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Regulation of collaboration in project-based learning mediated by CSCL scripting reflection

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ABSTRACT

Many studies attempt to effectively support student regulation of collaboration using CSCL tools to enrich learning outcomes. However, few studies are aimed at facilitating development of students' internal scripts for regulation of collaboration. This study focuses on developing and evaluating a computer-mediated learning environment for project-based learning to facilitate student internal scripts for regulation by designing external scripts for effective reflection. Forty-eight first-year university students participated in this study as part of their curriculum. Our analyses of their internal scripts before and after PBL participation revealed that significantly more students who encountered an unfamiliar situation during collaboration constructed new regulation scripts. Moreover, in case studies, we found that students augmented their scripts for socially shared regulation when recognizing socio-cognitive challenges, whereas they augmented co-regulation and self-regulation scripts when recognizing socio-emotional challenges.

1. Introduction

Collaboration is a key practice for success in the twenty-first century economy. Worldwide organizations like ATC21S consider productive, innovative, and efficient collaboration as necessary skills (Griffin, MacGaw, & Care, 2012). In education research, these necessary skills have been viewed as regulation of collaboration (Hadwin, Järvelä, & Miller, 2011). To succeed, collaborators are expected to negotiate task goals and standards, to act strategically while monitoring, to revise processes and outcomes, to use suitable technological tools, and to productively deal with the challenges they face. Studies have demonstrated that many learners experience difficulty in developing required competencies through classroom learning (Järvelä, Järvenoja, Malmberg, & Hadwin, 2013; Lust, Elen, & Clarebout, 2013; Strijbos, Kirschner, & Martens, 2004; Winne, Hadwin, & Perry, 2013; Wu, 2015).

In response to such circumstances, educational researchers have conducted studies for supporting student regulation in collaboration. The research comprises two streams: theory development research that examines how learners engage in regulatory processes (e.g., Rogat & Adams-Wiggins, 2015), and instructional intervention research that develops computer-supported collaborative learning (CSCL) systems (e.g., Järvelä et al., 2016; Raes, Schellens, De Wever, & Benoit, 2016).

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1.1. Regulation of collaboration: theory development research

Hadwin et al. (2011) describe four assumptions in the context of extending regulated learning from the individual level to the group level. The first is that regulated learning is intentional and goal-directed. Learners should be engaged in the process of setting and committing to learning goals. Goals are learners' interpretations of their tasks in the form of specific strategic objectives and directions (Winne & Hadwin, 1998, 2008), and these vary in nature. They primarily function as standards for monitoring and evaluating learner progress and outcomes (Winne et al., 2013). The second assumption is that regulated learning is metacognitive, namely, that self-regulated learners can appropriately plan, monitor, and revise their learning as necessary. The third assumption is that regulated learning involves sustained control of behavior, cognition, motivation, and emotion. In collaborative learning, learners should be engaged in two distinct processes: shared knowledge construction focused on the domain knowledge, and shared regulation focused on the construction of metacognitive, meta-motivational, and meta-emotional knowledge (Järvelä & Hadwin, 2013; Winne et al., 2013). The fourth assumption is that regulated learning occurs in social contexts. Recent models of regulation of collaboration (Hadwin & Oshige, 2011; Hadwin et al., 2011; Volet, Vauras, & Salonen, 2009) emphasize the social nature of the regulatory process.

When contributing to a collaborative task, learners must regulate themselves, others, and the group (Winne et al., 2013). In self-regulated learning (SRL), learners regulate their learning to contribute to group performance, based on individual perceptions of task and strategic knowledge. In co-regulated learning (CoRL), learners mutually engage in self-regulation. Specifically, each learner in a group self-modifies actions and supports others' processes while monitoring others' task perceptions, goals, and standards. In socially shared regulation of learning (SSRL), learners collectively regulate group cognition. In Hadwin et al. (2011), SSRL is defined as “interdependent or collectively shared regulatory processes, beliefs, and knowledge orchestrated in the service of a co-constructed or shared outcome/product” (p. 69). In SSRL, learners engage in the shared planning, monitoring, evaluation, and regulation of social, cognitive, and behavioral aspects of their learning.

Studies over the last decade have empirically supported the importance of social regulatory processes for collaborative learning. For instance, Järvenoja and Järvelä (2009) found three forms of regulation—individual, other, and shared regulation—which are used to maintain group work when students encounter challenges. Moreover, they found that social regulation is associated with the use of productive learning strategies and learning transfer. Building on these findings, other studies (e.g., Hadwin & Oshige, 2011; Hadwin et al., 2011; Miller & Hadwin, 2015) have identified and described forms of co-regulation. Members sometimes support other group members such that both contribute to the collaboration. In another form of co-regulation, a single member attempts to co-regulate others in the group to maintain more productive collaboration. Rogat and Adams-Wiggins (2015) further extended the discussion by investigating members' co-regulatory strategies. They found two forms of co-regulation, directive and facilitative. In directive co-regulation, members attempt to control others' behavior and contributions based on their task perceptions and monitoring. Yet, this form of co-regulation often results in negative or disrespectful socio-emotional reactions. In another form of co-regulation, facilitative co-regulation, members attempt to support others' behavior and contributions while respecting their ideas and actions. In comparison with the directive approach, facilitative co-regulation usually results in positive socio-emotional interactions and respectful reactions.

While learning outcomes might be more successful if learners appropriately engaged in SSRL, they often find it difficult to engage in metacognitive-level strategies. Miller and Hadwin (2015) summarize the difficulties students encounter when engaging in a collaborative task. In individual-level contexts, students may not appropriately or correctly interpret the academic task. This is even seen at the university level. Moreover, there can be significant misalignments in collaborative contexts if task interpretation and goal-setting varies among group members (Hadwin et al., 2011; Winne et al., 2013). The task perception phase plays a vital role in students' regulatory processes, but they often have difficulty in constructing task perceptions. For example, Rogat and Linnenbrink-Garcia (2011) have found that students do not pay attention to their perceptions of task completion. Considering these findings, accurate task perceptions should be shared among group members for fruitful and productive collaboration. However, this process requires students to engage in social interaction to compensate for their lack of metacognitive knowledge, regulatory skills, and strategies.

1.2. Instructional intervention research: CSCL for regulation of collaboration

With this theory development in mind, we now review instructional intervention research. This line can be divided into two types, studies for developing CSCL environments and elements for supporting learner regulation, and studies of CSCL intervention practices.

