if I did well in the course"*) and autonomous motivation (e.g. *"I actively participate during CSCL… because I feel it is a good way to improve my understanding of the material; … because a solid understanding of instructional sciences is important to my intellectual growth"*). Items were scored on a five-point Likert scale, ranging from 1 (completely disagree) to 5 (completely agree). Internal consistency was high for the subscale 'autonomous motivation' (α= .87) and acceptable for the subscale 'controlled motivation' (α= 0.71).

**4.2.5 Self-efficacy beliefs.** Students' self-efficacy for learning was measured one day after the CSCL-intervention (see Figure 3) by means of the Perceived Competence for Learning scale (Williams & Deci, 1996). The scale is comprised of four items, to be answered on a five-point Likert scale (1= completely disagree, 5= completely agree), that inquire about how confident and able students feel to learn in a particular course (e.g. *"I am capable of learning the material in this course", "I feel able to meet the challenge of performing well in this course"*). The scale demonstrated high internal consistency (α= .85).

### 4.3 Data analysis

**4.3.1 Coding strategy for identifying/analysing CSCL-participants' metacognitive regulation.**

The discussion transcripts of the last CSCL-session were coded following multiple steps (see Author, 20xxa). First, each transcript was divided into episodes of task execution (i.e. non-metacognitive contributions that are relevant for solving the assignment), metacognitive regulation (i.e. contributions referring to monitoring and control of cognition), or off-task (i.e. contributions that are not relevant for the assignment). An episode represented a specific discussion topic addressed by different students.

In the second step, statements of metacognitive regulation were identified in each episode of metacognitive regulation, in order to map individual group members' metacognitive regulation. A statement of metacognitive regulation encompasses regulation of cognition expressed by one student at a turn in the episode of metacognitive regulation[5]. The instrument [blinded for review purposes] (Author, 20xxb) was used to code the statements of metacognitive regulation. Each statement was given (a) a code indicating whether it encompassed task analysis, prior knowledge activation, time-related planning, strategic planning, comprehension monitoring, monitoring of progress, product evaluation, or process evaluation, and (b) a code indicating which student expressed the statement.

In the third step, the focus of metacognitive statements (i.e. individual-oriented or socially shared) was decided upon by checking both the students involved and the reciprocity of the reactions following a metacognitive statement. When a student expressed a metacognitive statement that was aimed at regulating his/her personal learning process or that was not reacted upon by fellow CSCL-participants, the metacognitive statement was coded as 'individual-oriented metacognitive regulation' (see Appendix). In total, 2839 individual-oriented statements of metacognitive regulation were segmented. Alternatively, events of SSMR were identified by segmenting chain reactions of statements of metacognitive regulation expressed by different students (Author, 20xxb). In the current study, an event of SSMR encompasses multiple metacognitive statements referring to a particular regulation skill, that are expressed by at least half of the group members (i.e. at least three students), who react to each other's statements in a reciprocal way. An event of SSMR is consequently revealed when students are interdependently involved in orienting on, planning, monitoring, or evaluating the organisation or the content of CSCL. In total, 616 events of SSMR were identified, that represented 4929 statements of metacognitive regulation expressed by individual CSCL-participants[6].

In the last step, the function of each event of SSMR (i.e. whether SSMR led to continuing/discontinuing ongoing interaction) was coded. The function was decided upon based on the impact that an event of SSMR generated on the episode in the discussion transcript that followed

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[5] For example, an episode of metacognitive regulation in which three students all contributed once, consisted of three turns, representing three metacognitive statements.

[6] It should be noted that 2251 statements of metacognitive regulation were not coded in the third step because their focus was not individual-oriented neither shared. In general, these concerned statements of metacognitive regulation by one student that were reacted upon by only one group member.

the respective event of SSMR. Four functions of SSMR (see Appendix) were distinguished as coding categories (Author, 20xxa; Iiskala et al., 2015). When SSMR resulted in continuing ongoing interaction, the function was coded *(1) 'SSMR confirming CSCL'*. When an event of SSMR led to elaborating upon ongoing interaction by taking the discussion a step further, the function was coded *(2) 'SSMR activating CSCL'*. When SSMR resulted in questioning ongoing interaction and alternating its direction, the function was coded *(3) 'SSMR changing CSCL'*. When SSMR resulted in a brief interruption of the discussion without meaningful consequences for its subsequent course, the function was coded *(4) 'SSMR stopping CSCL'*. Students' frequent/limited contribution to an event of SSMR with a particular function was acknowledged by duplicating the code given to an event of SSMR based on its function, in the metacognitive statements of that respective event of SSMR.

The discussion transcripts were coded by two trained coders. They independently segmented the transcripts of three CSCL-groups in episodes, respectively metacognitive statements, and events of SSMR. They compared their segmentation and compromised on discrepancies by discussing their segmentation until they fully agreed. Afterwards, both coders double-coded the segmented discussion transcripts. Cohen's Kappa indicated sufficiently high interrater-agreement for coding episodes ($\kappa$=.88), statements of metacognitive regulation ($\kappa$=.79), the focus of metacognitive regulation ($\kappa$=.78), and the function of SSMR ($\kappa$=.81). Next, both coders independently segmented and coded the discussion transcripts of the remaining CSCL-groups.

