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Challenges in online collaboration: effects of scripting shared task perceptions

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Abstract Difficulties with planning, such as negotiating task understandings and goals, can have a profound effect on regulation and task performance when students work collaboratively (Miller and Hadwin, *Computers in Human Behaviour, 52*, 573-588, 2015a). Despite planning being a common challenge, teams often fail to identify strategies for addressing those challenges successfully. The purpose of this study was to examine the effect of team planning support in the form of awareness visualizations (quantified, nominal, and no visualization of individual planning perceptions summarized across group members) on the challenges students face during collaboration, and the ways they report regulating in the face of those challenges. Findings revealed differences across conditions. Individuals in the no visualization condition (a) rated planning as more problematic, and (b) were likely to encounter *doing the task*, *checking progress*, and *group work* challenges when they encounter *planning* challenges, (c) reported more *time* and *planning* main challenges compared to *doing the task* and *group work* challenges, and (d) reported that *planning* strategies (adopted as a team) were most effective for addressing planning challenges, followed by *teamwork* strategies which were less effective. In contrast, individuals belonging to groups who received one of the two visualizations (a) reported that both *planning* and *teamwork* strategies to be equally effective for addressing planning challenges, and (b) reported higher levels of success with their strategies than groups without a visualization support. Findings attest to the importance of supporting group planning with planning visualizations.

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Regulation has been increasingly recognized as important for successful collaboration (Hadwin et al. 2011; Hadwin et al. 2017). However, examples of groups lacking or neglecting to use critical regulatory skills and strategies are well documented in the literature (Strijbos et al. 2004). Difficulties with planning, such as negotiating task understandings and articulating goals and standards for tasks, can have a profound effect on regulation and task performance regardless of whether students work individually or collaboratively (Miller and Hadwin 2015b). Despite reporting planning problems as a main challenge during collaboration, students often fail to identify productive strategies for ameliorating[1] those challenges (McCardle et al. 2011). In other words, when students recognize planning problems, they don't know what to do about them. Computer-supported collaborative learning (CSCL) tools offer potential for remediating challenges in collaboration.

In our research, we have systematically examined technological tools for guiding regulation during collaboration, particularly by supporting group planning. Specific to this study, we examined a support tool designed to promote better awareness of planning beliefs and processes amongst group members by providing visualizations of group members' planning beliefs and perceptions. Planning support included (a) explicit guidance in the form of planning *scripts* to guide groups to discuss and negotiate shared beliefs and perceptions (i.e., task perceptions) and goals for the upcoming collaborative task; and (b) implicit guidance in the form of *visual display* illustrating similarities and differences between group members in terms of task perceptions and goals for the collaborative task at hand (see Reimann and Bannert 2017; Miller and Hadwin 2015a). We posit that supporting group planning has potential to promote (a) proactive planning discussion resulting in the co-construction of shared task perceptions and plans for group work, and (b) adoption of appropriate strategies for ameliorating challenges as they arise during collaboration.

Importance of regulating planning for successful learning and collaboration

Self-regulating learners take control of their learning by (a) planning and setting goals, (b) choosing and using strategies, (c) monitoring progress in pursuit of goals, and (d) adapting to cope with challenges (Winne and Hadwin 1998; Zimmerman 1990). Although multiple models of regulation exist, this study draws on Winne and Hadwin's model of self-regulation for three reasons. First, the Winne and Hadwin model teases apart two important components of planning: generating task perceptions and defining goals or plans for the task at hand. Second, this model emphasizes the importance of adapting and adjusting regulation during tasks as well as across tasks. This latter point is important because it recognizes the socio-historic nature of learning whereby current experiences are enriched by past knowledge of self, task, group, and context (Hadwin et al. 2017). From this perspective, challenges students encounter create opportunities for regulation to occur and generate information to guide successful regulation

[1] We use the term ameliorate to imply that successful teamwork may not depend on challenges to be eliminated, but rather on groups and group members to respond to challenges in ways that minimize the impact of challenges by resolving them or making them more manageable/tolerable as they arise.

in future tasks. Third, the same model has been extended to explain how multiple forms of regulation arise in teamwork: individual regulation (SRL), shared or joint regulation (SSRL), and co-regulation (CoRL; Hadwin et al. 2017; Järvelä and Hadwin 2013).

Planning plays a critical role in regulation of learning. Planning comprises two main phases of SRL: (a) interpreting task criteria, purpose, and context informed in part by one's own experiences, past performance, strengths, and weaknesses (task perceptions) and (b) translating tasks into personalized goals and plans that direct efforts and approaches to the task (goal setting and planning). Task perceptions form the metacognitive knowledge about task requirements and specifications. Metacognitive knowledge can be jointly constructed, such as when collaborative groups create a shared foundation of the task at hand and use that knowledge to (a) negotiate goals and plans for strategically approaching the task and (b) generate shared standards against which to monitor and evaluate their processes, progress, and products (Hadwin et al. 2017; Winne and Hadwin 1998, 2008). If planning knowledge resides in the mind of individuals and is never shared or negotiated amongst team members, there is a risk of exerting time and energy working at cross-purposes or in ways ill-suited to the task. As it turns out, this is a common difficulty reported by teams (e.g., Barron 2003; Fransen et al. 2011).

Research indicates task perceptions influence subsequent regulation and achievement (Greene et al. 2012; Schellings and Broekkamp 2011). However, learners often struggle with task understanding and fail to prioritize negotiation of shared task perceptions during teamwork (Hadwin et al. 2010; Luyten et al. 2001). For example, in a case study, Miller et al. (2013) found groups constructed incomplete perceptions of a group project and failed to discuss one another's personal interpretations of that project. In addition, shared planning discussions and activities did not emerge until the project was already underway. Hadwin et al. (2010) similarly found task perceptions held by members of a group were often misaligned with each other as well as the instructor. Finally, Rogat and Linnenbrink-Garcia (2011) found groups working on a face-to-face mathematics task sometimes overlooked planning and jumped into task completion with little discussion or attention to task requirements. The authors concluded that low quality engagement in planning may have disrupted group progress by undermining engagement and interfering with monitoring.

Findings to date also highlight the importance of planning for minimizing socioemotional challenges in collaboration. Rogat and Linnenbrink-Garcia (2011) found that a group experiencing sustained positive socioemotional interactions also engaged in higher quality planning, monitoring, and behavioral engagement than groups who experienced negative socioemotional reactions. Similarly, Bakhtiar et al. (2017) found differences in socioemotional climate between groups receiving loose planning guidance (general open-ended planning questions) and groups receiving detailed planning guidance (pre-stocked planning choices). Group members who received a high level of scripting for individual planning were better prepared for the collaboration overall and reported a positive socioemotional climate during group work. Findings point to the importance of regulatory processes for mitigating socioemotional challenges during collaboration.

Supporting planning in collaborative contexts

At least two types of technological support tools offer promise for remediating difficulties in planning: (a) scripting tools structure collaboration by specifying and sequencing activities to be enacted in complex collaborative learning situations (Fischer et al. 2013; Rummel et al. 2009) and

(b) group awareness tools use graphic summaries of group processes and activities to support group members to optimize collaboration (Järvelä et al. 2015). However, the potential of scripting and awareness tools for supporting regulatory processes such as shared task perceptions in socially shared regulation has been largely overlooked (Järvelä and Hadwin 2013; Miller and Hadwin 2015a).

Our research has systematically examined two ways of promoting regulation during computer supported collaboration: (a) planning scripts explicitly guide groups to negotiate shared task perceptions and goals, and (b) visualizations collate and display each individual's task perceptions and goals to optimize joint awareness and stimulate negotiation where needed [names deleted to maintain integrity of the review process]. We posit that prioritizing planning as a target for supporting collaboration should prompt students (and groups) to adopt appropriate strategies for ameliorating challenges as they arise during collaboration and reduce the frequency of planning-related challenges in particular.

Past work comparing different levels of support in planning scripts has revealed important differences (Hadwin et al. 2015; Miller and Hadwin 2015b). For example, Miller and Hadwin (2015b) examined the effect of CSCL supports on group construction of shared task perceptions for a collaborative task. Groups were assigned to one of four conditions differing in the kind of support provided for individual planning and group planning sessions. Planning support consisted of a series of key planning questions. In the high support condition, students responded to questions by selecting from pre-stocked planning items. Items either matched or did not match the assigned task description, criteria, and purpose. Pre-stocked planning items were designed to prompt planning discussion by giving explicit guidance about what to discuss. In the low support condition, the same planning questions were provided with an open-ended text field to document planning ideas. Open format questions were designed to prompt planning discussions but provide minimal explicit guidance about what to discuss. Findings indicated that, regardless of level of individual support, providing a high level of support for group planning resulted in (a) more accurate shared task perceptions, (b) building on individuals' task perceptions, and (c) engaging in more transactive planning discussions.