1.2.1. CSCL environments for supporting regulation in collaboration

There are two approaches to supporting learner regulation through CSCL environments: focusing on educational affordance or on social affordance (Järvelä et al., 2015; Kreijns, Kirschner, & Vermeulen, 2013). CSCL environments focused on educational affordance attempt to determine particular actions taken in a given situation through instructional intervention. gStudy (Winne et al., 2006), a representative work taking the educational affordance approach, attempts to facilitate learner SRL, CoRL, and SSRL through various tools embedded in a CSCL environment (Hadwin, Oshige, Gress, & Winne, 2010; Winne, Hadwin, & Gress, 2010). gStudy is an environment for knowledge co-construction in which learners or instructors can create or import learning content (called *learning kits*). gStudy enables three types of activities: (1) working on individual learning kits and sharing the outcomes, (2) collaboratively working on learning kits, and (3) working on individual learning kits and sharing them as collaborative learning kits. Learners can work on learning kits using tools such as a chat tool where instructors can make prompts and give feedback, a guided chat tool where generic and role-assigning prompts are embedded, or template notes. These activities stimulate learner's SRL, CoRL, and SSRL, and the embedded tools enable instructor co-regulation. gStudy gathers detailed process data and metadata of learner actions to leverage feedback for learners, for analyses, and for the further development of CSCL tools (Hadwin et al., 2010; Kumar, Gress, Hadwin, & Winne, 2010; Winne et al., 2010). Meanwhile, van Joolingen, Jong, Lazonder, Savelsvergh, and Manlove (2005) developed an environment called Co-Lab that is augmented with a tool called the Process Coordinator. Co-Lab is an environment that facilitates collaborative discovery learning in the natural sciences. Process Coordinator supports learner's regulation processes such as planning, monitoring, and evaluation by providing a hierarchy of preset goals, hints and explanations, and a template for the final report. In this environment, learners engage in conducting experiments through simulations and expressing their understandings in a shared space, while the environment affords and supports their regulation process. In another study, Molenaar, van Boxtel, Sleegers, and Roda (2011) developed a dynamic scaffolding tool called AtgentSchool. AtgentSchool includes an attention management system that tracks and gathers information of learner acts in computer-based learning environments. AtgentSchool scaffolds learner cognition, metacognition, and motivation dynamically via a virtual agent by leveraging that information.

Recent studies supporting learner regulation through CSCL environments have shown the importance of social affordance. Such CSCL environments attempt to determine specific social interactions to promote learner awareness of own, other, and group processes and performances. While poor interactions would clearly result in socio-emotional conflict and dysfunctional collaboration (Teasley & Roschelle, 1993; Barron, 2003), supporting those affective issues has been neglected in CSCL research (Dillenbourg, Järvelä, & Fischer, 2009). Recent studies of developing Virtual Collaborative Research Institute (VCRI; Jaspers, Broeken, & Erkens, 2004; Phielix, Prins, & Kirschner, 2010) and SSRL tools (e.g., Järvelä et al., 2016) have thus focused on social affordance. VCRI has often been used to extend collaborative work in virtual settings via chat and co-writing (Co-Writer) tools while encouraging learners to self- and peer-assess their social and cognitive performance using a Radar tool. Learners further reflect on their individual and collaborative behavior and performance using a tool called Reflector (Phielix et al., 2010). The self- and peer-assessment data that Radar collects can be anonymously visualized for the group. The VCRI environment is expected to help learners improve their social performance in a way that results in better cognitive performance.

The Adaptive Instrument for Regulation of Emotion (AIRE; Järvenoja & Järvelä, 2009; Järvenoja, Volet, & Järverä, 2013) marked a new stage in the development of SSRL tools. AIRE focuses on assessing learner experiences of socio-emotional challenges and the individual or socially shared regulation they executed. The instrument asks learners to rate how well generic statements and scenarios of goals, regulation strategies, and socio-emotional challenges describe their cognition and experiences on a 4- or 5-point Likert scale. AIRE data reveal learner goals, interpretations of socio-emotional challenges, the degree of SRL and SSRL, and coherence of these across group members. Implementation of AIRE found that interpretation of socio-emotional challenges varies among group members and among groups. The ideas and findings of AIRE were later adapted in SSRL tools such as the Socio-Emotional Sampling Tool (SEST; Webster & Hadwin, 2013), Individual Planning Tool and Shared Planning Tool (IPT and SPT; Hadwin, Miller, & Webster, 2013; Miller, Webster, & Hadwin, 2013; Miller & Hadwin, 2015), and OurPlanner and OurEvaluator (Järvelä et al., 2015). SEST supports learner regulation by scripting and prompting learners to monitor and evaluate their current emotions before, during, and after the task. SEST requires learners to complete a reflection essay related to motivation and emotion by filling in blanks and choosing items from drop-down menus. In contrast, AIRE asked learners to rate how well statements and scenarios describe their experiences. IPT and SPT help learners define tasks, set goals, make plans, and reflect on the challenges encountered individually (IPT) or collaboratively (SPT) using a series of questions asking them to fill in blank text boxes before each task.

While developing these SSRL tools in consideration of VCRI, Järvelä et al. (2015) identified three design principles to support SSRL: "(1) increasing learners' awareness of their own and others' learning process, (2) supporting the externalization of students' and others' learning process and helping in sharing and interaction, and (3) prompting the acquisition and activation of regulatory processes" (p. 136). Furthermore, by building on VCRI while incorporating the ideas of SSRL tools, they reshaped VCRI to promote SSRL on the basis of these three design principles. They tailored the Radar tool and reformulated the Co-Writer, OurPlanner and OurEvaluator. The tailored Radar assisted promoting and sharing learner awareness of motivation, self-efficacy, group capableness, and task interpretation. OurPlanner and OurEvaluator facilitate shared planning and evaluation based on SPT. The three design principles they identified and the environment they developed presented a way to facilitate learners' mutual interactions and regulatory processes that improve cognitive performance. By incorporating the ideas of AIRE, they offered a new way to collect otherwise unobservable individual and shared metacognition during learner collaboration, which is useful for supporting learners and conducting research.

1.2.2. CSCL intervention practices

Since CSCL intervention practices are being carried out concurrently with CSCL development research, there is educational practice research that leverages existing tools (e.g., Adobe Connect 9) in addition to using the CSCL environment described above. In this section, we provide a review of studies adopting the CSCL environment and utilizing existing CSCL tools, while describing research design based on the experimental approach and case-based methods.

1.2.2.1. Experimental approach. Some studies that used experimental design concluded that instructional interventions did not necessarily facilitate learning outcomes over the control condition (Janssen, Erkens, Kanselaar, & Jaspers, 2007; Manlove, Lazonder, & Jong, 2009; Molenaar, Roda, van Boxtel, & Sleegers, 2012; Raes et al., 2016). Manlove et al. (2009) carried out physics inquiry learning implementing the Co-Lab environment mentioned in section 1.2.1. Students using Process Coordinator from which all regulative directions were removed were assigned to the control condition while students using Process Coordinator with supports were assigned to the experimental condition. Contrary to expectations, they found that Process Coordinator with supports had only partial effects on supporting regulation. Compared with the control condition, it only increased the frequency of planning. Moreover, regardless of the condition, the more students used planning and content monitoring supports, the higher their lab report quality but the lower their physical model quality. Similar to Manlove et al. (2009), Molenaar et al. (2012) examined that how AtgentSchool (mentioned in section 1.2.1.) supports student SSRL. With the support of a virtual agent, students in the experimental condition worked in pairs over six lessons (45 min each), finding and writing reasons why they wish or do not wish to live in New Zealand. Students in the control condition did not receive supports. The results revealed that students under the experimental condition wrote better essays and asked more questions than did students under the control condition, but there were no significant differences between the conditions with regards to scores on tests regarding domain knowledge about New Zealand. Manlove et al. (2009) and Molenaar et al. (2012) argued that the instructional intervention they implemented led students to focus on lab report or essay content, but not on modeling work or acquisition of domain knowledge.

