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Exploring facilitation strategies to support socially shared regulation in a problem-based learning game

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ABSTRACT: Successful problem-based learning (PBL) often requires students to collectively regulate their learning processes as a group and engage in socially shared regulation of learning (SSRL). This paper focuses on how facilitators supported SSRL in the context of middle-school game-based PBL. Using conversation analysis, this study analyzed text-based chat messages of facilitators and students collected during gameplay. The analysis revealed direct modeling strategies such as performing regulative processes, promoting group awareness, and dealing with contingency as well as indirect strategies including prompting questions and acknowledgment of regulation, and the patterns of how facilitation faded to yield responsibilities to students to regulate their own learning. The findings will inform researchers and practitioners to design prompts and develop technological tools such as adaptive scaffolding to support SSRL in PBL or other collaborative inquiry processes.

Keywords: Problem-based learning, Socially shared regulation, Facilitation, Collaborative inquiry, Conversation analysis

1. Introduction

Problem-based Learning (PBL) is an instructional approach emphasizing learning through collaborative small group problem-solving (Hmelo-Silver, 2004). It has been applied in K–12 education to design scientific inquiry and promote student-centered classrooms (Kim et al., 2018; Merritt et al., 2017; Wirkala & Kuhn, 2011). The integration of PBL with Computer-Supported Collaborative Learning (CSCL) can enhance students' problem-solving in technology-rich learning environments (Lu et al., 2010). While the emphasis of PBL has predominantly been on social knowledge construction, there is a noted gap in the literature regarding its role in facilitating collaboration to highlight students' agency and socially shared regulation in learning. Meanwhile, CSCL places a significant emphasis on socially shared regulation, focusing on enabling students to collaboratively manage their learning processes (Panadero & Järvelä, 2015). To address this gap, our study aims to incorporate the notion of socially shared regulation, typically associated with CSCL, into PBL frameworks. This integration seeks to understand how to support the collaboration process of PBL in CSCL contexts.

While engaging in PBL processes, students are required to take responsibility, regulate their own learning, and engage in socially shared regulation of learning (SSRL) to collectively manage their learning as a group (Järvelä et al., 2010; Volet et al., 2009). Groups with effective SSRL should develop strong connections among members and engage in productive collaboration processes. Successful engagement in SSRL includes attending to several processes such as planning, monitoring, and evaluating tasks before, during, and after engaging in those group tasks (Li et al., 2022; Lee et al., 2015). Shared monitoring of tasks and actions, in particular, requires mutual efforts to keep their collective work on track (Dindar et al., 2019). At the same time, teachers assume the role of facilitator in the classroom, focusing on supporting students' learning process including SSRL rather than providing content knowledge directly to students (Ertmer & Simons, 2006). During facilitation, a major challenge for teachers to support SSRL is to provide just the right amount of intervention at just the right time and balance between supporting meaningful conversations and students' agency (Ertmer & Glazewski, 2015). Therefore, a critical facilitation skill is for teachers to nurture SSRL instead of regulating the work for students (Kim & Lim, 2017).

Facilitation takes an essential role in promoting SSRL for PBL by supporting group collaboration through guiding students' learning, pushing for critical thinking, and modeling the inquiry process (Hmelo-silver, 2006). Moreover, technology can play an important role in advancing learning, such as enabling students to work together and communicate ideas during the learning process (Jeong & Hmelo-Silver, 2016; Holstein et al., 2019; Martinez Maldonado et al., 2012; Gobert et al., 2023) and to seek assistance from a teacher or facilitator (Hmelo-Silver et al., 2019). In CSCL, technology can support facilitation through structured scaffolds embedded in the learning environment (e.g., Hong et al., 2022; Chen et al., 2018). For example, design principles of CSCL

environments have been proposed to support group SSRL (Järvelä et al., 2015). Yet, despite technology's contributions, the irreplaceable role of human facilitators in PBL remains. Facilitators are expected to closely monitor the discussion, understand the context based on their expertise, and intervene with appropriate strategies as needed, providing adaptive scaffolding of cognitive, motivational, and emotional levels, based on their insights of problem-solving and collaborative inquiry. Technology-rich learning environments might also introduce challenges for facilitators as they must adapt the facilitation strategies developed in face-to-face learning environments. For example, facilitating a virtual discussion will entail different dynamics than supporting a face-to-face conversation (Kamin et al., 2009; Good et al., 2008). Despite the importance of facilitation in CSCL, there have been few studies on the strategies that facilitators use to support SSRL in technology-rich PBL classrooms. Therefore, this study looks at how human facilitators use strategies to support technology-rich PBL with an SSRL lens. We investigate this by adopting a grounded approach to classroom discourse to unpack how SSRL was impacted by facilitation moves.