Using similar planning support tools, Hadwin et al. (2015) examined the effects of scripting support on challenges encountered during collaboration. When students were provided with a high level of support during individual planning they reported fewer task management and engagement challenges during collaboration. In comparison, groups with low scripting support reported higher levels of task management and communication challenges. However, providing low levels of scripting during both individual and group planning (under scripting), and providing high levels of scripting during both individual and group planning (over scripting) resulted in higher mean frequencies of reported planning and task enactment challenges than providing high levels of scripting during either individual or group planning sessions alone. Findings suggest providing too much planning support in the form of scripting may be as deleterious as providing too little scripting support for planning. Therefore, the current study combined high levels of scripting for individual planning, such as those used by Hadwin et al. (2015), with visual summaries of individual planning that could be leveraged by groups to stimulate joint planning.

Visualizations are a second form of planning support. They consist of presenting students with visual summaries illustrating similarities and differences between group members in terms of knowledge, understandings, task progress, or task contributions. Visualizations are typically designed to stimulate awareness and discussion amongst group members about level of activity and contributions, pace, progress, or task completion (Buder and Bodemer 2008; Leinonen et al. 2005). For example, environments such as Github (2008) leverage visualizations to facilitate Q1 distributed software development and project management. To date, these types of visualizations have been under-examined in terms of their potential to give feedback to groups about planning perceptions and progress. However, we posit these types of visualizations may have potential to (a) stimulate metacognitive awareness of similarities and differences in planning perceptions and goals amongst group members, and thereby (b) stimulate more active and dynamic shared planning discussions with the ultimate goal of improving collaboration.

The present study augmented high individual planning supports (questions and pre-stocked planning ideas) such as those examined by Hadwin et al. (2015) with team visualizations displaying alignment and misalignment in planning beliefs and perceptions amongst group members. The goal was to stimulate shared planning discussion and processes prior to collaboration by confronting groups with graphical information about each other's planning perspectives. In a pilot study, Miller and Hadwin (2013) presented teams with a quantified visualization of individual planning ideas and responses. The image displayed each key planning idea and the number of students identifying each item as important for their collaboration task. In depth analysis of chat records revealed the quantified visualization constrained planning discussion altogether. Rather than leveraging information in the visualization to discuss and negotiate discrepancies in planning beliefs, groups selected the most frequently chosen planning ideas with little or no discussion at all. They did this even when the most popular item was a little off track and someone in the group had previously correctly identified target items on their own. Furthermore, planning discussion was constrained to exchanges such as the following, where students did not discuss or even name the planning idea, but just listed the letter indicating its sequence in a list of items:

Sarah: *In the group summary [visualization] ...all of us chose A*
Haden: *?*
Sarah: *That's all of our responses to the [individual] solo planning we did*
Sam: *ohhhh*
Sarah: *I think it is A, H, I, J because we answered those with the most %*
Sam: *ok, just put that as our answer [plan] Haden*

Building on past research about scripting and visualizing planning, the current study incorporated high individual planning support consisting of planning prompts in the form of questions and pre-stocked items that either matched or did not match task requirements and purpose (see Hadwin et al. 2015). To guide planning discussions, open-ended planning prompts were provided at the group level, and planning support was augmented by one of three types of visualizations: (a) graphical summaries of collective responses with frequencies included (quantified visualization), (b) graphical summaries of collective responses without frequencies (nominal visualization), and (c) no visualization at all. The goal was to test the efficacy of combining scripted solo planning with non-quantified visualization to stimulate more active and productive planning discussion amongst team members.

Given that scripting and visualization were designed to prompt pro-active shared planning prior to the collaboration task, this study aimed to compare the three planning support conditions in terms of the kinds of challenges students reported experiencing and the strategies they tried for ameliorating those challenges during collaboration. Theoretically, better planning should lead to (a) encountering fewer planning-related challenges during teamwork, and (b) resolving planning challenges more easily when they are encountered because groups are better poised to anticipate and respond to them.

Challenges as opportunities to regulate learning

Self-regulated learning is about being strategic and adaptive (Butler and Winne 1995; Hadwin and Winne 2012). Self-regulating learners engage in four critical processes while working on academic tasks. First, they draw on past experiences and current situational conditions to assess what is needed (task perceptions). Second, they are active agents directing their engagement by adopting goals, identifying, and implementing methods and approaches they deem to be well-suited to attaining those goals given the situation and their personal attributes (goal setting and planning). Third, they regularly monitor and evaluate their progress with respect to goals (metacognitive monitoring). Fourth, they respond strategically to discrepancies between goals/standards and progress/performance by persisting, trying something new, or adjusting their own goals, expectations, or perceptions. In many ways, actions taken when discrepancies between goals/standards and progress/performance are detected characterizes self-regulation-in-action (adaptation and metacognitive control).

Theoretically, regulation engages learners and teams in a series of contingent events that drive strategic adaptation. When learners detect misalignment between goals and progress, they are faced with one of a limited set of options including (a) persist with whatever they were doing and hope it will work better in the future, (b) try a new strategy or approach, (c) adjust or fine tune the strategy, (d) update or change planning in the form of task understanding or goals, or (e) reduce effort or withdraw from the task altogether. Taking action in response to detected problems invites a new round of monitoring and evaluating which may in turn lead to continued refinement in approaches. This cyclical process is the essence of strategic and adaptive regulation.

From this perspective, encountering new challenges, situations, or failures during collaboration invites regulation as a means for optimizing progress toward personal and/or collective goals and standards. We argue the mark of self-regulation is not what people do when things are proceeding well, but instead the way they respond to ameliorate problems. In other words, regulation is strategically enacted when self, task, domain or social conditions demand it. For example, learners engage in positive social interactions by promoting engagement and acknowledging contributions when a situation increases frustration and apprehension amongst the group. Learners overtly encourage one another when cognitive engagement wanes or negative emotions rear up. Timely, rather than persistent, self-monitoring and action positions learners to toggle regulation on and off as needed.

Research to date points to at least five broad types of challenges experienced by groups across a variety of settings (see also Koivuniemi et al. 2017). (1) *Motivational challenges* tend to center around differing personal priorities such as competing goals, or differing participation levels. Typically, these challenges result in declines in effort, engagement or participation (Blumenfeld et al. 1996; Järvelä et al. 2010; Mulryan 1992; Walker 2001). (2) *Socioemotional challenges* refer to challenges in creating and maintaining a positive climate such as relational problems associated with achieving psychological safety, communicating effectively, and navigating power relationships (Barron 2003; Chiu and Khoo 2003; De Dreu and Weingart 2003; Näykki et al. 2014; Van den Bossche et al. 2006). (3) *Cognitive challenges* refer to difficulties in achieving shared understanding of the task and domain, or in choosing effective solution paths and strategies (Barron 2003; Fransen et al. 2011; Kirschner et al. 2008; Summers and Volet 2010; Van den Bossche et al. 2006; Van Ginkel and Van

Knippenberg 2008). (4) *Metacognitive challenges* relate to difficulties monitoring, evaluating and reflecting on group processes, products and progress (Fransen et al. 2011; Janssen et al. 2012). (5) *Environmental challenges* relate to external conditions surrounding collaborative work such as technology, task complexity, task duration, resources, and group composition (Edmondson and Roloff 2009; Gunawardena et al. 2001; Hommes et al. 2013; Romano and Brna 2001; Zarnoth and Sniezek 1997). We posit the occurrence of these challenges demands varying modes of regulatory action and warrants future investigation.

Identifying challenges teams encounter during collaboration has potential to inform research about regulation in three main ways. First, knowing what challenges stimulated specific tactical responses shifts the focus to *strategies* that have intent or purpose, and away from behaviors or actions that may merely represent habits or routines. Second, identifying segments of time when challenges began and are either resolved or discarded, creates opportunities to examine an array of behavioral, cognitive, emotional and motivational responses that occur in response to challenges. Finally, when challenges are matched with specific strategies that resolve or remediate those challenges, it is possible to distinguish between effective and ineffective strategies. However, there is a paucity of research examining (a) the ways regulatory processes of planning, enacting the task, and checking progress impact challenges, or (b) how individuals and teams regulate in the face of those challenges.