In another study, Raes et al. (2016) carried out web-based inquiry learning using collaboration scripts provided in WISE (Slotta & Linn, 2009). Collaboration scripts assigned students working in pairs to a role responsible for searching the web and typing answers, or to a role responsible for metacognitive evaluation. Students were prompted to switch roles at the beginning of each new activity. Similar to findings in previous studies, only one marginally significant effect of collaboration scripts, namely, facilitating students to compare several sources and reach consensus about the usefulness of the source, was found as compared with the non-script condition. Moreover, they found that the scripted condition did not specifically influence group performance. Regardless of the condition, the task analysis led students to better group performance. This was also confirmed in a case analysis of four groups focusing on the best- and worst-performing groups in each condition. Results suggested that each member of the best-performing groups had the motive, ability, and responsibility for their role and belief that peers could perform their role. These resulted in even activity and careful elaboration of information processing, regardless of the assigned or emergent roles. Examining student improvement in strategic knowledge for web-based inquiry learning, Raes et al. (2016) moreover found that students in both the experimental and control conditions improved their strategic knowledge, and that there was no significant difference between the conditions. Similar to Raes et al. (2016), Janssen et al. (2007) reported that the CSCL environment they developed did not affect group performance. They augmented an early version of VCRI (Jaspers et al., 2004) with Participation Tool for students in the experimental group. The tool graphically represented each member's contribution to the group and to the community and facilitated student SSRL, but did not affect group performance in the experimental condition over the control condition.

Results from some studies provide evidence that CSCL supports student regulation of collaboration. Jermann and Dillenbourg (2008), for instance, developed experimental equipment for evaluating graphical feedback for student contributions. They conducted two experiments that each required students to engage in a 1-h task, namely reducing traffic congestion by adjusting the timing of traffic lights in a simulation. In contrast with Janssen et al. (2007), they found that providing graphical feedback with a standard of desirable participation balance was most effective. This kind of feedback facilitated student planning, resulting in successful group performance.

The above studies have yielded mixed results, and little is known about the generalizable effectiveness of scripting (e.g., Vogel, Wecker, Kollar, & Fischer, 2016). The studies further suggested that supports were particularly effective only when suited to each task, student, and group (Janssen et al., 2007; Manlove et al., 2009; Molenaar et al., 2012; Raes et al., 2016). Since the effectiveness of interventions and scripting depends on context, it is necessary to aggregate further findings by collecting narratives in more detail. The case-based method may provide more information on how learners in successful collaboration engage in regulatory processes and what is missing in unsuccessful groups.

1.2.2.2. Case-based method studies. Case-based method studies are classified as (1) single case analyses and (2) comparative analyses of multiple cases. Näykki, Järvelä, Kirschner, and Järvenoja (2014) analyzed a group that had fallen into socio-emotional conflict while members worked on inventing a new teaching practice through the experience of engaging in technology-enhanced learning activity for twelve weeks. Students used Web 2.0 tools such as wikis (Laru, Näykki, & Järvelä, 2012). They indicated that students tend to adopt avoidance-focused emotion regulation when encountering socio-emotional conflict, and thus could not maintain a well-balanced atmosphere, resulting in lower performance. Further, negative social interactions such as overruling, undermining, and normative interaction created socio-emotional challenges. Meanwhile, Lajoie et al. (2015) analyzed regulation while medical students learned how to deliver bad news to patients in an international web-based, problem-based learning environment. They used Adobe Connect 9 as the CSCL environment. The students were supported by facilitators. They found that as activity advances, the frequency of metacognition trends higher, and planning, monitoring, and executing are followed by reflective phases such as monitoring, evaluation, and elaboration. In contrast to Näykki et al.'s (2014) case, they revealed that co-regulation and positive reciprocal actions tend to occur together to advance discussion and develop shared understanding.

Lee, O'Donnell, and Rogat (2015) described a comparative case study of a shared regulation group and a directive co-regulation group. They analyzed chat logs of students engaged in three interrelated hour-long tasks to examine how students used regulatory sub-processes such as planning, monitoring, and evaluation. They used Sakai as the CSCL environment, and prompts facilitated shared regulation in each task. First, they revealed that the form of planning and task monitoring activities reflected group ambiance (socially shared or directive co-regulated). Members in the socially shared group engaged in shared planning and task monitoring and created a socially shared ambiance. In the directive co-regulated group, however, one member was responsible for planning and task monitoring, and other members followed. Second, content monitoring played a vital role in high-quality co-construction of knowledge. In both groups, students engaged in a high quality of shared content monitoring, such as monitoring the development of task responses using elaboration and revision, which is directly connected to the high-quality co-construction of knowledge. The directive co-regulation group maintained high-quality shared content monitoring and co-construction of knowledge as did the socially shared group, even though uneven sub-processing of regulation would be expected to result in low performance. Lee et al.

(2015) suggested that members, except for co-regulators, in a directive co-regulation group could invest regulatory resources to content monitoring and co-constructing the task response, because the directive co-regulator oversaw planning and task monitoring. They further discussed non-face-to-face learning environments, where group members have limited access to social and affect reactions, resulting in successful directive co-regulation instead of socio-emotional conflict.

Schoor and Bannert (2012) also conducted a comparative study between high- and low-performing groups working on a 90-min task to explore sequences of regulatory sub-processes and their relationships to group performance. Each student was provided with different learning texts on a statistical topic and asked to individually develop a handout. They then cooperated with students who studied different texts to create a joint handout. They communicated only via chat and a shared editor on the course management system (Schoor & Bannert, 2011). Students were prompted to first review each other's individually created handouts and develop consensus, and then to create a joint handout while elaborating it. Using a process-mining technique, they found no remarkable difference between the two groups. They further suggested that insufficient task interpretation resulted in lower group performance. Expanding on this study, Malmberg, Järvelä, Jävenoja, and Panadero (2015) implemented a tailored VCRI environment (mentioned in section 1.2.1) to collect further student information of unobservable metacognition (e.g., interpretation of the challenge) and to support regulation. Over two months, students wrote nine brief essays about how to leverage technology in educational contexts. Malmberg, Järvelä, Järvenoja, and Panadero (2015) identified 391 challenges, 383 regulation strategies, and 27 combinations of challenges and regulation strategies. Comparing the regulation processes of higher and lower performing groups, they found that the higher-performing group progressively focused on regulating cognitive, motivational, and social challenges, while the lower-performing group focused on regulating external constraints such as the learning environment and time. Kwon, Liu, and Johnson (2014) reported findings similar to those of Malmberg et al. (2015). They used discussion forums for group communication and wikis for collaborative writing, and assigned students with tasks for creating a clinical ethics case scenario. They found that successful collaborators interacted with each other from early stages of the sixteen-week task while maintaining positive socio-emotional interaction and adapting their regulation strategies as the task proceeds. Further, they found that poor collaborators showed few interactions and least socio-emotional interactions throughout projects, or rushed at the end of the project without negotiating a clear group coordination plan.