2. Literature review

The interplay between Problem-Based Learning (PBL) and Socially Shared Regulation of Learning (SSRL) has steadily garnered academic attention. Historically, PBL's pedagogical roots lay in the practice of promoting collaborative problem-solving and ensuring student-centric classrooms, emphasizing individual students' self-directed learning (Evensen, 2000) and social knowledge construction (Kim et al., 2018; Merritt et al., 2017). In juxtaposition, SSRL emerges from Computer-Supported Collaborative Learning (CSCL), focusing on the joint monitoring and managing of learning processes (e.g., Gobert et al., 2023; Ochoa et al., 2023). Research suggests that students engaged in PBL should not only be accountable for their individual learning but also be proficient in SSRL to regulate group learning (Dang et al., 2023; Michalsky & Cohen, 2021). Therefore, effective SSRL can contribute to robust group connections and productive collaboration dynamics, potentially demonstrated in processes like planning, monitoring, and evaluating group tasks (Li et al., 2022; Lee et al., 2015). Concurrently, the increased use of technology in classrooms has shown potential for facilitating SSRL, especially within CSCL environments (Järvelä et al., 2015). Nevertheless, while the potential of technology in enhancing facilitation is recognized, the critical role of human facilitators in PBL classrooms persists. Thus, we focus on points of connection between PBL, SSRL, and the evolving role of facilitation, particularly in technology-rich environments, setting the foundation for the current study's exploration into facilitation strategies that foster SSRL within PBL frameworks.

2.1. Problem-based learning (PBL)

Problem-based learning (PBL) is a pedagogical approach centering around collaboratively solving ill-structured problems in small groups (Barrows, 1986; Hmelo-Silver, 2004). PBL holds that knowledge evolves through social interaction, foregrounding students' active roles, and collaboration in the process of co-construction (Whitehill et al., 2014). During PBL, students are expected to experience the inquiry phases including setting up problem scenarios, identifying facts, generating ideas or hypotheses, making an action plan, defining knowledge gaps (i.e., learning issues), applying new knowledge, and reflecting on knowledge (Hmelo-Silver, 2004; Savery & Duffy, 1995), while negotiating with their peers as a group.

PBL has been utilized in K-12 education as an inquiry approach due to its demonstrated effectiveness in activating students' prior knowledge, fostering knowledge construction, advancing self-directed learning strategies, and developing collaboration skills (e.g., Merritt et al., 2017; Goodnough & Cashion, 2006). Despite all the benefits, implementing PBL in K-12 classrooms can bring challenges to both students and teachers. Students can be challenged in terms of readiness to shift into active roles in the classroom, especially in K-12 education where young students may lack previous experience in controlling their own learning (Belland et al., 2015; Hung et al., 2008). Moreover, teachers have reported frustration when facilitating under-prepared young students (Ertmer & Simons, 2006; Ertmer et al., 2009).

2.2. Facilitation in PBL

Facilitation is a critical feature of PBL. A PBL facilitator pushes students to think by modeling ways of engaging in PBL inquiry (e.g., questioning techniques), facilitating students in making disciplinary thinking visible, coaching them to focus on the problem at hand and generate multiple solutions, gradually fading their facilitation when students begin taking responsibility for their own learning, and providing opportunities for students to

reflect on their learning (Johnson & Tawfik, 2022; Bae et al., 2021; Salinitri et al., 2015; Glazewski et al., 2014). Facilitation in PBL needs to attend to multiple facets in the learning process, from deepening disciplinary understanding to fostering productive group collaboration. While carrying out the facilitation tasks, it is also crucial for teachers to withdraw the facilitation at the just-right moment and have students drive their own conversation (Bae et al., 2021). For K-12 settings, shifting a teacher's role to a PBL facilitator poses challenges, ranging from adjusting perception and belief about inquiry learning to adapting PBL facilitation strategies and improving teaching skills (Pimentel & McNeill, 2013).

While the core of PBL revolves around deep, meaningful learning and the active construction of knowledge, collaboration plays a fundamental role in this pedagogical approach (Chen et al., 2022; Unal & Cakir, 2021; Ertmer & Glazewski, 2015). Facilitators in PBL guide students through processes of identifying knowledge gaps, formulating hypotheses, and seeking relevant information. During the collaboration, students should interact, share, challenge, and build upon each other's ideas by collectively regulating their own learning (Nguyen et al., 2023; Bransen et al., 2022). Moreover, collaboration is not merely a byproduct of the PBL process but a crucial element that, when effectively addressed, can significantly enhance knowledge construction. Thus, we seek to inform the pivotal role collaboration plays in PBL and explore facilitation strategies that can contribute to both knowledge construction and collaborative interactions.