Purpose and research questions

The purpose of this study was to compare the effects of three different types of planning support on (a) challenges students report during collaboration, and (b) strategic choices they make to ameliorate those challenges. Planning support consisted of scripting individual planning with a series of questions and pre-stocked planning items (high scripting) combined with one of three different forms of visualizations to guide collaborative planning for the task (quantified, nominal, and no visualization of task perceptions of each group member). Our guiding hypotheses were as follows:

1. We hypothesized having access to visualizations of other team member's planning ideas during group planning would stimulate better group planning evidenced by the amelioration of common challenges encountered during collaboration.
2. We hypothesized *planning challenges* would be more frequently identified when no visualization support for planning was provided because groups were not explicitly confronted with discrepancies in planning beliefs and perceptions amongst group members. In contrast, awareness of differences stimulated by the quantified and nominal visualizations has potential to stimulate more active joint planning processes aimed at resolving those differences. More active planning early in collaboration has potential to ameliorate significant planning challenges later on.
3. Although we hypothesized *planning challenges* would be more dominant when no visualization support was provided during planning, the paucity of research about strategies used in collaborative work constrained the specificity of hypotheses further.
4. Finally, we conducted a series of exploratory analyses to uncover patterns of regulation with a broad hypothesis that providing planning visualization support would disrupt regulatory responses (challenge-strategy patterns) to planning challenges.

Method

Participants

Participants were 180 undergraduate students (106 females and 74 males) with an average age of 19.22 ($SD = 2.08$). Of the 102 students who reported their current year of post-secondary education, 62.38% were first-year students. Students were enrolled in an undergraduate elective course on learning strategies for university success. This educational psychology course teaches the theory, research and practice of strategic learning, motivation, and behaviour with a self-regulated learning lens. Data were gathered across two applied computer-supported collaborative assignments completed in Weeks 7 and 12. Lab instructors assigned students to groups of 3 (10 groups), 4 (28 groups) or 5 (8 groups). The 46 groups were heterogeneous based on past quiz performance, language proficiency, and gender.

Collaborative assignments

Each collaborative assignment consisted of three stages: (a) *planning*, in which learners planned and prepared for the collaborative task both individually and in groups, (b) *doing the collaborative task*, in which learners had 90 min to complete an online collaborative task via synchronous chat, and (c) *reflecting*, in which learners were guided to self-assess and reflect on their performance and processes during teamwork (see Fig. 1).

Planning phase During planning, students were prompted to prepare for the upcoming collaboration individually and then together (think, share, and co-construct). One week prior to shared planning, students completed the solo planning tool (~10 min). The following week, groups were given 20 min to complete shared planning together using (a) a text based chat tool to discuss answers to guided planning questions, and (b) a collaborative wiki to record answers. The wiki was editable by one person at a time but viewable by all students after refreshing the browser. Planning was an ungraded requirement for the course. Both solo and collaborative planning were required to be complete prior to proceeding to the collaborative task.

Both solo and collaborative planning were supported by planning scripts. During solo planning, individuals received a highly-structured planning script. The planning script provided a pre-stocked selection of answers and required individuals to choose items that best captured their perceptions of task requirements, as well as the challenges they anticipated facing in the task. During shared planning, groups received a loosely structured planning script prompting them to discuss and construct answers to seven open-ended planning questions.

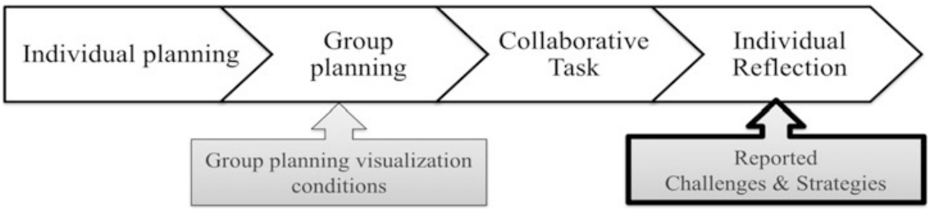

Fig. 1 Summary of the research procedure and data collection. Data in this study include students' reflections after the collaborative task has ended

Planning questions prompted groups to draw on past experiences collaborating with groups to proactively plan for the upcoming collaborative task.

Collaborative task phase The collaborative task required groups to analyze a fictitious scenario about a student studying. Scenarios were complex and challenging by design, incorporating weekly course concepts covered in the course (task understanding, strategic goal setting, information processing, memory and deep processing, regulating time and procrastination, and regulating motivation). Students collaborated online using a text-based chat tool and a wiki space to discuss and construct answers to a series of analysis questions. The wiki was editable by one person at a time, and viewable by all group members using web-browser refreshes. The finished analysis responses recorded in the shared wiki space were graded for accuracy, use of course concepts, and alignment with the scenario content.

Collaborative task 1 The 868-word scenario detailed the experience of a student preparing for, writing, and submitting a major essay for an undergraduate history course. The scenario was written to include a breadth of inter-related issues related to academic success concepts taught in the first 6 weeks of the course. In Part A of the collaborative task, students were given a list of 18 course concepts and asked to: (a) provide an example or quote from the scenario demonstrating the concept, and (b) explain and justify if it was a strength or weakness for the student in the scenario. Part B consisted of two open-ended questions: (a) Identify the source problem for the student in the scenario, and (b) Explain and justify why this was the main problem for this student.

Reflecting phase After collaborating, students completed an individual online written reflection about the collaborative process (Solo Reflection Tool). Reflection was guided by 17 questions. Individual reflections were graded (5 marks) with full marks granted if (a) all questions were attempted, (b) reflections of what happened (good and/or bad) were genuine and consistent with what the instructor and other group members observed during collaboration, and (c) there was an attempt to proactively plan forward to make future collaboration better. In other words, students gained marks for engaging in the reflective process, rather than providing predetermined responses.

Visualization comparison conditions Groups were randomly assigned by lab section to one of three visualization conditions (see Fig. 4). Visualizations were intended to inform group planning by visually summarizing or compiling individual planning information gathered from each member of the group during their solo planning sessions: (a) the *quantified visualization* depicted the range and frequency of task perceptions and goals/standards identified by individual group members (Fig. 2a), (b) the *nominal visualization* provided information about the range (but not frequency) of task perceptions and goals/standards identified by individual group members (Fig. 2b), and (c) the *no visualization* group received no information about individual task perceptions or goals/standards (see Miller and Hadwin 2015b).

Figure 2 shows sample visualizations for two different groups in different visualization conditions. The quantified visualization depicted in Fig. 2a indicates 4 members of this group believe the collaborative task requires them to "*Create a problem case scenario*." In comparison, only one member of the group believes the task requires them to "*Describe what the student did*." The nominal visualization depicted in Fig. 2b indicates at least one member of this group believes the task requires them to "*Describe what the student did,*" but no one in the group believes the task requires them to "*Create a problem case scenario.*"

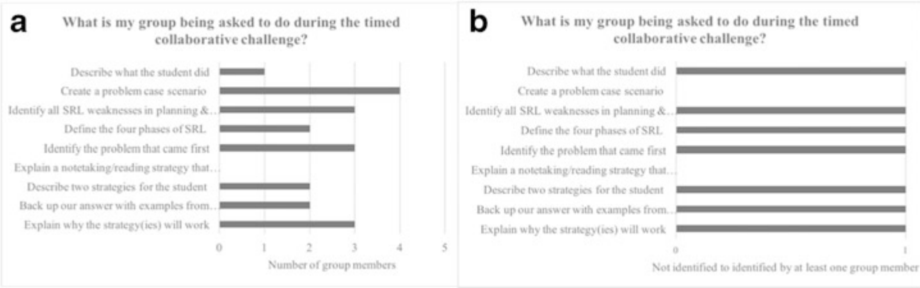

Fig. 2 **a** Quantified visualization of individual group member's task perceptions of explicit task features. **b** Nominal visualization of individual group member's task perceptions of explicit task features

Variables

The focus of this study was on data collected during the reflecting phase outlined earlier. Specifically, this study compared the challenges students reported after completing the collaborative task and the ways they reported responding to those challenges (i.e., strategies taken) across planning visualization conditions.

Categories of challenges A list of 22 specific challenges was informed by (a) challenges reported in a published measure of socioemotional challenges (AIRE; Järvenoja and Järvelä 2009; Järvenoja et al. 2013), and (b) challenges identified in two earlier pilot studies done at our lab in which students were invited to provide a text-based description of a challenge. Challenges were grouped into four categories (see Table 1): (a) *planning challenges* included difficulties associated with task understanding, goal setting, or task planning (Phase 1 & 2 of Winne and Hadwin's model of SRL); (b) *doing the task challenges* included difficulties related to cognitive and behavioural actions, states, or knowledge contributing to task processes and products; (c) *checking progress challenges* included difficulties monitoring and evaluating progress or products against standards, or adapting based on evaluations generated from monitoring; and (d) *groupwork challenges* encompassed socioemotional interaction and communication challenges typically referred to in the teamwork and team process literature (e.g., Kempler and Linnenbrink 2006; Kreijns et al. 2003; Van den Bossche et al. 2006).