**4.3.2 Statistical analyses.** In view of answering the first research question, a two-step clustering method was applied. First, hierarchical cluster analysis, was run using Ward's method with squared Euclidian distance (Gore, 2000). The frequency of students' individual-oriented regulation strategies and of their engagement in the functions of SSMR were included as cluster variables. As the scale measurements of the latter were comparable, data were not standardised. Second, *k*-means cluster analysis was performed to verify the clustering (Gore, 2000).

Based on the results of the cluster analyses, the cluster membership for each CSCL-participant was used as a starting point for examining differences between the regulation profiles in more detail. Pre-analysis investigations were conducted to check the normal distribution of data, homogeneity of variance, homogeneity of regression, the linear relation between students' test performance and prior knowledge, and the multicollinearity between students' autonomous and controlled motivation for learning, and their self-efficacy for learning. No assumption was violated. A one-way analysis of covariance (ANCOVA) was conducted to investigate whether regulation profiles differed in their performance on a knowledge test regarding their understanding of the learning content addressed during CSCL, after correcting for students' prior knowledge as a covariate (research question 2). To examine whether regulation profiles are related to individual learner characteristics (research question 3), a multivariate analysis of variance (MANOVA) was conducted. Students' autonomous and controlled motivation for learning as well as their self-efficacy for learning were included as dependent variables. The significance level was set at .05 for all analyses. Partial $\eta^2$ is reported to study the effect size of significant differences between regulation profiles (with $\eta_p^2$=0.01 as small, $\eta_p^2$= 0.09 as medium, and $\eta_p^2$= 0.25 as large effect).

## 5. Results

### 5.1 Descriptive results

CSCL-participants were mainly focussed on executing the task at hand (59.8%). They metacognitively regulated their personal and the group's learning to a lesser extent (32.6%) and only limitedly provided off-task input (7.6%). 28.3% of students' metacognitive regulation was individual-oriented, whereas 49.2% was shared among students. Results further revealed that 9.3% of students' SSMR was directed at orienting, 21.4 % at planning, 39.7 % at monitoring, and 29.6 % at evaluating. Regarding the function of SSMR, Table 2 demonstrates that SSMR majorly confirmed the course of collaborative learning (24.9%), whereas it changed the direction of ongoing interaction (11.8%) or activated a new direction (9.9%) to a lesser extent. Students were only limitedly involved in SSMR that stopped the course of collaborative learning (2.6%). Table 2 further indicates that CSCL-participants' motives for learning were on average highly autonomous (*M*=3.82, *SD*=0.62) and less controlled (*M*=3.24, *SD*=0.47). Their self-efficacy beliefs were moderate (*M*=3.54, *SD*=0.67).

### 5.2 Profiles of regulators during CSCL (research question 1)

In a first step, hierarchical cluster analysis was conducted based on the frequency scores of students' engagement in individual-oriented regulation and in each of the functions of SSMR. An initial run of one to five clusters was analysed, given that there were no literature-based expectations regarding the number of clusters (Vermunt & Magidson, 2003). Inspection of the dendogram indicated a two- to four-cluster solution, whereas analysis of changes in agglomeration coefficients, pointed at a three-cluster solution. Based on the mean scores for students' individual-oriented and shared regulation behaviour for each cluster, we discerned three regulation profiles (see Table 3). The first cluster, representing the majority of students (n=108; 55.10%), revealed high mean scores on individual-oriented regulation and on SSMR that confirms ongoing interaction. Students in the first cluster are, however, only limitedly involved in SSMR that elaborates collaborative learning by changing its course or by activating a new direction. Their adoption of SSMR that stops interaction is negligible. Given the particularities of students' regulation behaviour in the first cluster, we label the latter as 'all-round-oriented and affirming regulator' (AOAR). In the second cluster (n=57; 29.08%), students' regulation behaviour is characterised by a large involvement in both SSMR that changes the direction of collaborative learning and in SSMR that activates a new direction for ongoing interaction. Their adoption of SSMR that confirms the course of collaborative learning is remarkably smaller and their engagement in SSMR that stops ongoing interaction is very limited. Although students in the second cluster demonstrate a high mean score on individual-oriented regulation, their activation of this regulation behaviour is considerably smaller as compared to AOAR's (see Table 3). The second cluster was named 'social-oriented and elaborating regulator' (SOER). Finally, the third cluster (n=31; 15.82%) represented students whose regulation behaviour is in general limited and mainly individual-oriented. In case these students do engage in SSMR, they dominantly stop interaction (see Table 3), implying they fail to have a meaningful impact on the ongoing interaction when contributing to SSMR. Mean scores for the adoption of SSMR that confirms or changes the course of collaborative learning, or that activates a new direction for ongoing interaction are, in contrast, extremely low. The third cluster was labelled 'individual-oriented and passive regulator' (IOPR).