2.3. Socially shared regulation of learning (SSRL) in collaboration

In asking students to direct their own learning process, self-regulation is an essential skill in collaborative learning, including PBL (Hadwin et al., 2011). Self-regulation in education is described by Zimmerman (2005) as "the self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p. 14). Many efforts have been made to support self-regulation in learning, theoretically and empirically, such as adaptive system elements as pedagogical tools (Azevedo & Hadwin, 2005), by making thinking visible, reflection prompts, and self-evaluation (Hu & Driscoll, 2013; English & Kitsantas, 2013; Kingir et al., 2013).

Collaboration is one of the essential features in PBL, through which regulation of learning is shared while students learn together and collectively regulate their learning as a group (Malmberg et al., 2015). SSRL refers to a group-level process in which students collectively take control of the learning tasks through shared, negotiated, and iterative regulating actions (Järvelä & Hadwin, 2013; Winne et al., 2013; Volet & Mansfield, 2006). Socially-shared regulation of learning broadens perspectives on learning beyond individual cognitive processes and outcomes, including the active roles of motivation, emotion, metacognition, and strategic behavior in successful learning (Hadwin et al., 2016). Acknowledging that SSRL is often discussed in CSCL contexts, this study expands this notion to PBL, helping us elaborate on how facilitators support group collaboration by fostering SSRL to reach the pedagogical goals of PBL. Therefore, in this paper, SSRL refers to the socially shared regulation process when students engage in collaborative problem-solving in PBL.

2.4. Support for SSRL in technology-rich environments

Although there have been many efforts to support SRL at the individual level (Evensen, 2000), less attention has been paid to supporting SSRL at the group level (Järvelä et al., 2015). SSRL requires complex and dynamic interaction, which is in addition to the requirements of individual regulation. For example, the individual inquiry process is characterized primarily by how individuals define their goals and regulate processes and approaches as part of reaching their goals. However, in SSRL learners must also engage in complex interactions to reach goals which can consist of learner-process, learner-learner, learner-group, and learner-goal interactions (Thompson & Fine, 1999). Järvelä et al. (2015) proposed three design principles to support SSRL in CSCL: "(1) increasing learners' awareness of their own and others' learning processes, (2) supporting the externalization of students' and others' learning process in a social plane and helping in sharing and interaction, and (3) prompting the acquisition and activation of regulatory processes (p. 7)." Based on the three principles above, they designed online planning and evaluation tools embedded in a virtual collaborative system to enhance the awareness of group members and receive anonymous peer feedback. They reported the positive effect brought by their designed SSRL tools with 103 first-year teacher education students as participants working synchronously online. The result showed that groups with SSRL tools, compared to those without, were coordinating and maintaining a positive socioemotional balance among group members (Malmberg et al., 2015). This suggests that SSRL tools can be one source of prompting successful shared regulation. In addition, Zheng et al. (2017) proposed a socially shared regulation-embedded CSCL tool to support collective regulation of learning from

planning to evaluation for undergraduate students and demonstrated a significant improvement in learning achievements and group performance.

Järvelä et al. (2015) argued for the need to develop adaptive and personalized tools tailored to each individual and group's learning needs. For example, a dashboard visualizing collaboration enabled by learning analytics can better inform learners and teachers in CSCL (Chen et al., 2021; Greller & Drachsler, 2012). Though highlighting technology, learning in CSCL involves interactions not only with computers but also among human participants such as teachers. In fact, teachers play a major role in CSCL to monitor and provide complex support in CSCL, including nurturing SSRL (Ingulfsen et al., 2018).

2.5. Challenges in supporting SSRL in technology-rich environments

Unlike collaboration without technology, students in technology-rich environment scenarios may have more limited strategies for responding to their peers and regulating their learning when interacting with the virtual environment, which creates new challenges for SSRL during the learning process (Savin-Baden, 2007; Lobczowski et al., 2022). For example, sending text-based messages might pose challenges in gaining other students' attention. This is more straightforward during face-to-face interactions in which there are physical cues and clearer markers of turn-taking (Garcia & Jacobs, 1999).