Strategy categories Sixteen specific strategies for addressing challenges in collaborative work were informed by (a) strategies listed in a questionnaire designed for examining groups' emotion regulation (AIRE; Järvenoja and Järvelä 2009), and (b) two previous pilot studies conducted at our lab. The first two authors organized individual strategy items according to Winne and Hadwin's (1998) four-phase model of SRL, yielding strategies targeting planning, doing, and progress checking. Two additional categories were added (a) strategies aimed to regulate general teamwork issues related to socioemotional interactions and communications, and (b) a "no strategy" option for when nothing was done to regulate the experienced challenge (see Table 2). On the rare occasion that "other" was chosen, strategies described in the open text field were coded by two independent researchers and classified into one of the five strategy categories. When the description of a strategy was unclear or no strategy was actually described in the open-ended response, it was coded as "uncodable."

t1.1 **Table 1** Main challenge categories and specific challenges

t1.2	Challenge Categories	Challenge Statements
t1.3	Planning	Constructing or aligning accurate perceptions of the task, identifying goals and priorities, planning strategies or approaches
t1.4		Different goals/standards for our work
		Different ideas about how to organize our time
		Different ideas about how to start
		Different ideas about how to work together
		Different understandings of what we need to do
t1.5	Doing the task	Actions, states, or knowledge contributing to task processes & products
t1.6		Different levels of commitment to the task
		Different strategies or approaches
		Different understandings of the course material
		Different working styles
		Trouble staying on task
		Trouble using the technology
		Trouble understanding each other
		Running out of time
t1.7	Checking progress	Checking process or progress against goals/standards and making adjustments as necessary
t1.8		Different ideas about how to check progress
		Different ideas about what to do when we run into problems
		Different ideas about when to check progress
t1.9	Groupwork	Socioemotional interaction and communication
t1.10		Unmotivated group member(s)
		Unequal participation or distribution of work
		Unsupportive group climate (e.g., uncomfortable, unfriendly, lack of trust)
		Different styles of interacting (e.g., quiet, bossy, confrontational)
		Different communicating due to language barriers

t2.1 **Table 2** Main strategy categories and specific strategies

t2.2	Strategy Categories	List of Strategies
t2.3	Planning	Made sure we understood what we are supposed to do and why
		Set specific goals about what we wanted to learn
		Developed a good plan of attack
t2.4	Doing	Used our individual expertise and knowledge
		Got motivated
		Made use of good strategies to get the task done
		Maintained focus on the task
		Managed the environment
		Asked for help
t2.5	Checking	Monitored our task progress as we went
		Made changes to our approach when we recognized things weren't going well
t2.6	Groupwork	Developed a positive group climate
		Used good communication skills (e.g. listening to each other, contributing ideas)
		Developed confidence and assertiveness
		Assigned specific roles to group members
t2.7	No strategy	Did nothing, just moved on

Measures

Group task performance The collaborative assignment grade served as a measure of group task performance. Assignment products were scored using a rubric created by the course instructor. A product score was calculated using the proportion of correct target concepts included in the group product. To establish reliability, a second rater independently scored a random sample (20%) of assignment products. The interrater reliability index was $\alpha = .97$.

Types and severity of challenges In the reflection phase, individuals reported the degree to which each of four types of challenges (planning, doing the task, checking progress, and groupwork) posed problems for their group on a 5-point Likert scale, from 1 (*not a problem*) to 5 (*a very big problem*). Each of the four types of challenges was augmented with a list of specific examples. For instance, the examples provided for planning challenges included having different ideas about how to work together and having different goals and priorities.

Main challenge and strategy A narrative constructor prompted students to construct a reflective statement about one salient challenge encountered by their group. Reflective statements were completed by selecting one option from a dropdown list to populate a sentence about (a) the biggest tension or difficulty (selected from the list of 22 challenges in Table 1), (b) the degree to which the tension/difficulty affected their group work from 1 (*did not affect*) to 5 (*very strongly affected*), (c) the strategy used to overcome the tension/difficulty (selected from the list of 16 strategies in Table 2), (d) who took responsibility to execute the strategy (self, others, or the team), and (e) the degree of success in implementing the chosen strategy to overcome the tension/difficulty on a five point scale ranging from 1 (*not at all successful*) to 5 (*very successful*). Figure 3 shows an example of a narrative statement produced using the narrative constructor. This fictitious student identified *different goals/standards of work* as the main tension experienced by the group, and felt that the tension *did* affect their work. In response, this student reported the group *made sure they understood what they were supposed to do and why* and this *somewhat successful strategy* was something others in the group helped the student to do.

Future strategy A second narrative constructor prompted students to construct a plan about how to address this type of challenge should it occur again in the future. Students selected from items in dropdown lists to report (a) a future strategy (from the list of 16 strategies in Table 2)

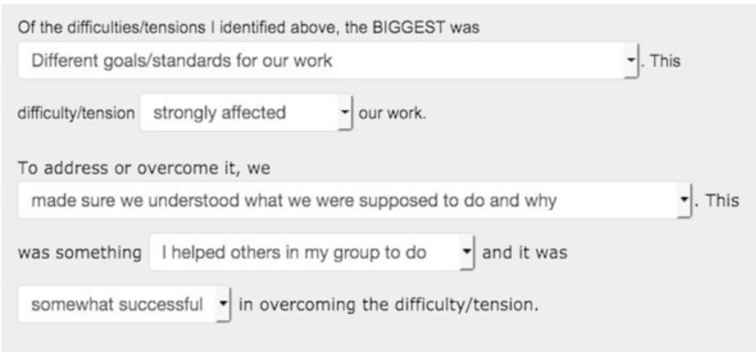

Fig. 3 Example narrative constructor used to report about the main challenge encountered during collaboration

and (b) who should take responsibility to execute that strategy in future collaborative tasks (*I should do individually, I should help others do, others should help me do, we should do as a group*). Figure 4 provides an example. This fictitious student recognized that the group as a whole should better prepare for the activity next time.

Findings

Descriptive information and preliminary analyses

Table 3 summarizes relevant descriptive information about the three visualization conditions. The three conditions were similar in terms of number of groups, number of students, and overall collaborative task performance. With the homogeneity of variance assumption met, differences between visualization conditions on collaborative task performance did not reach significance, $F(2,43) = 0.56$, $p = .57$. Having a visualization support did not influence groups' success with the domain knowledge assessed in the collaborative task.

Should data be treated at the individual level or as nested data? Challenge data were collected at the individual level. However, individual observations were not independent because individuals were nested within small groups. As a result, any significant findings about individual differences analyzed using a single-level analysis may be inaccurate as Type-1 error may have been inflated. To test whether self-reported challenges were dependent on group membership, a series of intercept-only models were performed to estimate the proportion of between-group variance to total variance (i.e., the intraclass correlation coefficient-ICC) in each challenge rating (Raudenbush & Byrk, 2002). The ICC for *planning* was $r = .07$, for *doing the task* was $r = 0.08$, for *checking progress* was $r = 0.03$, and for *groupwork* was $r = 0.22$. Variations at the group level for planning, checking, and doing the task challenges were not significant, indicating that analyzing the data at two different levels (i.e., individual and group) was not necessary. For *groupwork* challenges, individual responses were more group-dependent ($p < .001$); however, the design effect–estimation of the correction needed for the standard error given the study's sampling design (1.88) fell below the recommended criterion (2.0) for a multilevel analysis (Muthén and Muthén 2010). Furthermore, our sample size (46 groups with fewer than 5 cases per group) lacked sufficient power for multilevel analyses (Hox et al. 2010). Although single-level analysis was most appropriate in this case, we imposed a robust standard error (where applicable) to account for potentially inflating Type 1 error.

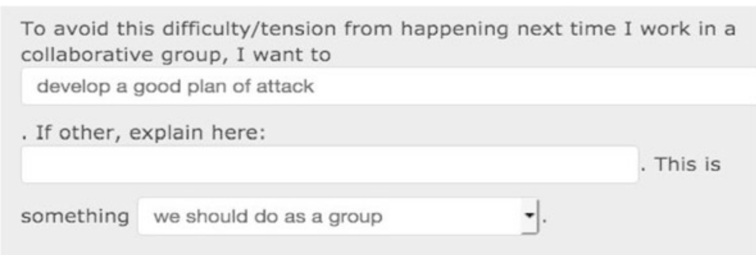

Fig. 4 Items assessing students' plan for adaptation in future collaboration

Table 3 Descriptive information across visualization conditions

	Quantified	Nominal	No Visualization
Number of groups	14	16	16
Number of students	53	67	60
Mean task performance (SD)	5.69 (1.22)	6.03 (1.15)	5.64 (1.06)

Comparison of visualization conditions on severity of challenges

To examine differences in the degree or severity of challenges reported between visualization conditions, a series of one-way ANOVAs across the three visualization conditions were conducted. Scores approaching 5 indicate high severity of challenge, meaning very strong effect on group work. Low scores indicate low severity of challenge, mean minimal effect on group work. The alpha levels for these analyses were corrected using the Holm-Bonferroni correction (Holm 1979).