In a second step, *k*-means cluster analysis was performed aimed at validating the cluster solution unravelled during hierarchical cluster analysis. Table 3 reveals that the final three-cluster solution was confirmed. 52.04% of students could be profiled as AOAR, 32.65% as SOER, and 15.31% as IOPR. An additional MANOVA pointed at significant differences in the frequency scores for individual-oriented regulation and for the functions of SSMR, when comparing the three clusters (*Pillai's trace*= 1.84; $F$(10, 380)= 430.22; $p$<.001; $\eta_p^2$=.61).

In a third step, the stability of the cluster solution was checked for by randomly splitting the sample into halves and repeating the cluster analysis on each subsample (Breckenridge, 2010). Clustering solutions of both subsamples were compared for agreement by means of Cohen's kappa. Cluster analysis on the first ($n$=98) and second split-half dataset ($n$=98) pointed at the same three-cluster structure revealed for the entire sample, as well as at a comparable distribution of students across the regulation profiles in the first (53.62% AOAR, 30.34% SOER, and 16.04% IOPR) and second split-half dataset (52.38% AOAR, 32.13% SOER, and 15.49% IOPR). The three-cluster solution moreover demonstrated the highest agreement ($\kappa$= 0.87), justifying retaining this cluster structure for further analysis.

To sum up the results on the first research question, three profiles of regulators during CSCL could be discerned. The first, all-round-oriented and affirming regulator (AOAR), is actively involved in regulation activities at both the individual and interpersonal level. AOARs' regulative engagement at both levels is, moreover, well-balanced. Their contributions to SSMR are characterised by a confirmation of peers' thinking, resulting in a continuation of ongoing interaction. The second profile, social-oriented and elaborating regulator (SOER), is particularly active at the interpersonal level of regulation. SOERs more specifically react critically and elaboratively to peers during SSMR, which generally moves CSCL in an alternative direction. The third profile, individual-oriented and passive regulator (IOPR), is characterised by a limited engagement in regulation. Regulation activities are, moreover, predominantly focussed on CSCL-participants' personal learning. In the rare cases that IOPRs show SSMR, they fail to generate a meaningful impact on the course of CSCL.

### 5.3 Regulation profiles in relation to students' conceptual understanding (research question 2)

The results of the ANCOVA revealed significant and large differences between the regulation profiles in their understanding of the learning content that was addressed during CSCL ($F(1,192)= 112.50$; $p<.001$; $\eta_p^2=0.54$), after adjusting for students' prior knowledge. Students typified as SOER obtained the highest performance score on the cued-recall knowledge test (*adjusted M*= 20.34, *SD*= 1.99). Post-hoc comparisons by means of the Bonferroni correction confirmed that they significantly outperformed both AOARs (*adjusted M*= 17.95, *SD*= 2.00; *mean difference*= 2.39, $p<.001$) and IOPRs (*adjusted M*= 13.56, *SD*= 2.36; *mean difference*= 6.78, $p<.001$). The analysis further indicated that AOARs obtained significantly higher scores on the knowledge test, as compared to IOPRs (*mean difference*= 4.39, $p<.001$).

### 5.4 Regulation profiles in relation to students' motivation and self-efficacy for learning (research question3)

Results of the MANOVA revealed that the regulation profiles differed significantly in their motivation and self-efficacy for learning (*Pillai's trace*= 0.99; $F(6, 384)= 130.32$; $p<.001$; $\eta_p^2=0.37$). Regarding motivation for learning, the findings revealed significant differences for both autonomous ($F(2,193)= 425.70$; $p<.001$) and controlled motivation ($F(2,193)= 62.55$; $p<.001$). Whereas the effect of regulation profile is large for autonomous motivation ($\eta_p^2=0.31$), it appears medium for controlled motivation ($\eta_p^2=0.19$). Particularly SOERs (*M*=4.04; *SD*=0.20) and AOARs (*M*=4.07; *SD*=0.30) appeared autonomously motivated. Post-hoc comparison by means of the Bonferroni correction demonstrated significant higher levels of autonomous motivation for SOERs as compared to IOPRs (*M*= 2.53; *SD*= 0.26; *mean difference*= 1.50; $p<.001$). Similarly, students typified as AOAR are significantly more autonomously motivated as compared to students typified a IOPR (*mean difference*= 1.54; $p<.001$). AOARs and SOERs do, however, not differ significantly from each other regarding their autonomous motivation for learning (*mean difference*= 0.35; $p= .999$). Comparable results were demonstrated for students' controlled motivation for learning. Students typified as IOPR demonstrated the highest levels of controlled motivation (*M*=3.91; *SD*= 0.43). Post-hoc comparisons showed that these regulators hold significantly more controlled motives for learning as compared to AOARs (*M*= 3.07; *SD*= 0.40; *mean difference*= 0.84; $p<.001$) and SOERs (*M*= 3.20; *SD*= 0.26; *mean difference*= 0.71; $p<.001$). In contrast, AOARs and SOERs demonstrated similar levels of controlled motivation (*mean difference*= 0.13; $p=.094$).