Compared with studies using rigorous experimental designs (e.g., Janssen et al., 2007; Jermann & Dillenbourg, 2008; Manlove et al., 2009; Molenaar et al., 2012), case-based method studies provide more information on how learners engage in regulatory processes and what is lacking in unsuccessful groups. Successful learners engaged in adequate task monitoring and used correct task interpretations and high-quality content monitoring to elaborate their task response (Lee et al., 2015; Schoor & Bannert, 2012). They also adopted positive reciprocal actions to reduce and regulate motivational and socio-emotional challenges (Kwon et al., 2014; Lajoie et al., 2015; Malmberg et al., 2015; Näykki et al., 2014). Unsuccessful group members often failed to construct adequate task perceptions (Schoor & Bannert, 2012) and tended to engage in poor mutual interactions that resulted in socio-emotional conflict, avoidance-focused regulation when facing socio-emotional conflict, and regulating external challenges (Kwon et al., 2014; Malmberg et al., 2015; Näykki et al., 2014).

1.2.3. Focus of the present study

Although many studies emphasize collaboration skills (Griffin, McGaw, & Care, 2012), few examine progress in learner regulation as improvement of collaboration skills and knowledge. For instance, many studies (e.g., Janssen et al., 2007; Jermann & Dillenbourg, 2008; Manlove et al., 2009; Molenaar et al., 2012; Raes et al., 2016) examined whether intervention facilitated student regulation and resulted in a high-quality domain-specific knowledge construction. Some studies (e.g., Lajoie et al., 2015; Lee et al., 2015) have elucidated how regulation strategies contribute to the construction of shared understanding and group atmosphere. Other studies (Kwon et al., 2014; Malmberg et al., 2015; Näykki et al., 2014; Schoor & Bannert, 2012) instead clarify how students who successfully create high-quality task responses were engaged in regulatory processes, and further identify how other students fail. These studies focus on regulation in relation to the task response, but do not examine progress in students' regulation of collaboration. For designing effective learning environments for learners to develop their regulatory skills and knowledge in collaboration, we further need to examine the relationship between collaborative learning process and change in their regulatory skills and knowledge as a consequence. Hence, the present study attempts to examine progress in student regulation of collaboration.

To do so, we focused on ill-structured tasks that require learners to engage in long-term collaborative efforts to develop their thoughts and ideas for two reasons. First, long-term courses are necessary for examining progress in student regulation, because students significantly improve general learning skills when they use such skills extensively and repetitively (e.g., Bereiter & Scardamalia, 2014; Paavola, Lipponen, & Hakkarainen, 2004). In long-term course studies elucidating how students engaged in regulation processes (Kwon et al., 2014; Lajoie et al., 2015; Malmberg et al., 2015; Näykki et al., 2014), students were found to adapt their regulation strategies as the task advances. They engaged in a comprehensive regulatory process including motivational and socio-emotional regulation for successful task accomplishment. In short-term course studies (Lee et al., 2015; Schoor & Bannert, 2012), on the other hand, monitoring task and content played a vital role in completing tasks. Monitoring tasks and content is a part of the regulatory process, but it does not cover the comprehensive process. Long-term courses are therefore suited toward fostering students' regulatory skills. Second, an ill-structured long-term task requires learners to exert extra effort toward regulating motivational and socio-emotional aspects. When working on ill-structured tasks collaboratively, learners are challenged out of their comfort zones through confronting socio-cognitive challenges such as discussing and negotiating to consolidate ideas. They strive for identity and sense of belonging, because they often must change their initial beliefs, thoughts, and opinions during the elaborating process (Näykki et al., 2014; Paavola et al., 2004). Thus, they must reciprocally care for their emotions to smoothly accomplish tasks. Discomfort gives rise to socio-emotional conflicts. The studies that we classified as long-term courses above (Kwon et al., 2014; Lajoie et al., 2015; Malmberg et al., 2015; Näykki et al., 2014) also adopted ill-structured tasks and revealed that motivational and socio-emotional regulation were key processes for success. We therefore presume that long-term courses with ill-structured tasks meet our instructional goal: understanding how to manage collaborative learning. Considering the recent emphasis on long-term collaborative construction of ideas and knowledge as well as students' motivational and socio-emotional regulation (Bereiter & Scardamalia, 2014; Dillenbourg et al., 2009; Paavola et al., 2004), studying how students progress in their regulation under such settings has profound significance in educational research.

In examining the effectiveness of CSCL environments for facilitating student collaboration regulation, we attempted to extend the previous studies toward CSCL implementation for mediating face-to-face collaboration. As Dillenbourg et al. (2009) discussed, CSCL environments not only allow face-to-face collaboration in virtual settings, but also augment it. CSCL tools shape verbal interactions in several ways, such as scripting and graphical representations for both settings. To augment face-to-face collaboration, it is crucial to support unique computer-mediated interaction that is not available in simple face-to-face situations. For instance, Manlove et al. (2009), Molenaar et al. (2012), and Raes et al. (2016) implemented a computer-mediated learning environment and examined its effectiveness. However, it is necessary to further examine the effectiveness of the environment—while also aiming at facilitating progress in their regulation—of long-term courses with ill-structured tasks, because most previous studies have assigned students with short-term, well-structured tasks.

1.3. Current study

This study aimed at designing a computer-mediated learning environment that facilitates regulation and its improvement while students work on an ill-structured task. We develop a long-term project-based learning course using Knowledge Forum (KF; Scardamalia & Bereiter, 2014). We tailored KF based on the three design principles (*awareness*, supporting *externalization*, and *prompting*) by Järvelä et al. (2015). KF was used as a digital portfolio where students collaboratively reflected on face-to-face project-based learning. To activate regulation strategies, we provided learners with metacognitive question prompts by customizing KF's scaffold function.

To facilitate and evaluate progress in student regulation of collaboration, we followed the "script theory of guidance" by Fischer, Kollar, Stegmann, and Wecker (2013). With four script components (*play*, *scene*, *role*, and *scriptlet*) and seven principles, the script theory of guidance provides a useful framework for examining how collaboration processes are shaped by learners' dynamically configured and reconfigured internal scripts, and how internal scripts develop through experiencing collaboration while considering the influence of external scripts. The internal scripts are learner knowledge regarding how to regulate collaboration, and are described from the abstract level (play) down to the concrete action level (scriptlets). Since we aimed at designing an environment that facilitates student regulation scripts, we focused on six interrelated principles of internal script development. According to the script theory of guidance, learner understanding and actions are guided by dynamically configured and reconfigured internal scripts (the "internal script guidance principle"), which are influenced by learner goals, by situational perception (the "internal script configuration principle"), and by external scripts that inhibit the automated use of available internal script components. External scripts induce a functional configuration of internal script components in order to orient learners toward productive actions (the "external script guidance principle"). Learners configure a new set of available internal script components when encountering unfamiliar situations (the "internal script induction principle"), and modify internal scripts that do not lead to understanding or successful actions (the "internal script reconfiguration principle"). Through experiencing collaboration and iterative reconfiguration of internal scripts, learners develop and internalize internal scripts as knowledge and collaboration skills that are also useful in other settings. External scripts are most effective for learners when they are not too specific ("over-scripting" (Dillenbourg, 2002)), do not prevent autonomous use of internal scripts and do not inhibit reconfiguring and developing a new set of internal script components (the "optimal external scripting level principle").

In our study, we examine students' regulation scripts as a repertoire of regulatory processes in SRL, CoRL and SSRL, and whether the repertoire had increased after the project-based learning. We also consider the optimal external scripting level principle as a design principle for developing the learning environment. Therefore, the research questions in this study are (1) do students augment regulation scripts through experiencing collaboration in the developed learning environment, and (2) how do they advance their regulation scripts?