We hypothesized having access to visualizations of other team member's planning ideas during group planning would stimulate better group planning evidenced by the amelioration of common challenges encountered during collaboration. A priori contrast (visualization vs. none) was used to test this hypothesis. Findings indicated that students in the no visualization condition rated planning as more problematic for their groups than students in the quantified and nominal visualization conditions, $t(177) = 2.206$, $p = .029$, *Cohen's* $d = .21$. However, there were no statistically detectable differences across visualization conditions for doing the task ($F(2,177) = .566$, $p = .57$), checking progress ($F(2,177) = .805$, $p = .45$), or groupwork challenges ($F(2,177) = 1.22$, $p = .29$), and the contrast in those challenge types did not reach significance (see Table 4). Overall, the severity of *planning* challenges during the collaborative task was reduced for groups who received planning support in the form of visual summaries of group member's planning ideas.

Theoretically, successful planning sets the stage for successful collaboration. Therefore, we hypothesized higher reports of planning challenge severity would be correlated with increased severity of other challenges during collaboration. To test this hypothesis, cross-correlation statistics among challenge categories were conducted for each visualization condition (see Table 5). Findings indicated reports of severity of challenges (planning, doing, checking, and groupwork) were correlated for the no visualization condition only. In other words, when planning became a problem for the no visualization group, doing the task, checking progress, and groupwork also became challenging.

Table 4 Comparison of mean ratings of challenge severity by visualization condition

	Quantified	Nominal	None	All Conditions	Visualization vs. None $t(177)$
Planning	1.71 (.76)	1.96 (.89)	2.17 (1.1)	1.96 (.95)	2.21, $p = .03$
Doing	2.23 (1.01)	2.31 (1.14)	2.45 (1.21)	2.33 (1.13)	−1.07, $p = .32$
Checking	2.04 (.98)	1.81 (.97)	1.92 (1.03)	1.92 (.99)	.03, $p = .97$
Groupwork	1.81 (.94)	2.10 (1.29)	1.85 (1.11)	1.93 (1.14)	.60, $p = .55$

Numbers in parentheses are standard deviations for the respective means. High scores indicate high levels of challenge

Table 5 Cross-correlations between challenge types for each visualization condition

	Quantified	Nominal	No Visualization
Planning x Doing	.13	.42**	.44**
Planning x Checking	.06	.20	.60**
Planning x Groupwork	.22	.35**	.32**
Doing x Checking	.30*	.14	.48**
Doing x Groupwork	.33*	.43**	.41**
Checking x Groupwork	.26	.02	.36**

** $p < .001$; * $p < .05$

Comparison of visualization conditions on main challenge

We hypothesized *planning challenges* would be more frequently identified when no visualization support for planning was provided because groups were not explicitly confronted with discrepancies in planning beliefs and perceptions amongst group members. In contrast, awareness of differences stimulated by the quantified and nominal visualizations has potential to stimulate more active joint planning processes aimed at resolving those differences. More active planning early in collaboration has potential to ameliorate significant planning challenges later.

To examine differences in the main challenge reported within and across visualization conditions, a series of chi-square goodness of fit tests were performed. Given that time pressure was a specific design feature for this collaborative task, "*Running out of time*" was treated as its own challenge category for the remaining analyses. Table 6 shows the frequency and percentage of students identifying each challenge by visualization condition. The *checking progress* category was removed due to low frequencies. Although no between-condition differences were found across visualization conditions, within-condition differences were found. Students in the no visualization condition reported more *planning* (28.3%) and *time* (35%) challenges compared to *doing the task* (18.3%) and *groupwork* (11.7%) challenges, $x^2(3) = 8.29$, $p = .04$, *Cramer's* $V = .22$. Students in the quantified visualization condition most frequently identified *time* as the main challenge encountered, $x^2(3) = 20.63$, $p < .001$. Finally, no differences were found in the frequency of reporting planning, doing, time, checking progress or group work challenges for students in the nominal visualization condition, $x^2(3) = 1.62$, $p = .66$.

To examine differences in reports of the impact of main challenges (from *did not affect* to *very strongly affected*) across visualization conditions and whether those differences were dependent on the type of main challenge identified, a 4 × 3 (Challenge Categories x Visualization Conditions) ANOVA was performed. The homogeneity of variance assumption was met, and estimated means were computed to account for the unequal number of participants between cells. Findings indicated that the main challenge reported by students had a weak to moderate impact on group work, $M = 2.7$, $SD = .94$, and did not differ across types of challenges, $F(3, 168) = .45$, $p = .72$, or visualization conditions, $F(2, 168) = .94$, $p = .39$.

Comparison of visualization conditions on strategy used to address main challenge

Although we hypothesized *planning challenges* would be more dominant when no visualization support was provided during planning, the paucity of research about strategies used in collaborative work constrained the specificity of hypotheses we could make. Several years ago, a pilot study conducted with engineering and environmental studies teams engaged in a group project indicated that students may have a limited repertoire of strategies to draw upon

Table 6 Percent (and n) of students reporting each main challenge across each visualization condition

%age and N of students identifying that challenge	Quantified	Nominal	None	Overall
Planning Challenges % (n)	15% (8)	16% (11)	28% (17)	20% (36)
Different goals/standards for our work	0	2	1	3
Different ideas about how to organize our time	3	1	7	11
Different ideas about how to start	3	4	4	11
Different ideas about how to work together	0	1	5	6
Different understandings of what we need to do	2	3	0	5
Doing the task Challenges % (n)	15% (8)	25% (17)	18% (11)	20% (36)
Different levels of commitment to the task	0	3	1	4
Different strategies or approaches	2	2	1	5
Different understandings of the course material	1	4	0	5
Different working styles	1	3	1	5
Trouble staying on task	0	0	1	1
Trouble using the technology	1	4	2	7
Trouble understanding each other	3	1	5	9
Time Challenges % (n)	49% (26)	24% (16)	35% (21)	35% (63)
Checking progress Challenges % (n)	7% (4)	9% (6)	7% (4)	8% (14)
Different ideas about how to check progress	0	3	1	4
Different ideas about what to do when we run into problems	3	1	0	4
Different ideas about when to check progress	1	2	3	6
Groupwork Challenges % (n)	13% (7)	25% (17)	12% (7)	17% (31)
Unmotivated group member(s)	0	5	1	6
Unequal participation or distribution of work	3	4	2	9
Unsupportive group climate (e.g., uncomfortable, unfriendly, lack of trust)	0	0	0	0
Different styles of interacting (e.g., quiet, bossy, confrontational)	0	2	0	2
Different communicating due to language barriers	4	6	4	14
TOTAL (N) of reported challenges	(53)	(67)	(60)	(180)

when they encounter challenges, particularly planning challenges (McCardle et al. 2011). To explore this issue further, we compared the frequency of reported strategies for addressing challenges to see if there were differences between groups who received different types of planning visualization support.

To examine differences in the main strategy reported within and across visualization conditions, a series of chi-square goodness of fit tests were performed. As their main strategy, students in the quantified visualization condition chose planning (21%), doing (12%), checking (27%), and groupwork (33%) strategies equally frequently, $x^2(3) = 5.5$, $p = .14$. Similarly, students in the nominal visualization chose planning (23%), doing (23%), checking (17%), and groupwork (29%) as their main strategy, $x^2(3) = 2.13$, $p = .54$. Despite the no visualization condition showing a trend to choose planning (15%) and checking (14%) less frequently than doing (27%) and groupwork (34%) strategies, the difference across strategy types was not significant, $x^2(3) = 7.45$, $p = .06$.

Comparison of visualization conditions on strategy effectiveness

Differences in reported strategy effectiveness were also compared across the three visualization conditions. To examine whether strategies were more effective for particular main challenges and strategy types under specific visualization conditions, a 4 × 4 × 3 (Challenge Types x Strategy Types x Visualization Conditions) factorial ANOVA was performed. To account for unequal participants between cells, weighted means and standard errors were used. Tables 7 and 8 shows the means and standard errors for each visualization condition by challenge and strategy type.

Overall, strategy effectiveness ratings differed across visualization conditions, $F(2,119) = 2.83$, $p = .02$, partial $R^2 = .06$. Post hoc comparisons indicated that students in the no visualization condition reported less success with strategies when compared to the quantified condition (*Mean difference* = −.49, $p = .03$), but reported similar success with strategies when compared to the nominal condition (*Mean difference* = −.43, $p = .05$). Providing quantified representations of individual planning ideas to support collaborative planning led to greater perceived success using strategies to address challenges arising during collaboration. Furthermore, strategy effectiveness was not dependent on the types of main challenge students encountered, $F(3,119) = 2.64$, $p = .05$, nor was it dependent on the types of strategy they chose to enact, $F(3,119) = .66$, $p = .55$.