Further, the regulation profiles differed significantly from each other regarding self-efficacy for learning ($F(2,193)= 318.82$; $p<.001$). The effect of regulation profile is large ($\eta_p^2=0.27$). Post-hoc comparison by means of the Bonferroni correction demonstrated significantly higher levels of self-efficacy for learning for SOERs (*M*= 4.21; *SD*= 0.31) as compared to AOARs (*M*= 3.52; *SD*= 0.34; *mean difference*= 0.69; $p<.001$) and IOPRs (*M*= 2.39; *SD*= 0.31; *mean difference*= 1.82; $p<.001$). Self-efficacy beliefs of students typified as AOAR are further significantly higher as compared to these of IOPRs (*mean difference*= 1.13; *p*<.001).

## 6. Discussion and conclusion

The present study aimed at profiling students based on their activation of individual-oriented metacognitive regulation and their adoption of SSMR with specific functions (i.e. confirming, activating, changing, or stopping ongoing interaction) during asynchronous CSCL. Additionally, it studied the regulation profiles in relation to students' test performance and individual learner characteristics (i.e. motivation and self-efficacy for learning).

### 6.1 Three distinct regulation profiles

More than half of the CSCL-participants was typified as 'all-round-oriented and affirming regulator' (AOAR), activating both individual-oriented and SSMR and reinforcing peers' thinking during SSMR, confirming ongoing interaction. They perform moderately when assessing their conceptual understanding after CSCL, hold moderate self-efficacy beliefs, and are autonomously motivated for learning. Less than a third of CSCL-participants was typified as 'social-oriented and elaborating regulator' (SOER). These students are particularly active on the social level of regulation, where they critically react to peers' thinking with elaborative comments, either changing ongoing interaction or activating a new direction. SOERs report autonomous motives for learning and high self-efficacy beliefs. Their good performance on the cued-recall knowledge test demonstrates that these regulators pick up most from CSCL. Last 'individual-oriented and passive regulators' (IOPR) were identified, who remain rather inactive during regulation of CSCL. In case they do activate regulation strategies, these are situated at the individual level. IOPRs doubt their ability to learn and report controlled motives for learning. They perform poorly when assessing their conceptual understanding after CSCL.

In line with SDT (Ryan & Deci, 2000) and with previous findings on SRL and SSMR (Author, 20xxa; Co-author, 20xx; Isohätälä et al., 2017; Li et al., 2020), we put forward SOER as the most favourable regulation profile, particularly in CSCL-settings directed at conceptual knowledge co-construction. These regulators combine an active use of regulation strategies with qualitative motives and strong beliefs in one's competence to learn. They succeed in activating individual and interpersonal regulation and dare to challenge each other's thinking, which is known to create learning opportunities in the group, to move the CSCL-process forward, and to benefit the outcomes of the students involved (Järvenojä et al., 2019; Koivuniemi et al., 2018). The current study demonstrates, nevertheless, that majority of CSCL-participants does not spontaneously adopt the behaviour of SOERs. This highlights the need for integrating metacognitive scaffolds in CSCL-environments, that can prompt collaborative learners to regulate their personal learning, to jointly regulate the group's learning, and to elaborate upon or question peers' contributions (Hadwin et al., 2018; Kim & Lim, 2018; Splichal et al., 2018). The identified regulation profiles moreover stress the need for differentiated instruction in and support of metacognitive regulation during CSCL, customized to the strengths and weaknesses of CSCL-participants' regulation profile (Schnaubert & Bodemer, 2019; Wang et al., 2017). For example, AOARs would particularly benefit from reflection-provoking prompts encouraging them to explore alternative interpretations or to rethink suggested problem solving strategies. In contrast, IOPRs are in need of a multitude of support mechanisms that encourage their activation of regulation strategies at both the individual and interpersonal level and that support both affirmative and interrogative contributions during SSMR. Such highly adaptive and differentiated regulative support is both relevant and necessary, particularly in the (post-)COVID-19 era. Large scale (e.g. university-wide) initiatives of blended or distance learning by means of CSCL have become a new reality, but students often fail to activate an appropriate repertoire of regulation strategies when having to take quasi-full responsibility for managing their own and their group's learning (Järvelä & Rosé, 2020; Melzner et al., 2020). The highly-advanced educational technologies that are currently available (e.g. adaptive tools for learning analytics, intelligent tutoring systems) hold moreover promising opportunities to track CSCL-participants' learning and regulation and to provide them with the customized support they need (Wang et al., 2017; Yilmaz & Yilmaz, 2019; Wise et al., 2021). The results of the present study should be interpreted as practical guidelines to facilitate this.