2. Method

2.1. Participants and project

Forty-eight first-year students in the Department of Informatics at a Japanese public university participated in a 13-week (one semester) course. The course was a curricular requirement for students in the department. They were randomly divided into twelve groups of three to five. The instructional goal was to improve student understanding of collaboration regulation. Students were challenged to collaboratively propose innovative solutions for reducing waste at convenience stores. Five mentors supported group activities and collected classroom observational data. Students engaged in 90-min face-to-face sessions followed by writing their reflections regarding regulatory processes on Knowledge Forum each week.

Table 1
Course description.

Face-to-face activity	Week	KF activity
Students decided their jigsaw group name, then each member selected one of four article sets describing different stakeholder perspectives.	Week 1	–
Students with the same article sets co-constructed understanding of each stakeholder's perspective. (Expert group activity)	Week 2 Week 3 Week 4	Reflect on expert group activity by writing a group progress note and individual reflection notes every week (supported by metacognitive prompts).
Students individually completed a free-response questionnaire about their regulation of collaboration.	Homework	–
Students integrated ideas in the four article sets and worked on proposing solutions. (Jigsaw group activity).	Week 5 Week 6 Week 7 Week 8 Week 9 Week 10	Reflect on jigsaw group activity by writing a group progress note and individual reflection notes every week (supported by metacognitive prompts).
Poster fair	Week 11	
Reflecting on overall jigsaw group activity by collaboratively writing a group reflection essay.	Week 12	Submit the group reflection essay.
Students individually completed a free-response questionnaire about their regulation of collaboration.	Week 13	–

2.2. Learning environment and external scripts

We designed the course curriculum based on the jigsaw method for facilitating acquisition of domain-specific knowledge and constructive interaction for innovating ideas (Miyake & Kirschner, 2014). As particular scaffoldings, we took the scripting approach to the design principles of Järvelä et al. (2015), namely, awareness, supporting externalization, and prompting. Considering the optimal external scripting level principle, we provided scene-level scaffoldings supporting student reflection on their regulatory actions. We further supported student regulation through metacognitive prompts serving as second-order scaffolding (van Merriënboer & Kirschner, 2013; Järvelä et al., 2015, 2016). Järvelä et al. (2015, 2016) propose that metacognitive prompts do not support the acquisition of domain-specific knowledge, but rather support student use and advancement of regulation scripts as general knowledge and skills through their activation. Table 1 shows the course description. In the first week, we prepared four article sets describing how to reduce waste at convenience stores from the perspectives of four stakeholders, namely, customers, store managers, chain offices, and logistics companies. We asked students to decide jigsaw group names and who would work on which articles. In weeks 2 through 4, students in charge of the same sets of articles regathered in the expert groups, and collaboratively discussed the issue in the articles from their assigned perspective. Each week, we asked students to collaboratively write a group progress note as a public KF note and to add their individual reflections as public build-on notes (Fig. 1). To support their reflection, we provided metacognitive prompts through KF's scaffold function (Table 2). In the expert group activity, we implemented the prompts to support domain-specific knowledge acquisition. Prompts for the expert group activity facilitated shared monitoring of the group progress note, and evaluation and revision at the individual or group level for individual reflections. After the expert group activity, we assigned a questionnaire survey as homework, the details of which are described in the next section. During weeks 5 through 10, students returned to their jigsaw groups, in which they integrated ideas from the four article sets to collaboratively propose solutions. Like in the expert group activity, students wrote group progress notes and individual reflections in KF. For the jigsaw group activity, we developed prompts that facilitated shared planning and monitoring of the group progress notes and monitoring, evaluation, and revision of the individual reflections (Table 2). After six weeks of jigsaw group activities, students held a poster fair in week 11. Poster presentations were held in two 30-min rounds, with students switching between presenter and listener roles. In week 12, we asked students to collaboratively write group reflection essays on their jigsaw group activity as KF notes. The essay addressed two questions: (1) *"Describe how you resolved challenges you encountered. If unresolved challenges remain, describe why,"* and (2) *"Describe how you could have improved your group work."* In week 13 we also conducted a questionnaire survey, the details of which are described in the next section.

2.3. Data collection and analysis

The data collected in this study were students' written discourses in KF notes (group progress notes, individual reflection notes, and group reflection essays), mentors' observations as reported in private KF notes (concealed from students), and student responses to two free-response questionnaire surveys.

To address the first research question, we analyzed the questionnaire responses. We conducted questionnaire surveys before and after the jigsaw group activity to evaluate students' internal regulation scripts at each point in time. We focused on student advancement of regulation scripts during the jigsaw group activity, because the activity emphasizes students' SSRL for generating and integrating ideas. In the two questionnaire surveys, we asked students to individually describe how they engaged in group work (*"Describe what did and did not go well in your group work. Also, describe how you or others further improved your group work."*).