Furthermore, teachers as facilitators experience similar challenges when supporting students in CSCL, such as technology-rich PBL environments. In PBL, teachers serve as facilitators in classrooms to help students build and maintain a productive discussion but in addition need to balance providing structure for students while also supporting their agency to monitor their own learning (Hmelo-silver, 2006; Järvelä et al., 2015). Although the technology might enable closer monitoring of students' learning activities, it can also add to the complexity of the learning process, requiring dynamic and nuanced facilitation strategies. For example, technology enables facilitators to monitor group-level discussions by reading students' streaming chat so that they can intervene when out-of-domain conversation is happening (Jeong & Hmelo-Silver, 2016). However, it is hard for one teacher to monitor multiple groups at the same time (Dillenbourg, 2013). In addition, despite the limited capacity each teacher has, for students, too much intervention from facilitators might inhibit discussion among students as they fear surveillance in the classroom (Feyzi Behnagh & Yasrebi, 2020).

In conclusion, earlier studies had a rich discussion over the system-level support of SSRL with the design of technological tools. However, previous studies have not focused on teachers' facilitation in PBL to support SSRL. While it is evident that teacher facilitation serves a critical role in promoting students' learning during the collaborative inquiry process, there is a lack of investigation into how facilitators delicately navigate their support through the integrative use of different strategies.

3. Research objective

The goal of this research was to explore the strategies facilitators use to support middle school students' SSRL within a game-based computer-supported PBL context to inform a deeper understanding of SSRL and offer practical guidance for facilitation with PBL. The guiding research question was as follows:

What strategies do facilitators use to support groups' development of collective regulatory processes such as setting goals, monitoring learning, evaluating learning, and regulating shared social space in a game-based computer-supported PBL context?

4. Method

4.1. Research design and analytical framework

This research was guided by ethnography with the lens of conversation analysis (CA) to derive insights from a detailed investigation of social interaction patterns (Sacks, 1992; Ten Have, 2007; Gumperz, 1981). Ethnography refers to a qualitative research method that involves immersing oneself in a particular cultural or social setting, aiming to understand the perspectives, practices, and social interactions of the people within that context (Brewer, 2000). From an ethnographic perspective, the research should be situated in its social environment, closer to the phenomena, rather than manipulated in a lab (Hammersley & Atkinson, 2007). CA is a qualitative

approach, focusing on the talk-in-turn of everyday conversation, thus deeply investigating the nuances of the interaction. One of the major goals of CA is to unveil what has been taken for granted in everyday life for reflection and improvement.

As the interaction in this study was happening in an online learning environment, we took special consideration of in-game text-based chat-informed digital CA specifically. Digital CA shares the conversation analysis (CA) constructionist position believing that context matters for conversations and language goes beyond representing literal internal cognitive states (Paulus et al., 2018). Thus, for this study, discussion in the chat does not represent what is going on in the group member's mind but it also shapes and reshapes the group dynamic through interaction. Giles et al. (2015) highlight the importance of adopting a digital CA approach based on the traditional CA approach, in terms of using naturally occurring data and applying CA iterative procedures while considering how the online data differs from spoken and other types of online data. Therefore, in this research context with chat messages, the game elements were taken into account, considering that the pattern of interaction in the chat interface within the game might be significantly different from a face-to-face discussion (Koivisto et al., 2023).

In online communication, particularly when navigating in technology-rich learning environments, CA stands out as an analytical choice to surface micro-level interactions pivotal in a learning context (Meredith et al., 2021). At the core of CA's strength is its rigorous emphasis on the sequential nature of interactions (Stahl, 2012). Distinct from many other forms of textual data, chat messages are inherently structured in sequences; each utterance not only reflects a response to preceding messages but also sets the stage for subsequent interactions. This continuous ebb and flow, instrumental for co-constructing meaning and co-regulating learning in collaborative dialogues, is a strength of CA. For instance, a facilitator's prompt in a learning chatroom might be followed by a student's query, which then elicits further clarification. Such multi-turn exchanges are not just linear interactions but are laden with layers of meaning, inference, and pedagogical strategy, requiring a method like CA to zoom in and comprehend. Because of the conversational nature of facilitation, CA is adopted for analyzing the continuum of interaction between both the scaffold and the learner (Radford et al., 2015) to explore how facilitation moves were made to support SSRL. It aims to provide a multi-faceted, layered, and nuanced understanding of online chat interactions, complementing and, in many instances, enhancing insights that other methodologies might offer.

4.2. Technology-rich PBL game context

The game CRYSTAL ISLAND: ECOJOURNEYS was designed and developed by the research team for middle school students to learn about ecosystems through collaborative problem-solving. In the game, students traveled to a fictional island where they encountered a problem: a local fish farm is reporting that tilapia are falling sick at an alarming rate. Students are presented with claims that may explain why the fish are sick, and they must gather data in their groups to substantiate or contradict these claims. After individually collecting information about the problem, students shared ideas and negotiated with their peers through a structured collaborative whiteboard embedded in the game to make sense of what their investigations revealed. On the board, each student places their collected notes onto columns that they believe align with hypotheses that are relevant to the tilapia fish's problem (see Figure 1).