**6.2 Regulation profiles in relation to students' performance and learner characteristics**

Whereas the current study's importance primarily lays in its practical implications outlined above, its findings also imply a step forward for the growing theory on shared (metacognitive) regulation. On the one hand, the results on how the regulation profiles are related to students' performance and motivation for learning confirm previous findings on SRL (e.g. Baars et al., 2017; Co-author, 20xx; Liu et al., 2014; Paans et al., 2019; Zheng et al., 2020). This means that the many gaps in the current theory on SSMR during CSCL might up to some level be filled by relating to findings obtained in individual learning settings. This insight directly advances the literature on SSMR. The result that IOPRs performed poorly on the knowledge-test, whereas AOARs performed moderately and SOERs performed well when recalling content-knowledge after CSCL, corroborates previous insights on the importance of an active engagement in regulation in view of better learning outcomes (e.g. Co-author, 20xx; Paans et al., 2019; Vuopala et al., 2019). It moreover confirms the benefits of introducing some kind of challenge by involving oneself in regulation that questions the learning taking place (Author, 20xxa; Koivuniemi et al., 2018). It seems plausible to assume that being confronted with peers' conflicting ideas on the learning content, organisation, or learning products of CSCL, encouraged students to monitor and explore alternate perspectives, probably not only stimulating them to rethink ongoing interaction, but also deepening their conceptual understanding (Vuopala et al., 2019). This might explain why SOERs performed best on the knowledge-test after CSCL. The result that AOARs and SOERs were autonomously motivated for learning, whereas controlled motives drove the learning of

IOPRs, is further in line with SRL-studies stressing that active self-regulators generally hold qualitative motives for learning (e.g. Co-author, 20xx; Liu et al., 2014; Vandevelde, 2015; Vansteenkiste et al., 2009).

On the other hand, the finding that IOPRs hold the lowest self-efficacy beliefs and that SOERs perceive themselves significantly more capable for learning as compared to AOARs, implies a refinement of available insights on the relation between students' regulation and their self-efficacy for learning. Although it confirms previous SRL-studies stating that actively regulating learning is facilitated when strongly believing in one's ability to learn (e.g. Co-author, 20xx; Vandevelde, 2015; Wilson & Narayan, 2016), it also demonstrates that in CSCL the relation between students' regulation and self-efficacy is determined more by the content (i.e. function) of SSMR than by the frequency of activating SSMR. SSMR that changes ongoing interaction or that activates a new direction, easily creates difficulty in the group by challenging students to rethink their learning (Author, 20xxa). It should therefore not be surprising that SOERs hold stronger self-efficacy beliefs that facilitate their persistence to engage in this complex regulation behaviour (Pajares, 2008; Wilson & Narayan, 2016), as compared to AOARs who strive more for consensus. This finding is important for it emphasizes the partly unique character of interpersonal regulation by showing that empirical evidence on SRL does not necessarily fully apply to shared regulation during CSCL.

**6.3 Suggestions for future research**

Despite contributing innovative insights, the present study is not free from limitations. The conducted cluster analysis was based on frequency measures of CSCL-participants' overt regulation strategy use, while it can be assumed that not all regulation behaviour (e.g. automated strategies) was made explicit by students (Järvelä et al., 2019). Future research should therefore aim to validate the current cluster solution making use of mixed-methods for assessing students' repertoire of regulation strategies (e.g. eye-tracking, learning analytics, self-report, …). Additionally, it is advisable to replicate the cluster-analysis with larger samples and alternate student populations or other CSCL-formats to examine the stability of the identified regulation profiles. Since it remains unclear whether the current regulation profiles exclusively apply to CSCL, it is further preferable to conduct person-oriented analyses on the regulation behaviour of collaborative learners who meet face-to-face as well. Although particularly the digital tools embedded in many CSCL-settings hold promising opportunities to design flexible regulative supported, adapted to the competences of the regulation profiles (Miller & Hadwin, 2015), it should be acknowledged that the cluster variables that appeared decisive to delineate the regulation profiles are most likely also at play in face-to-face settings. In fact, online peer discussions are frequently shorter and less reciprocal, whereas the synchronous nature and proximity of fellow students in face-to-face settings invite students more easily to deeply operate on each other's thinking

(Fehrman & Watson, 2020; Pifarré & Cobos, 2010). As such, alternate regulation profiles might be unravelled during face-to-face collaborative learning.

Another limitation concerns the current conceptualisation of individual-oriented regulation as cluster variable. By merely focussing on the frequency of occurrence, potential differences in the depth of adopted individual-oriented regulation strategies are neglected (Author, 20xxa; Co-author, 20xx). In line with the functions of SSMR it could, however, be assumed that some individual-oriented regulation strategies (e.g. considering various problem solving approaches) might create more learning opportunities as compared to others (e.g. routinely planning when to submit an individual contribution to the asynchronous group discussion). Taking into account the frequency and depth of both individual-oriented and shared regulation might consequently result in more accurate regulation profiles. Correspondingly, it should be noted that interpersonal regulation can also take the form of co-regulation, implying that one group member instructs a peer to regulate (i.e. dyadic regulative exchanges; Iiskala et al., 2015; Panadero & Järvelä, 2015). CSCL-participants' involvement in co-regulation was, however, not taken into consideration. Further, the present study narrowly focussed on CSCL-participants' regulation of cognition, to the disadvantage of motivational, behavioural, and contextual aspects that can be equally be regulated during CSCL (Hadwin et al., 2017; Isohätälä et al., 2019). Future studies might therefore unravel more comprehensive regulation profiles when integrating the complete social spectrum and all pillars of regulation as cluster variables.