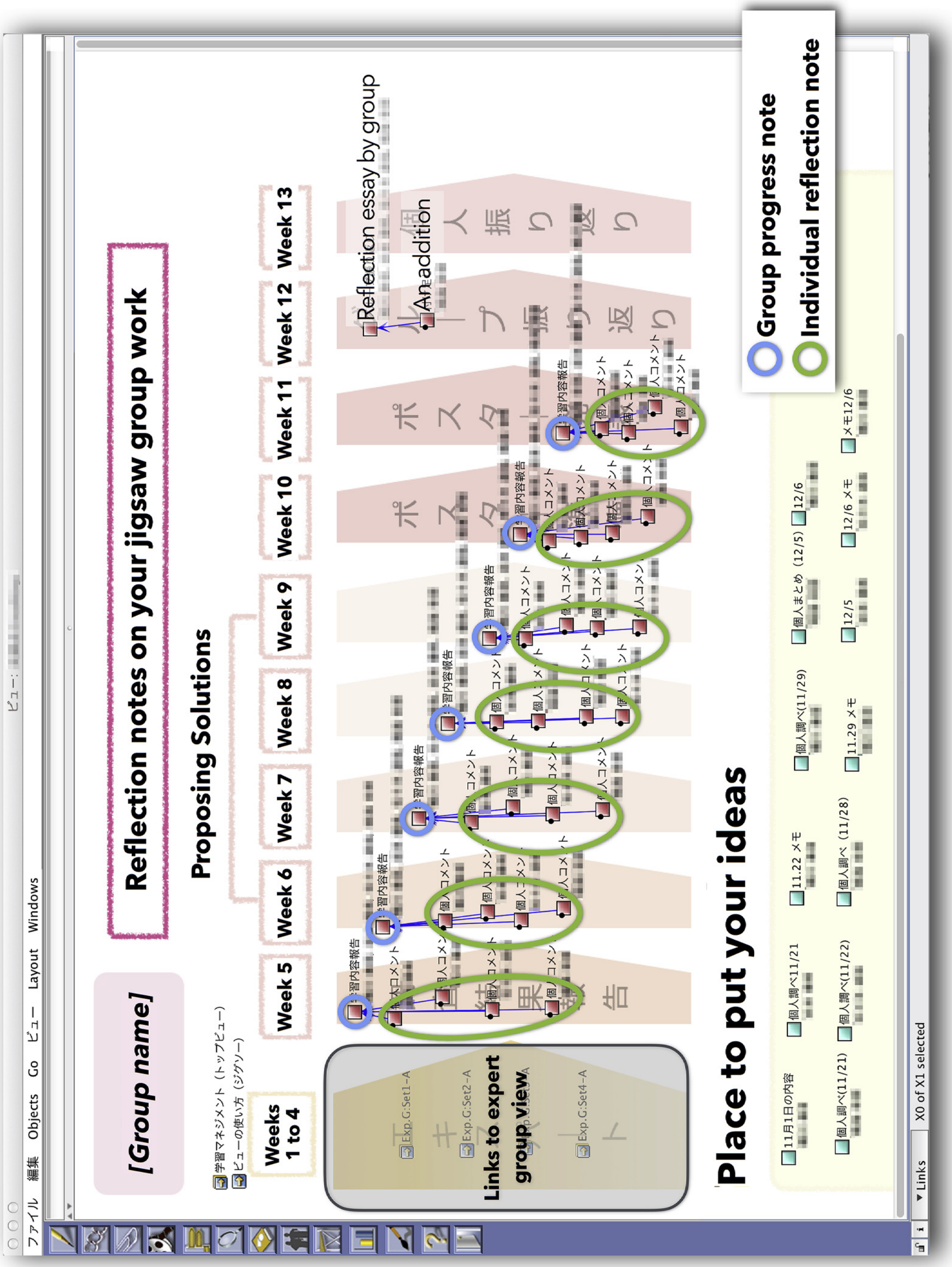

Fig. 1. Knowledge Forum view for a group project.

Table 2
Metacognitive prompts for each note.

Activity	Note	Metacognitive prompts
Expert group activity	Group progress note	*What issue did you discuss?*
		Further issues you found from the discussion
		Opinions from different stakeholders (customer, store manager, chain office, logistics company)
	Individual reflection note	*Evaluate your group progress and state reasons*
		Add ideas for further improvement of your group
Jigsaw group activity	Group progress note	*What was today's plan to do as a group?*
		How much did the group achieve?
		Did you decide individual tasks for the next week?
		Plans for the next class
	Individual reflection note	*Was the goal shared among members?*
		Were members aware of their own roles?
		Did you have rules facilitating group work? Did you follow them?
		Did you use any tools for recording the activity or sharing the information?
		Did each member proactively contribute?
		Overview: How was the activity today? Did it go well? Are there any possible improvements?

Regulation scripts were detected by coding student responses to the questionnaires. We excluded from the analysis five students who did not properly return the individual questionnaire (the questionnaire was not returned, returned after a long delay, etc.). We coded student responses to the questionnaire before the jigsaw group activity as *pre-scripts*. *Post-scripts* after the jigsaw group activity were coded by aggregating responses to both questionnaires. Raes et al. (2016) discussed this methodological issue by emphasizing the necessity to collectively measure strategic knowledge at each point before and after the intervention as post-knowledge, because students often do not mention their previously reported strategic knowledge. Moreover, from the perspective of the script theory of guidance, student post-scripts should be assessed by collectively measuring their initial and revised regulation scripts, since students develop internal scripts through expanding upon them (Fischer et al., 2013).

Table 3 shows the coding rubrics, which were generated from the framework of Winne et al. (2013). We first identified three regulation categories (SRL, CoRL, and SSRL) based on students' standards. We identified SRL when a student held personal standards to evaluate their own learning process. Similarly, we identified CoRL when a student held standards for others to evaluate others' learning process and SSRL when a student held standards for groups to evaluate learning process as a collective. Moreover, when a student referred to their own, others', or the group's goals and plans, we acknowledged that the student had internal scripts of planning at SRL, CoRL or SSRL, respectively. In a similar fashion, when a student described on their own, others', or the group's progress, we recorded that the student had a monitoring script at the SRL, CoRL or SSRL level. When a student described how to revise their own, others', or the group's learning process, we acknowledged that the student had a revising script corresponding to each category (SRL, CoRL, or SSRL). Thus, each individual questionnaire response was assessed with respect to three aspects (goals and plans, monitoring, and revising) of each regulation category (SRL, CoRL, and SSRL). Students writing about an aspect of a regulation category were assigned a score of 1. Students addressing all aspects of all categories were thus scored 3–3–3. The first and the second author independently coded student responses and reached almost perfect agreement (Cohen's kappa was 0.95). Disagreements were resolved through discussion.

Regarding the second research question, we first subtracted pre-scripts as three-digit scores (e.g., 2–1–1) from post-scripts (e.g., 3–3–3) to identify which category of regulation scripts students augmented during their collaboration, namely *script augmentation* (e.g., 1–2–2). To further examine the characteristics of regulation scripts that students augmented and consequently developed through their experiences, we conducted clustering analyses on the scores of script augmentation and post-scripts. We also conducted case analyses of four purposefully chosen jigsaw groups. We used questionnaire data, student KF notes, and mentor observation KF notes to identify student challenges and regulation strategies, and examine how students augmented their regulation scripts.

Table 3
Coding rubrics.

Category	Aspects	Criteria	Example
SRL	Goals & Plans	Referring to own goals and plans	*I should approach this task from …*
	Monitoring	Describing about own progress	*I did …*
	Revising	Describing how to revise student's own learning process	*I would modify my …*
CoRL	Goals & Plans	Referring to other's goals and plans	*I encouraged her to …*
	Monitoring	Describing about other's progress	*She did …*
	Revising	Describing how to revise others' learning process	*I should calmed her down to …*
SSRL	Goals & Plans	Referring to group's goals and plans	*We should approach this task from …*
	Monitoring	Describing about group's progress	*We did …*
	Revising	Describing how to revise group's learning process	*We would modify …*

Table 4
Summary of cluster analyses of post-script scores and script argumentation scores.

		Clusters of script augmentation						
		SSRL & SRL	SRL	SSRL	None	CoRL (modestly)	SSRL & CoRL	CoRL
Clusters of post-scripts	SSRL-oriented	F1	E1	G1, H1	J1			
	Well-organized	D4	C4, I1	A1, B4, E2, F2			A2, A3, H2, K1	
	Insufficient	J2	B3		G2	C1, C2, C3, D1, E3		
	SRL-oriented		F3, G3, I2, K2,	J3	B1	H3		
	CoRL- & SRL-oriented		J4, K4, L1	H4	B2	E4, G4, I3		A4, D2, D3, K3

Note. Each student is placed in a cell coordinated by a cluster according to post-script and script-augmentation scores. Capital letters indicate the jigsaw-group identification.

3. Results

3.1. Advancement of regulation scripts

To examine whether students augmented internal scripts for regulation through their participation in this coursework, we conducted a two-tailed binomial test of frequencies for students categorized as zero augmentation ($N = 4$) versus others ($N = 39$). The results indicated that the proportion of students who augmented their scripts (91%) was significantly higher than would be expected by chance ($p < .01$). To further identify the type of student script augmentation and post-scripts, we conducted two clustering analyses on the three digits as data using the Ward method. As a result, we identified five post-script clusters and seven script-augmentation clusters. Table 4 shows a 5 × 7 contingency table representing the frequency distribution with student identification (A1–L1; the letters indicate the jigsaw-group identification). The table shows that eleven students successfully constructed substantial regulation scripts (*well-organized scripts*), while eight did not (*insufficient scripts*). We further found that five students' regulation scripts were *SSRL-oriented*, seven were *SRL-oriented*, and twelve were *CoRL- and SRL-oriented*. There were various trajectories for augmenting regulation scripts. To elucidate how students augmented their regulation scripts, we further conducted case analyses of four groups.