Comparison of visualization conditions on regulatory patterns

To understand students' strategic approaches to regulating their main challenge, we examined students' decision paths along four main branches: (a) the main challenge identified, (b) the strategy used to address that challenge, (c) the person(s) responsible for enacting the strategy, and (d) the degree of effectiveness in enacting the strategy. Conditional probabilities of self-

Table 7 Percent (and n) of students reporting each strategy across each visualization condition

Strategy chosen	Quantified	Nominal	None
Planning	21% (11)	23% (15)	15% (9)
Made sure we understood what we are supposed to do and why	3	9	3
Set specific goals about what we wanted to learn	1	2	1
Developed a good plan of attack	7	4	5
Doing	12% (6)	23% (15)	27% (16)
Used our individual expertise and knowledge	3	5	2
Got motivated	0	1	2
Made use of good strategies to get the task done	0	1	3
Maintained focus on the task	3	6	6
Managed the environment	0	0	0
Asked for help	0	2	3
Check Progress	27% (14)	17% (11)	14% (8)
Monitored our task progress as we went	5	5	5
Made changes to our approach when we recognized things weren't going well	9	6	3
Groupwork	33% (17)	29% (19)	34% (20)
Developed a positive group climate	3	3	1
Used good communication skills	9	10	16
Developed confidence and assertiveness	0	0	0
Assigned specific roles to group members	5	6	3
No Strategy	8% (4)	8% (5)	10% (6)
Did nothing, just moved on	4	5	6
TOTAL	52	65	59

Table 8 Estimated mean strategy effectiveness and standard errors by challenge category for all visualization conditions

		Quantified	Nominal	None	Overall
Main challenge	Strategy Type				
Planning	Planning	4.50 (.49)	4.25 (.43)	3.86 (.40)	4.13 (.26)
	Doing	3.00 (.99)	5.00 (.86)	4.00 (.76)	4.00 (.51)
	Checking	–	5.00 (.61)	5.00 (1.07)	5.00 (.59)
	Groupwork	4.67 (.57)	4.00 (.49)	3.67 (.44)	4.00 (.30)
Doing	Planning	4.50 (.41)	5.00 (.39)	4.50 (.76)	4.69 (.30)
	Doing	4.25 (.49)	3.67 (.29)	3.10 (.34)	3.52 (.22)
	Checking	4.00 (.29)	4.43 (.33)	4.50 (.54)	4.22 (.23)
	Groupwork	4.00 (.31)	3.89 (..29)	4.25 (.31)	4.06 (.18)
Checking	Planning	5.00 (.99)	5.00 (.86)	–	5.00 (.69)
	Doing	–	5.00 (.86)	5.00 (1.07)	5.00 (.69)
	Checking	4.0 (.99)	4.00 (.86)	2.50 (.76)	3.25 (.52)
	Groupwork	5.0 (.99)	5.00 (.86)	–	5.00 (.69)
Groupwork	Planning	–	4.60 (.39)	–	4.60 (.44)
	Doing	4.00 (.99)	3.25 (.43)	3.30 (.62)	3.38 (.41)
	Checking	4.00 (.99)	4.00 (.86)	1.00 (1.07)	3.00 (.56)
	Groupwork	4.33 (.57)	3.67 (.35)	2.50 (.76)	3.64 (.33)
Overall		4.09 (.21)	4.06 (.16)	3.57 (.19)	3.91 (.08)

High means indicate high level of strategy effectiveness. Dashed cells indicate that the choice was not selected, hence no success rating can be included

reported event sequences and the mean effectiveness rating for specific decision pathways were computed using Python scripts developed in our lab. Next, these decision steps were graphically represented as maps to identify dominant patterns across visualization conditions. To make maps readable and interpretable, branches were pruned by removing low probability events. In cases where more than one decision event had similar probability to another, both decisions paths were mapped. Given that planning was the focus for the visualization support conditions in this study, planning decision trees were compared between all three support conditions (Fig. 5) to test our hypothesis that providing planning visualization support would disrupt patterns of responses to planning challenges. In line with graph theory, we refer to the arrows as edges and the boxes as nodes. Edge weights (i.e., thickness of the arrows) correspond directly to the probability of transitioning to the connected node; the higher the probability the, the higher is the edge weight.

An example of a decision pathway can be seen Fig. 5. In the *quantified* condition, 15% of students identified a planning challenge; 50% of those students reported using a planning strategy to remedy the planning challenge, with all of them (100%) reporting this strategy was enacted by the team. The mean effectiveness rating provided by students who took these steps was 4.5, about a half standard deviation higher than the overall mean effectiveness rating of the sample.

Comparison of visualization conditions for regulating planning challenges The first set of decision trees were limited to regulation of planning challenges across Visualization conditions (Fig. 5). Overall, the probability of identifying a planning challenge was higher for students who received no visualizations to support team planning (28%) than students who received nominal (17%) or quantified (15%) visualizations. All conditions reported similar patterns responding to planning challenges by adopting planning or team strategies. However, for students receiving planning support without visualization (no visualization condition),

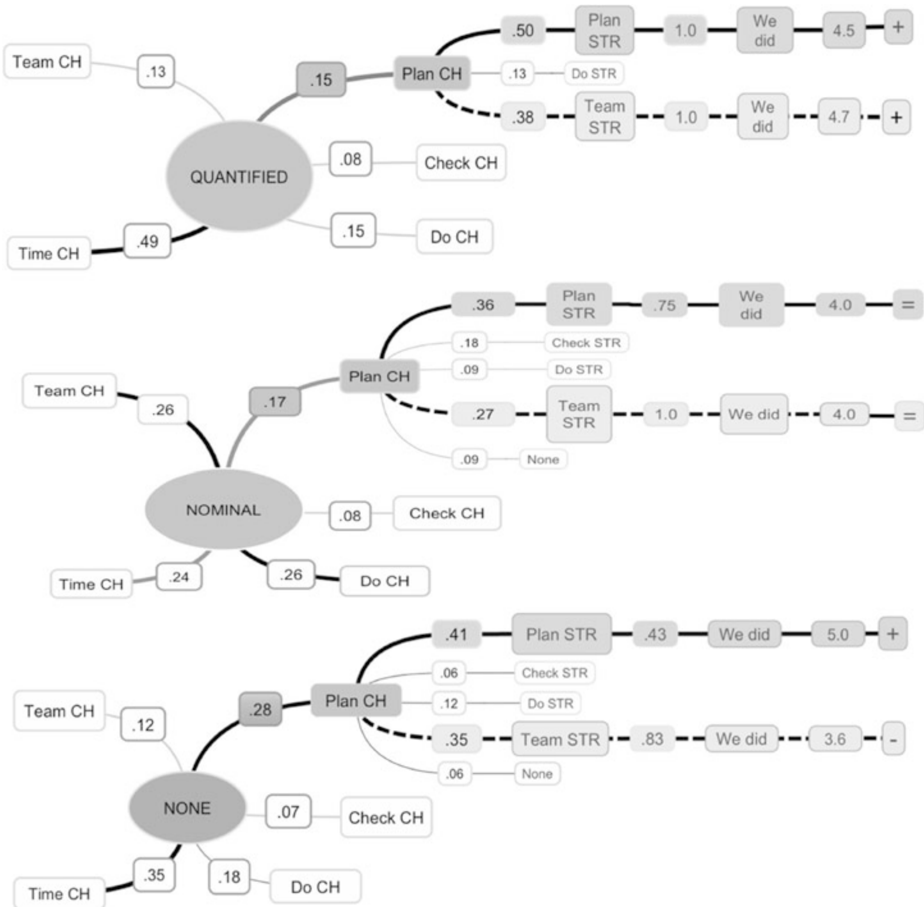

Fig. 5 Decision pathways for regulating planning challenges across visualization conditions, from the probability of encountering the challenge to the probability of selecting a specific strategy to the probability of enacting the strategy individually or socially, and the average effectiveness rating for the pathway

planning strategies were most effective ($M = 5.0$), compared to teamwork strategies, the other common strategy choice ($M = 3.6$). In contrast, students in both visualization conditions reported planning strategies and teamwork strategies as being almost equally effective for addressing their *planning challenges*. It is possible that *planning strategies* are most necessary when students have no explicit information about group members planning perceptions to guide shared planning. Of note, across all conditions, strategies for addressing planning challenges were something groups reported as shared or done by the group together, rather than being the responsibility of individuals within the group.