Further, more research is required on the academic success of CSCL-participants based on their regulation profile. The present results pointed at SOERs as the students who picked up most from CSCL. It should be noted, however, that the design of the cued-recall knowledge test that was included as performance measure, might have played a role in this respect. Apart from recalling learning content, CSCL-participants were expected to integrate and elaborate upon terminology and to apply the latter to instructional cases, which relates more to the learning and regulation of SOERs as compared to the other regulation profiles. Alternate measures of students' performance or more comprehensive learning outcomes in future studies might consequently yield other findings on the academic success of learners with a particular regulation profile. Furthermore, although SOER was put forward as the most favourable regulation profile in this study, it should be noted that this is mainly due to the objectives of the CSCL-intervention that were directed at co-constructing domain-specific knowledge. Future research is needed to examine whether students typified as SOER also contribute to, for example, positive socio-emotional interactions, whether they stimulate group cohesion, the extent to which they seek or provide help, the amount and type of feedback they give to peers, etc. (Isohätälä et al., 2021; Ludvigsen, 2016). These less cognitive dimensions of CSCL also have a significant impact on the success and outcomes of CSCL, but were not taken into account in the current study. Further study is consequently needed to confirm or correct the idea that students' regulation should be supported in the direction of SOER in all CSCL-environments.

**6.4 Implications of the current findings**

Despite the limitations outlined above, the current study contributes unique insights to the growing research on shared (metacognitive) regulation during CSCL. By identifying regulation profiles based on online measures of students' individual-oriented and shared metacognitive regulation, acknowledging the multifaceted character of SSMR based on its functions, the study extends the literature on the heterogeneity of SSMR and its differential effectiveness on CSCL-participants' conceptual understanding. Its findings particularly imply a call for differentiated support of (shared) metacognitive regulation during CSCL that meets the needs of collaborative learners' regulation profile.

Taking the abovementioned into account, the present findings imply a valuable starting point for designing customized scaffolding mechanisms in CSCL-environments. The study further highlights the need for eliciting conceptual confusion and critical thinking in the CSCL-group (e.g. by integrating thought-provoking prompts that question students' cognitive processing, or by providing them with automated feedback on digital self- or peer-assessments, which stimulates reflection and discussion on the correctness of their answers). Such confusing or reflective incidents appear to elicit SSMR that changes or elaborates ongoing interaction, often introducing new perspectives in the group. The finding that SOERs, who are frequently involved in SSMR that activates or changes ongoing interaction, performed best on a cued-recall knowledge test after CSCL, confirms that online instructors should aim at integrating scaffolds that challenge students' thinking.

The fact that the regulation profiles demonstrate significantly different correlations with both students' motivation and self-efficacy for learning is further interesting, since these learner characteristics are not fixed but can change depending on students' learning experiences. This implies that lecturers should design CSCL-environments that stimulate autonomous motives for learning and that promote CSCL-participants' self-efficacy beliefs (e.g. by letting students choose which assignments to complete or by including role-taking, such that they can take responsibility, meeting their need for autonomy; by differentiating the content of a learning path based on students' performance on a test or module, by offering tasks that are within a CSCL-participant's zone of proximal development, or by foreseeing automated feedback, and by organizing supervision sessions in which students reflect on their performance and learning, such that a student can perceive him-/herself competent). By fostering students' motivation and self-efficacy, lecturers can indirectly encourage students to shift away from IOPRs' behaviour, which hardly stimulates students' conceptual understanding.

To conclude, the present study sets an innovative agenda for examining the effectiveness of customized scaffolding mechanisms in CSCL-settings in future intervention studies, advancing current insights on how to optimally support CSCL-participants' (shared) regulation behaviour and learning outcomes.

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Appendix. Excerpts from the discussion transcripts illustrating the coding categories

**1. Individual-oriented metacognitive regulation**

| | | |
|---|---|---|
| example 1 | Sam: | *[multiple students activated prior content knowledge on summative and formative assessment but Sam did not interfere in the discussion so far]*<br>"I start to see that self-evaluation has nothing to do with instructional behaviourism that we discussed some weeks ago. I remember scripted self-evaluation from that theme. But now students decide on the evaluation criteria. That is not behaviouristic, I assume?"<br>*[no one reacts to this statement]* |
| example 2 | Rose: | *[the group outlined some suggestions on how to optimize solving the group assignment in the following CSCL-session]*<br>"I still doubt whether our answer on the fourth statement is complete. Shouldn't we explain our reasoning more and relate it to the concept of advance organizer?"<br>*[none of the group members picks up or reacts to this comment]* |