3.2. Case studies of student advancement of regulation scripts

3.2.1. Group selection

To further examine how students advanced their regulation scripts and what caused differences between successful and non-successful learners, we purposefully selected four groups for our case studies: (1) group A, in which three students augmented SSRL scripts and produced well-organized scripts, (2) group B, in which half of the members did not augment regulation scripts at all, (3) group C, in which three students produced insufficient scripts, and (4) group D, in which three students augmented CoRL scripts. We compared groups A, B, and C to ascertain what causes substantial regulation scripts, and we investigated groups A and D to identify the factors of SSRL- and CoRL-script augmentation. There was no group in which most members augmented SRL scripts. Table 5 shows the subjects of the case studies, including their challenges, script augmentation, and post-scripts.

Table 5
Subjects of the case studies.

Group ID	Student ID	Challenge(s)	Script augmentation	Post-scripts
A	A1	Socio-cognitive challenges	SSRL	Well-organized
	A2	Socio-cognitive challenges	SSRL & CoRL	Well-organized
	A3	Socio-cognitive and socio-emotional challenges	SSRL & CoRL	Well-organized
	A4	Socio-cognitive and socio-emotional challenges	CoRL	CoRL- & SRL-oriented
B	B1	Socio-cognitive challenge	None	SRL
	B2	Socio-cognitive challenge	None	CoRL- & SRL-oriented
	B3	Socio-cognitive challenge	SRL	Insufficient
	B4	Socio-cognitive challenge	SSRL	Well-organized
C	C1	Socio-cognitive and socio-emotional challenges	CoRL (modestly)	Insufficient
	C2	Socio-emotional challenge	CoRL (modestly)	Insufficient
	C3	Socio-emotional challenge	CoRL (modestly)	Insufficient
	C4	Socio-cognitive and socio-emotional challenges	SRL	Well-organized
D	D1	Socio-emotional challenge	CoRL (modestly)	Insufficient
	D2	Socio-emotional challenge	CoRL	CoRL- & SRL-oriented
	D3	Socio-emotional challenge	CoRL	CoRL- & SRL-oriented
	D4	Socio-emotional challenge	SSRL & SRL	Well-organized
	D5	Socio-emotional challenge	–	–

3.2.2. Group where three members produced well-organized regulation scripts

In group A, three out of four members produced well-organized scripts. They progressively worked on various socio-cognitive challenges and resolved them. They first had difficulty in integrating ideas from each expert group. For instance, A4 stated as follows in the week-5 individual reflection: "*We exchanged and added ideas from the expert group, but did not integrate those ideas*." To solve this situation, they utilized the chat tool to leave a record of what was said during face-to-face collaboration and examine their ideas through reflection (e.g., "*We used [the chat tool] to maintain logs and were able to work while repeatedly reflecting on our ideas,*" from A4's individual reflection for week 6). However, their ideas became increasingly chaotic, because they recorded every idea they talked about (e.g., "*The discussion became chaotic, and there were even times when no one knew what we should discuss*," from A1's individual reflection for week 6). The group thus decided to assign each perspective (customer, store manager, chain office, and logistics company) to each member to gather opinions regarding all of their ideas from each perspective (e.g., "*We had planned to present our ideas for each perspective, and as a result set a concrete future direction,*" from A2's individual reflection for week 7). Their discussion resulted in setting a topic that agreed with each member's opinion and conducting subgroup work for further investigation (e.g., "*They decided to do subgroup work*," from mentor observation notes for week 8). One member (A4) who augmented only CoRL scripts felt a socio-emotional challenge and resolved it through collaboration. In her questionnaire response for week 13, she mentioned that at first she could not criticize others' opinions, because they had only recently met each other. By the time of the final collaboration, however, she felt comfortable freely commenting on others' opinions. Member A3 had the same feeling ("*Since we had just met, at first I felt uneasy expressing my opinion,*" from questionnaire responses for week 13). In summary, we found that all members progressively used various regulation strategies through their experiences, and that some members faced socio-emotional challenges at first.

3.2.3. Group where half of the members did not advance regulation scripts

Half of group B members did not augment internal scripts at all, and the group failed to propose a concrete solution because group members could not collect sufficient evidence to support their ideas and agree on any solutions (e.g., "*They generated some ideas, but not concrete ones,*" from mentor observation notes for week 9). In their poster presentation, they did not discuss the prospects or feasibility of their solution. They had monitored and recognized this socio-cognitive challenge, but only searched on the Internet and discussed the information they found. All members repeatedly mentioned in their individual reflection notes that they had searched the Internet to find information that would support their solution (e.g., "*We have to discuss more about how to* support *our ideas,*" and "*We searched on the Internet for information,*" from B1's individual reflection for week 9). Further, many group conversations were not relevant to the task (e.g., "*We chatted too much today*," from B3's individual reflection for week 6). They did not use regulation strategies to reshape their ideas. Additionally, as one member (B4) who produced well-organized scripts mentioned in her response to the questionnaire on week 13, they discussed what they should talk about in their poster presentation right before the second round. However, this discussion was mentioned only in her response. To come to the point of this case, they monitored the same challenge and regulation strategies throughout their group work and failed to resolve the challenge because they repeated that regulation strategy. Half of the members did not augment their regulation scripts because they did not construct new regulation scripts. New strategies shared within the group (discussion right before the second round of the presentation) were internalized only by one member (B4), even though other members did not have regulation scripts related to that strategy (revision at the SSRL level) in pre-scripts.

3.2.4. Group where three members produced insufficient regulation scripts

In group C, three out of four members augmented CoRL scripts only somewhat, resulting in insufficient scripts and failure to create a lively discussion. They faced a socio-emotional challenge at first. On the first day of the course, a mentor wrote in a KF note that "*They did not talk much. This group took the longest to select a jigsaw group name, and C1 said, 'Since we have just met each other, we cannot decide on a group name; we have nothing in common.'* " This atmosphere continued until to the end of the course. Students C1 and C4 also ascribed this situation to socio-cognitive challenge by saying that "*Everyone became silent when we faced a difficult task*" (C1's response to the questionnaire in week 13), for instance. In her response to the questionnaire on week 13, C2 wrote, "*One of the good points of our group was that we had lively discussions.*" In contrast, the other three repeatedly mentioned in their individual reflections and responses that discussion ceased several times during face-to-face activities (e.g., "*Sometimes the discussion stopped,*" from C3's individual reflection for week 8). To resolve this situation, C1 prompted other members ("*I brought up a subject to talk about so that everyone could be involved in the discussion,*" from C1's response to the questionnaire in week 13), and C4 described how she reflected on ideas to bring up subjects for discussion ("*I reflected on our ideas and brought up new ideas for further discussion,*" from C4's questionnaire response in week 13). C2, C3, and C4 asked mentors for advice on resolving the situation (e.g., "*We asked the mentors for advice when our discussion stopped,*" from C2's individual reflection for week 8). They somewhat resolved the situation, and did not encounter remarkable challenge afterwards. In summary, we found that they perceived the same situation differently and used few regulation strategies after resolving their challenges.