Comparison of visualization conditions on regulating dominant (main) challenges The second set of decision trees examined regulation of all challenges across conditions (Fig. 6). Students in both the quantified visualization and the no visualization conditions followed similar dominant decision paths identifying *time* as a main challenge and *checking progress* as a strategy to address that challenge. The main difference between these two conditions was in the reported success of the checking progress strategy for addressing

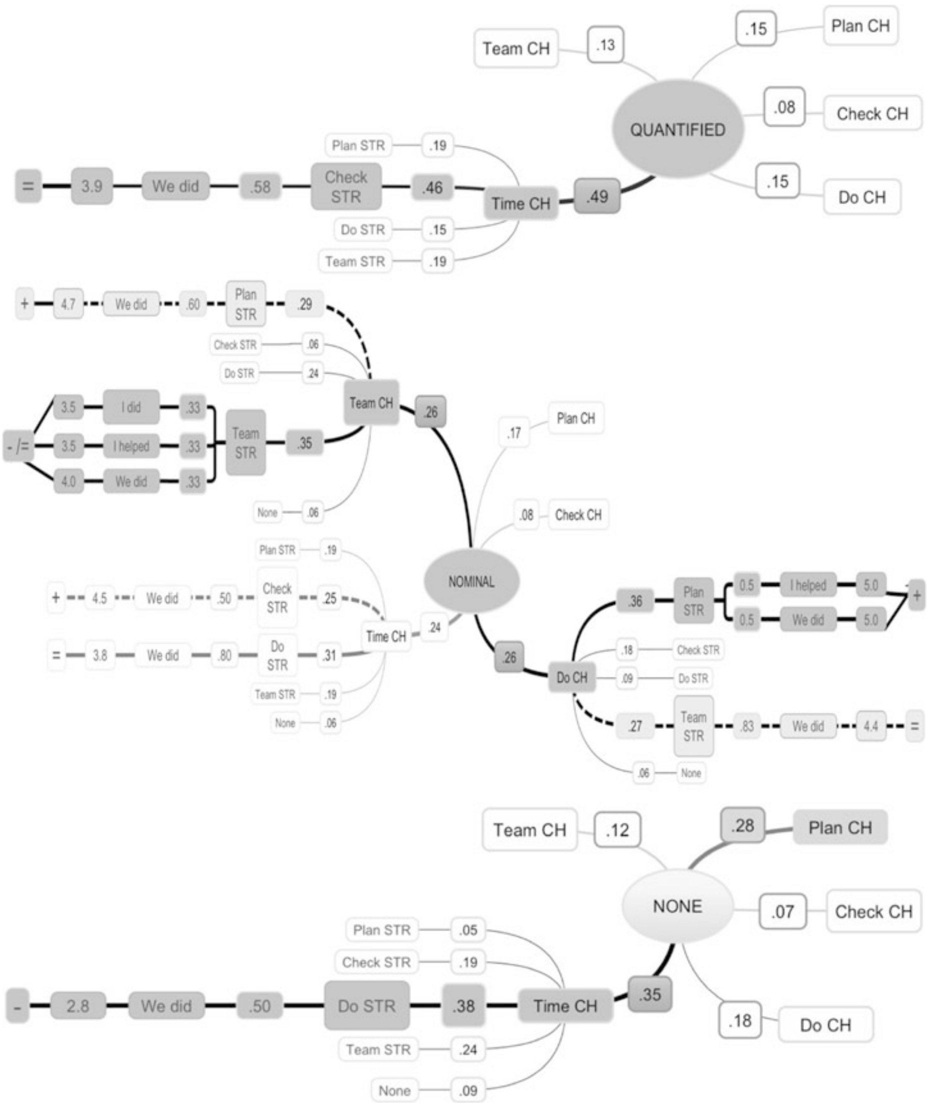

Fig. 6 Decision pathways for regulating dominant challenges across visualization conditions, from the probability of encountering the challenge to the probability of selecting a specific strategy to the probability of enacting the strategy individually or socially, and the average

time challenges. Students in the no visualization condition reported relatively low levels of success with that strategy ($M = 2.8$), whereas students who had planning support in the form of a graphic summarizing the frequency of planning responses across group members (quantified visualization), reported being moderately successful ($M = 3.9$) using the *checking progress* strategy to address time-based challenges.

Students in the nominal planning support condition demonstrated the most variability in their decision patterns. To begin with, probabilities for experiencing challenges with time, teamwork and doing the task, were almost equivalent (24–26% of the time) with planning challenges following closely behind (17% of the time). For students in this condition, collectively adopting planning strategies was reported to be highly effective when confronted with challenges associated with teamwork or doing the task itself ($M = 4.8$ and $M = 5.0$ respectively), whereas adopting teamwork strategies was much less effective ($M = 3.5–4.4$) regardless of whether the strategy was enacted individually, collectively or in support of others in the group. In contrast to the quantified and no visualization conditions, the nominal visualization condition reported a high level of success ($M = 4.7$) adopting *checking progress* together as a strategy for addressing challenges associated with time.

Comparison of visualization conditions on future strategy

Theories of self-regulation posit successful students draw on prior knowledge, experiences, and beliefs to adapt or make more strategic decisions in the future (Butler and Winne 1995; Winne and Hadwin 1998). Furthermore, this study attempted to disrupt patterns of challenges encountered during collaboration by providing different levels of support for planning prior to collaboration. Therefore, a follow up analysis was conducted to examine whether students identified planning as important for addressing a range of potential challenges in future collaboration. There were no detectable differences across visualization conditions (see Table 9). However, 57% of students identified planning as an important strategy for future collaboration with a slightly higher percentage of students identifying planning in the quantified and nominal conditions (62 and 59% respectively) than the no visualization condition (50%). In addition, across all conditions, students most frequently reported that successful strategies should be the responsibility of the group as a whole rather than individuals within the group alone (see Table 9).

Discussion

The purpose of this study was to examine the effect of team planning support in the form of awareness visualizations (quantified, nominal, and no visualization of individual planning perceptions summarized across group members) on the challenges students face during collaboration and the ways they report regulating in the face of those challenges. Two main questions are discussed with respect to findings in this study: (a) What challenges do students report during collaboration? (b) How do students strategically respond to those challenges?

Table 9 Summary of chosen future strategy across each visualization condition

	Quantified	Nominal	None	Overall
Choosing planning	31 (62.00%)	36 (59.02%)	30 (50.00%)	97 (56.73%)
I-approach	6	4	6	16
CoRL-approach	2	4	3	9
We-approach	23	27	19	69
Choosing other than planning	19 (38.00%)	25 (40.98%)	30 (50.00%)	74 (43.27%)
I-approach	1	3	0	4
CoRL-approach	1	3	0	4
We-approach	16	19	29	64
Total	50	61	49	171

What challenges do students report during collaboration?

The first research question examined the types of challenges students encountered during collaboration. As expected, students who received no planning support through visualizations reported planning as a more severe problem. Although the effect size was small, providing visual summaries of planning ideas across individuals in the group to stimulate group planning discussions resulted in reports of lower severity in planning challenges during collaborative work. Findings indicate planning support augmented with feedback about each other's individual planning perceptions may be valuable in helping groups manage planning challenges during collaboration.

For students who received no visualization planning support, we detected high positive correlations between the severity of challenge reported in planning and all other challenges. In other words, higher severity of reported *planning* difficulties for students in the no visualization condition co-occurred with higher severity of *checking progress*, *group work* and *doing the task* difficulties, which concurrently disrupted collaboration. Research indicates planning is important for ameliorating other challenges in collaboration (Greene et al. 2012; Rogat and Linnenbrink-Garcia 2011). When planning doesn't go well, other challenges are likely to emerge concurrently but the reason for that relation is unclear. For example, *checking progress* challenges may arise for at least three reasons: (a) standards or criteria do not exist (a planning problem), (b) monitoring is inaccurate, or (c) there is a failure to monitor at all (see Winne and Hadwin 1998). Therefore, the co-occurrence of *planning* and *checking progress* challenges for the no visualization condition warrants more in depth examination in future research.

Not surprisingly, given the nature of this timed collaborative test, a large proportion of students identified *time* as the most salient challenge they encountered during teamwork. However, students in the no visualization condition identified both *time* and *planning* more frequently than challenges associated with *doing the task* or *group work*. In other words, upon reflection, students recognize the role planning challenges played in the group's collaborative experience. This may suggest instruction and support that targets planning may be most salient when recent collaborative experiences together serve as a backdrop for planning for a subsequent collaborative task together.

Finally, challenges arise in the contexts of tasks, teams, and task situations. We acknowledge other tasks and task contexts may introduce challenges that did not emerge in this study by design. For example, in collaborative tasks where group membership is not assigned or work time is not defined and constrained, a host of other challenges may arise. The collaborative task for this study intentionally introduced time pressure. By design, we limited the possibility for group member selection and schedule coordination challenges to occur.