## 2. Functions of SSMR

potential impact on the course of CSCL

| unit of SSMR | | → | |
|---|---|---|---|
| **unit of SSMR** | Tina: "How will we organise this session? Does everyone make sure he/she completes the individual part by the end of this week and then checks the solutions of everyone else next week? Or does someone have another suggestion?"<br>Rose: "Last session that approach led some members to be very active and others rather passive. Maybe it is a better idea to introduce a rotation system, whereby student A comments on the answers of student B, B on C, and so on."<br>Bob: "I like the idea of Rose but then we will not study all statements in depth. Or we can also introduce the rotation system and agree that everyone checks the statements he/she is supposed to check by Wednesday next week. The remaining days are then for a true group discussion on all statements and cases. What do you think?"<br>Rose: "Good plan! I like it!"<br>Tina: "Me too! Let's plan our work that way!" | → | **Function: confirming CSCL**<br>Bob: "I already uploaded my answers on the statements that I was given. I see that the input of Sam is still missing so I will have to wait a bit longer before I can provide feedback. But Rose, you can already start correcting my interpretations!"<br>Rose: "I noticed that you already uploaded your file! I will start evaluating your answers soon, but first I want to finish answering my own statements so that I don't delay the work of Tina."<br>Nick: "My solutions are also on their way! Good strategy by the way, this rotation system!" |
| | | → | **Function: changing CSCL**<br>Bob: "Yesterday was the deadline for uploading our individual answers. I have to revise the answers of Sam but they are still not uploaded. I am starting to doubt whether this rotation system will work. I have also noticed huge differences in how extensive we answered our statements. I wrote like half a page per statement but Rose answered her statements very briefly. That means that Tina can probably add a lot of information, while Rose won't have much to add on my input. Shouldn't we make other arrangements?"<br>Nick: "I also have doubts. Some people are wasting time because they have to wait for the input of others and some can hardly have a meaningful contribution during the feedback phase because the answer is already complete. I am also still waiting. I cannot make a good impression like this, while I really want good marks for this course. Can't we just start evaluating the input that is already there? Irrespective of who posted it and who was supposed to revise it based on the rotation system?"<br>Bob: "Okay, lets' do that."<br>Rose: "Fine by me! Let's start the group discussion!" |

**Function: activating CSCL**

Tina: "This rotation system for providing feedback on each other's answers seems to work well. Maybe we can do something similar for evaluating our final group answer? So that each one consecutively does a final check?"

Nick: "Yes! And also that each one reflects on how we organized the assignment and what we can do to improve our collaboration. We can all list one good aspect and a point for improvement by Thursday and then discuss our collaboration with the whole group on Friday, before closing the session."

Bob: "Good! I like the idea!"

**Function: stopping CSCL**

*[Nick and Sam seem unaware of the rotation system]*

Nick: "There isn't much activity on the forum yet. I have a case on formative teacher evaluation. Is that the same as process evaluation by the teacher?"

Sam: "I don't know whether they are the same. Someone else who can help?"

*[no reaction is given by any other group member]*

Note: The illustration of the function "SSMR changing CSCL" is authentic. Other illustrations are, however, hypothetical in order to make the distinction between the four functions of SSMR as clear as possible.

Table 1. *Data on the quality of implementation of the CSCL-intervention*

| **Critical elements of the intervention** | *M* | *SD* |
|---|---|---|
| *Structure of CSCL-session* | | |
| individual problem solving | 4.42 | 0.39 |
| discussion | 4.59 | 0.24 |
| collective problem solving | 4.02 | 0.55 |
| evaluation | 3.07 | 0.87 |
| *Student activity during group discussion* | | |
| discussing learning content | 4.81 | 0.16 |
| asking questions | 4.77 | 0.39 |
| providing explanations | 3.81 | 0.51 |
| giving feedback | 3.37 | 0.68 |
| reporting | 4.61 | 0.42 |

Note: all items are scored on a five-point Likert scale

Table 2. *Descriptive results on CSCL-participants' metacognitive regulation, prior knowledge, performance, motivation, and self-efficacy*

| | ***frequency (metacognitive statements)*** | ***%*** | ***M*** | ***SD*** | ***min.*** | ***max.*** |
|---|---|---|---|---|---|---|
| individual-oriented metacognitive regulation | 2839 | 28.34 | 14.48 | 4.67 | 2.00 | 28.00 |
| SSMR confirming CSCL | 2496 | 24.91 | 12.73 | 8.43 | 0 | 28.00 |
| SSMR changing CSCL | 1185 | 11.83 | 6.05 | 5.22 | 0 | 19.00 |
| SSMR activating CSCL | 987 | 9.85 | 5.04 | 4.53 | 0 | 18.00 |
| SSMR stopping CSCL | 261 | 2.61 | 2.46 | 1.33 | 0 | 10.00 |
| prior knowledge | - | - | 8.36 | 2.85 | 3.00 | 18.00 |
| performance | - | - | 17.95 | 3.39 | 10.00 | 28.00 |
| autonomous motivation | - | - | 3.82 | 0.62 | 2.00 | 4.90 |
| controlled motivation | - | - | 3.24 | 0.47 | 2.29 | 4.57 |
| self-efficacy | - | - | 3.54 | 0.67 | 1.75 | 5.00 |

Note: In total, 10019 statements of metacognitive regulation were segmented, of which 2251 (22.46%) were not coded since they were not individual-oriented, neither shared.