3.2.5. Group where three members augmented CoRL scripts

In group D, three out of four members augmented CoRL scripts, but encountered a socio-emotional challenge in that they had one "silent" member (D5), who was excluded from the quantitative analyses. The mentor's observation notes for week 6 stated "*D5 did not talk at all.*" This was also mentioned in D5's individual reflection for week 7 ("*I could not speak a word today.*"). All group members except the silent member attempted to help her communicate with them (e.g., "*There was one person who did not give an opinion. I asked her for an opinion,*" from D1's individual reflection for week 5). One member (D4) who augmented SSRL and SRL scripts acted as a group director, controlling and facilitating group work, as indicated by D4's individual reflection for week 6 ("*I took the minutes and* *acted as moderator today.*") and the mentor's observations for week 4 ("*D4 is leading the discussion.*").

3.2.6. Summary of the case studies

Our case studies suggest three findings. First, students constructed new regulation scripts based on their perceptions of situations, and those perceptions varied across group members. In particular, students were likely to self-regulate themselves or co-regulate other members when they encountered socio-emotional challenges such as inactive discussions, while students tended to engage in SSRL when encountering socio-cognitive challenges such as obstacles to integrating ideas. Second, students who produced well-organized scripts shared the perceptions of challenges and progressively worked on them and used various regulation strategies. When students used similar strategies throughout the group work, they failed to produce well-organized scripts. Lastly, even when a strategy was shared among group members, there was a case where only specific members internalized it as a regulation scripts.

4. Discussion

This study designed and evaluated a computer-mediated learning environment that facilitates regulation and its improvement while students engage in project-based learning. To facilitate and examine advancement of regulation scripts, we relied on the script theory of guidance (Fischer et al., 2013). In this section, we address our research questions in terms of the results of our analyses.

Regarding our first research question, we expected students to augment regulation scripts through engaging in project-based learning. Quantitative analysis revealed that significantly more students augmented their regulation scripts as we expected. We found that all students could augment their regulation scripts before their participation in the course. The task given to students was sufficiently complex to elicit students' monitoring collaboration and reconfiguration of regulation scripts. Four students did not augment their scripts over their experiences in project-based learning, despite there being space for them to do so. The reason for this is discussed below.

Our second research question was how students augmented their regulation scripts. To answer this question, we conducted a clustering analysis to detect patterns of script augmentation. Results revealed that augmentation trajectories were diverse. Case studies indicated several factors that might explain the diverse trajectories. First, as discussed in previous studies of collaboration scripts (e.g., Fischer et al., 2013), students who experience new challenges not resolved by their pre-scripts are expected to augment their regulation scripts. As found in our case studies, 10 out of 12 students had experiences to apply new regulation strategies in their collaboration. The jigsaw activity as external scripts was designed to create a diversity of ideas in the student group activity, further directing students toward socio-emotional and socio-cognitive challenges. An interesting result of our analysis was that a diversity of trajectories of script augmentation was found within groups as well as between groups, even though it might seem that students would augment the same regulation scripts when they share and engage in the same task and challenges.

The case studies further suggested that the diversity of trajectories of script augmentation within groups emerged based on individual differences in perceiving the challenges. This finding has been discussed in previous research. For example, Fischer et al. (2013) discussed how internal scripts can be influenced and modified by learner perceptions of a situation (as the internal script configuration principle, internal script induction principle, and internal script reconfiguration principle). Studies of AIRE (Järvenoja & Järvelä, 2009; Järvenoja et al., 2013) revealed that interpretations of socio-emotional challenges vary among group members and across groups. Our finding bridges these previous findings in that (1) situations and challenges consist of several facets, and that each student has different standards, (2) individual differences in student perceptions of collaboration situations trigger different types of regulation strategies, and (3) these are internalized into regulation scripts in a variety of trajectories. In particular, we found a tendency where students augmented SRL or CoRL scripts when they perceived socio-emotional challenges, and augmented SSRL scripts when they perceived socio-cognitive challenges. We assume that students facing socio-emotional challenges would engage in SRL or CoRL to deal with their own or others' negative emotions, or to resolve the source of socio-emotional challenges such as negative interactions. We also assume that SSRL is essential to co-constructing creative, innovative, deep, and complex ideas and conceptual knowledge.

Finally, although there are group and individual differences in experiencing and perceiving challenges, we emphasize that student agency to share task perceptions plays a critical role in improving regulation scripts. As in the case of group A in particular, students augment regulation scripts in a well-organized manner when they share perceptions of challenges and collaboratively engage in regulation of collaboration. Miller and Hadwin (2015) and other studies (Hadwin et al., 2011; Rogat & Linnenbrink-Garcia, 2011; Winne et al., 2013) have discussed the influence of task perceptions on group activities. For learners to engage in productive collaboration through socially shared regulation, they first need to construct a shared task perception. When learners regulate groups in a socially shared manner, they can generate and apply a variety of regulatory strategies. The diversity of perceptions of challenges does not lead learners to individual differences, but rather to deeper consideration of the challenges themselves. Results suggest that we must design learning environments where the diversity of student perceptions of challenges is externalized and shared by students so that they engage in productive collaboration through socially shared regulation.

5. Conclusion, theoretical contribution, limitations, and future research

This study attempted to design a computer-mediated learning environment that facilitates student regulation and its improvement. It confirmed the effectiveness of the developed environment, in which first-year university students had diverse experiences that led them to augment regulation scripts. Through diversity of experiences and their prior internal scripts, students augmented their regulation scripts in a variety of ways. In addition, perceptions of experiences and challenges in collaboration influenced how they augmented their scripts. When students perceived socio-emotional challenges, they were more likely to augment SRL or CoRL scripts. When they perceived socio-cognitive challenges, they were more inclined to augment SSRL scripts.

We attempted to make further contributions to research on regulation of collaboration in several ways. Frist, we designed a learning environment that facilitates student regulation in the form of computer-mediated learning. This perspective is considered a crucial topic in CSCL studies (Dillenbourg et al., 2009), but nonetheless receives insufficient attention. Second, we proposed a methodology for examining progress in student regulation by relying on the script theory of guidance (Fischer et al., 2013). There are few studies that focus on improving student regulation itself, despite there being many studies of student regulation and its influence on learning outcomes. Third, we examined student scripts for regulating collaboration as comprising three layers (SRL, CoRL, and SSRL) based on the framework by Hadwin et al. (2011) and Miller and Hadwin (2015). While previous studies focused on SSRL (Malmberg et al., 2015) or CoRL (Lajoie et al., 2015), this study focused on all three layers.

There were some limitations to this study. First, we did not collect student interactions in their group activities, although we had field notes by mentors as well as students' reflection notes. To test our discussion more rigorously, we need to collect behavioral engagements in group activities using audio or video recorders. Second, our participants were university students, so our findings are not directly comparable with other age groups. Third, we should further investigate student advancement of regulation scripts in relation to metacognitive prompts by analyzing weekly KF notes. We expect that such analyses would theoretically contribute to establishing further generalizable findings to design a learning environment that facilitates student regulation and its improvement. Finally, since the present study has not examined the quality of student-produced ideas and task responses, we should further analyze student ideas in relation to regulation. It is important to develop learning environments that facilitate both the construction and innovation of knowledge and the development of general knowledge and skills such as regulatory skills (Bereiter & Scardamalia, 2014; Paavola et al., 2004).

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