How do students strategically respond to those challenges?

Our second broad aim was to examine strategies students adopted in response to a salient challenge during collaboration. From a self-regulatory perspective, encountering a challenge or a difficulty presents an opportunity to regulate by priming the need for a strategy (Butler and Winne 1995; Hadwin and Winne 2012). However, there is a paucity of research to date about the strategies students select to address challenges when they arise during collaboration (see Koivuniemi et al. 2017).

When confronted with planning challenges, students in this study reported adopting either planning or teamwork strategies. Planning strategies were reported to be more effective than teamwork strategies in the no visualization condition where information about each group members' planning perceptions and beliefs was unavailable. Students in the no visualization condition also reported experiencing planning challenges more often than the other conditions, and struggled more than the quantified condition to find appropriate strategies for successfully addressing planning challenges. In contrast, students who received graphical summaries about group members' individual planning thoughts (quantified and nominal conditions) reported both planning and teamwork as being equally effective for addressing planning challenges. One possible explanation is that visualizations stimulate active group planning prior to collaboration and making planning strategies less relevant and more focused when planning challenges resurface during collaboration. Overall, findings lend some support to (a) the importance of supporting strategic planning prior to collaboration and (b) the need for guiding students to use planning strategies when planning challenges occur during collaboration especially when group planning was under-emphasized or under-supported prior to collaboration. Sobocinski et al. (2017) found that during high challenge work sessions, teams switch between planning (forethought) and performance phases more often compared to low challenge work sessions. Together these findings point to the importance of planning at critical moments before and during collaboration.

Challenges associated with *time* were most frequently identified across all visualization conditions. However, regulatory responses and strategies for remediating *time* challenges varied by visualization condition. When confronted with *time*-based challenges, students reported trying strategies related to *checking progress* and *doing the task* with moderate to low success. In particular, students in the no visualization condition reported *doing the task* strategies were not particularly effective for addressing time-based challenges. This finding makes sense from a regulatory perspective because adopting strategies to change what you do during collaboration should only be successful when they are based on accurate and complete task perceptions and goals that are shared amongst group members (Hadwin et al. 2017). Similarly, the effectiveness of *checking progress* strategies is conceptualized as dependent on the task perceptions and goals negotiated by group members; goals comprise standards for calibrating "checking" actions (Hadwin et al. 2017). If group members check progress against different or irrelevant standards, strategies are unlikely to be successful.

Students in the nominal visualization condition who received information about the heterogeneity but not frequency of individuals' planning responses (a) reported experiencing *team, time*, and *doing the task* challenges in almost equal proportions, and (b) responded to those challenges with two dominant types of strategies. *Planning* strategies were reported to be more effective for team challenges than *doing the task* strategies, whereas *checking progress* was the most effective strategy for dealing with *time*-based challenges. This finding warrants further investigation. Students in this condition were presented with a visual summary of all the possible planning perceptions expressed by the group and challenged to converge on the 5 most accurate ideas in generating their group plan. If this stimulated more active and dynamic planning discussions amongst group members, it may have reduced the frequency of planning challenges and created a strong planning foundation to return to when other challenges arose.

Overall, being confronted with summaries of group members' planning perceptions and goals (quantified or nominal visualization) appears to have (a) changed the pattern of challenges students experienced during collaboration and (b) resulted in adopting effective planning strategies during collaboration. Future research should more closely examine the timing and content of planning discussions arising before and during collaboration. Knowing more about how students discussed and negotiated planning perceptions during the group planning session may provide more information about why the quantified planning visualization was most effective in ameliorating planning challenges.

Overall, *planning* and *checking* strategies were deemed most effective during collaboration. Furthermore, students identified *planning* strategies as important for future collaboration. Given that past research indicates students fail to prioritize shared planning during teamwork (e.g., Hadwin et al. 2010; Luyten et al. 2001), we view this as a promising finding indicating that students recognize the importance of prioritizing planning for future collaborative work. Students also indicated *planning* and *checking progress* should be enacted by the group collectively rather than independently. Together these findings lend support for future interventions introducing planning and checking strategies to groups in response to a range of challenges that arise during collaboration.

Limitations and future directions

We acknowledge this study draws from self-report data alone and offer this as both a strength and opportunity for future research. A strength of this approach is that it uncovers student perceptions of challenges and the ways they respond, either effectively or not, to those challenges as they arise in collaboration. We argue these perceptions play an important role in guiding regulatory decisions, self-evaluations of those decisions and future adaptation based on self-evaluations. Knowing something about students' perceptions of challenging situations in collaboration is important in at least four ways. First, knowing what challenges students perceive has potential for helping focus multi-modal data analysis and interpretation on critical moments when regulatory action and negotiation is warranted rather than looking for evidence of regulation over entire collaborative episodes. Second, knowing how students believe they respond to difficulties creates opportunities to examine the alignment between perceptions of strategies for addressing collaborative challenges and observable actions, discourse and responses within and across group members. Third, understanding perceptions of challenges has potential to guide interventions and tools to support regulation in the face of these difficulties. Finally, when conditions or situations that stimulate strategic responses (i.e., challenges) are matched with specific strategies used to address those challenges, researchers are better poised to identify the situations or conditions wherein which specific strategies are effective.

Despite the value of obtaining self-reports about challenges and strategies, incorporating multi-modal observation data to this type of research has potential to add to our understanding of the ways strategies can be used to ameliorate challenges during collaboration. Augmenting self-report data with this type of observation data also has great potential to reveal situations where perceptions are misaligned with observations of challenges and strategies during collaboration.

A second caution is that participants in this study were enrolled in a self-regulated learning course where they learned about the importance of planning in successful regulation. Having knowledge and exposure to these concepts may have increased the value of visualizations for stimulating planning because students had knowledge of its importance in regulation. However, despite all students knowing about the importance of planning, differences across visualization conditions were still observed. Future research should replicate this study with students collaborating on projects in other disciplinary areas such as business and engineering.

This study was exploratory in nature. It is the first study to explore the ways group awareness tools can be used to leverage shared planning. Specifically, we explored the kinds of challenges students report during collaboration, the strategies used to address challenges when they arise, and the perceived success of those strategies. Collaborative support in this study was designed to stimulate more proactive planning processes with the goal of preparing students to address challenges more successfully and minimize emergence of challenges where possible. However, it is also important to note that despite evidence of changing patterns and experiences of challenges across visualization conditions, there were no differences in the final collaborative task performance across visualization conditions. This may indicate that supporting planning alone is not sufficient to leverage task performance. Future research should examine the quality and accuracy of planning discussion to see if that differs across planning visualization conditions, or serves to mediate between planning condition and task performance.

Conclusions

Our findings lend support to theories of regulation and our claim that supporting planning for collaboration prompts students to navigate challenges by (a) adopting appropriate strategies for ameliorating challenges as they arise during collaboration, and (b) effectively enacting those strategies as a group. Awareness of members' task perceptions and goals at the beginning of collaboration appears to be critical for groups to coordinate strategic actions, particularly during challenging events. Hence, implementing computer-supported tools to facilitate the development of group shared task perceptions in collaboration is warranted. Future research should explore other properties of group awareness tools, and examine their effectiveness for supporting (a) group regulatory processes from planning to monitoring and adapting, and (b) group performance and learning outcomes.

Our findings make important contributions to theory, research, and practice in computer supported collaborative learning. Findings support the central importance of planning and of adopting planning strategies for ameliorating challenges during collaboration. In practice, findings point to the value of augmenting CSCL environments with tools that directly prompt and support planning processes as means for ameliorating challenges by reducing their severity, and prompting groups to more successfully respond to those challenges when they arise. In addition, this study introduces conditional decision pathways as an analytic tool for identifying successful strategic responses to challenges and comparing those patterns across different instructional support conditions. Future research should investigate the potential of these types of data visualizations for comparing high performing and low performing groups, as well as for detecting and alerting groups to regulatory patterns that have proven to be unsuccessful or successful for them in the past.

This study adds to a body of emerging research indicating that active shared planning prior to and early in the collaborative process has a considerable influence on the way collaboration unfolds. Planning processes set the stage for more positive and supportive socioemotional interactions (Bakhtiar et al. 2017; Isohätälä et al. 2017; Näykki et al. 2017), minimize the intensity and frequency of challenges encountered during collaboration (Hadwin et al. 2015; Järvelä et al. 2010; Kirschner et al. 2015), prepare teams to respond more productively to challenges when they arise (Bakhtiar et al. 2017; Hadwin et al. 2015), and increase metacognitive activity (Bannert and Reimann 2012; Sobocinski et al. 2017).

Compliance with ethical standards

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