Table 3. *Mean scores and standard deviations of the regulation profiles on the cluster variables*

| | **hierarchical clustering** | | | ***k*-means clustering** | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| **cluster variables** | AOAR (n=108) | SOER (n=57) | IOPR (n=31) | AOAR (n=102) | SOER (n=64) | IOPR (n=30) |
| individual-oriented metacognitive regulation | 17.72 (2.52) | 10.95 (1.64) | 9.71 (5.38) | 17.52 (2.33) | 11.02 (1.91) | 9.81 (5.03) |
| SSMR confirming CSCL | 19.87 (3.45) | 5.79 (1.78) | 0.97 (0.59) | 19.46 (3.40) | 5.88 (1.71) | 0.94 (0.57) |
| SSMR changing CSCL | 3.85 (1.67) | 13.42 (2.36) | 0.13 (0.04) | 4.02 (1.62) | 13.36 (2.42) | 0.09 (0.04) |
| SSMR activating CSCL | 3.28 (1.94) | 11.11 (2.62) | 0.00 (0.00) | 3.89 (1.68) | 11.03 (2.58) | 0.00 (0.00) |
| SSMR stopping CSCL | 0.64 (0.18) | 0.16 (0.04) | 5.90 (3.29) | 0.60 (0.15) | 0.14 (0.04) | 5.93 (3.21) |

*Figure 1.* Theoretical model of metacognition by Nelson (1996)

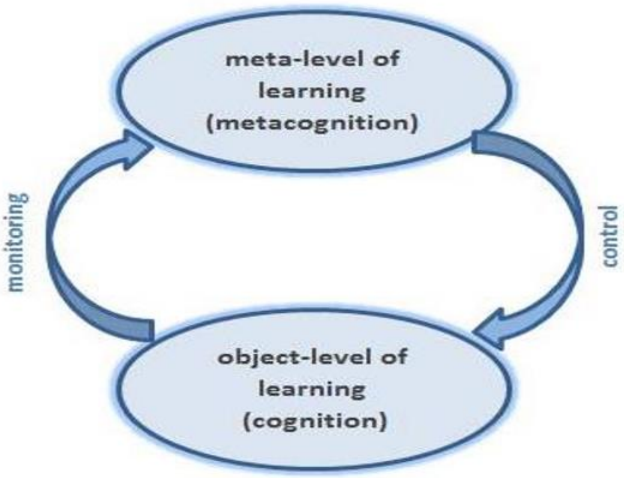

*Figure 2.* Forms of metacognitive regulation at the individual and interpersonal level

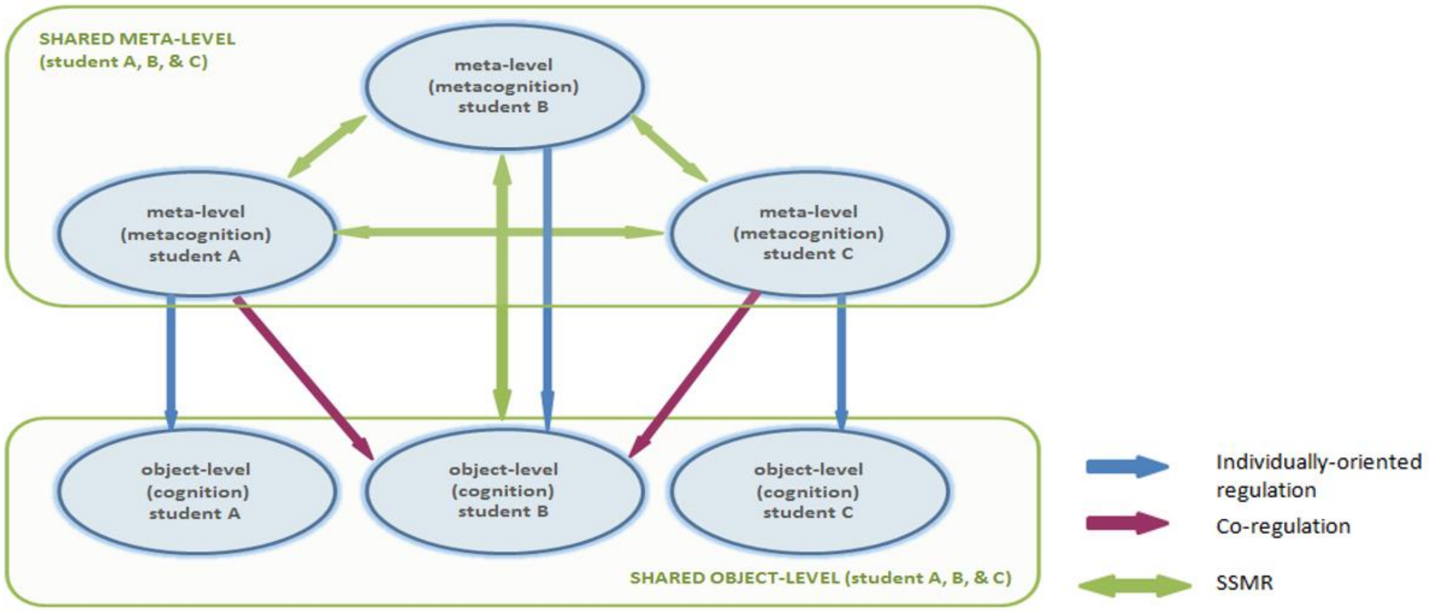

*Figure 3.* Chronological overview of the CSCL-intervention