Following this activity, students vote on whether the notes were relevant to the associated component and decide if they want to keep investigating each component as a group. To proceed, the group must reach agreements for removing or keeping a certain factor by evaluating and voting on its potential to influence the ecosystem and cause fish sickness. Different colors of notes represent different statuses in terms of group agreement, green indicating agreement on relevance, red meaning agreement on irrelevance, and orange highlighting disagreement among group members. For example, in the whiteboard shown in Figure 1, the group voted on the note "The water looks dirty" and the green color shown means that all the group members agree that that note supports the column "water quality" to be a component contributing to the fish's living. During these activities, students and facilitators communicated through in-game text-based chat as a group (see Figure 2).

4.3. Data collection

The game was implemented in a public school in the United States, involving 28 students and 4 facilitators as participants. The students were in sixth and seventh grade (10 females and 18 males), including three students identified as African/American, four as multi-racial, two as Asians/Pacific Islanders, one as Hispanic/Latinx, one as Native American/American Indian, and 17 as White. Students were seated in groups of four. While they were

in a common physical space, students were asked to communicate via online chat embedded in the game. The collected classroom videos have validated that very little verbal conversation was taking place during the implementation, indicating the major group discourses were recorded through in-game chat messages.

Each student group was assigned a facilitator to guide collaborative inquiry discussions. The facilitators were researchers who were trained to help students engage in productive discussions while they proceeded through the game. Although they had prior experience in PBL facilitation, they were not trained with SSRL-related facilitation strategies. During the classrooms, they should develop their own strategies to reach that goal through talk-in-interaction depending on each group’s unique situations. In addition, none of the 32 participants had known that the collected chat data would be analyzed through the SSRL lens.

Overall, 5190 text-based chat messages were collected from seven groups during two 120-minute sessions, with students working in groups of four and engaged in the game-based learning environment CRYSTAL ISLAND: ECOJOURNEYS.

Figure 1. In-game collaborative whiteboard for groups to vote on ideas

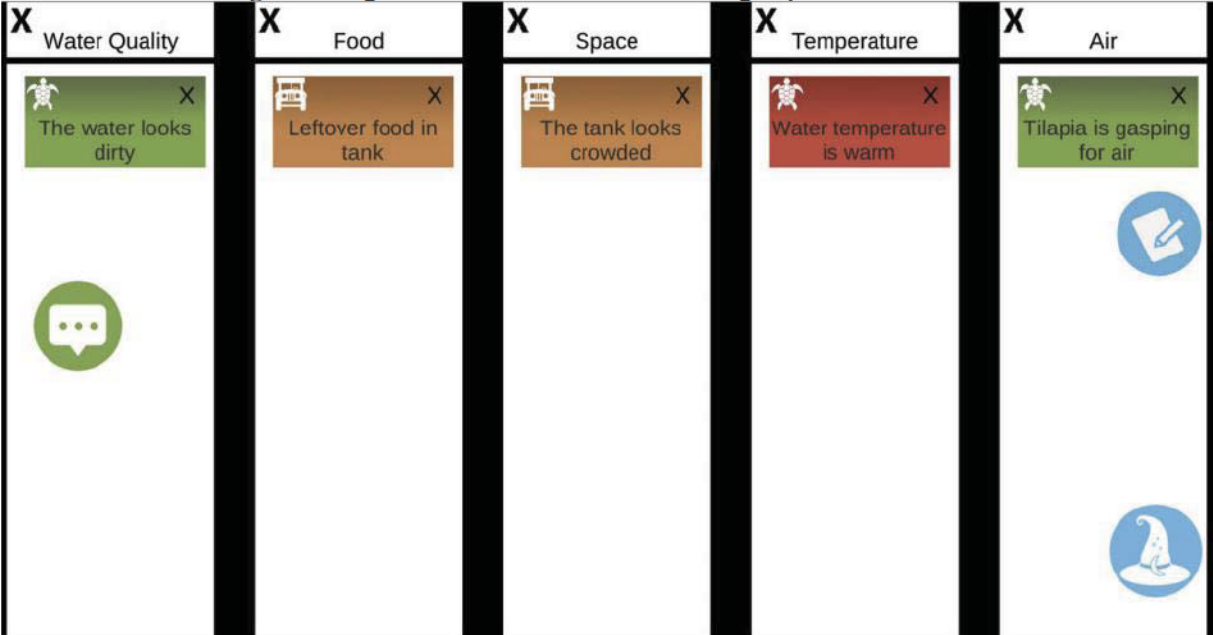
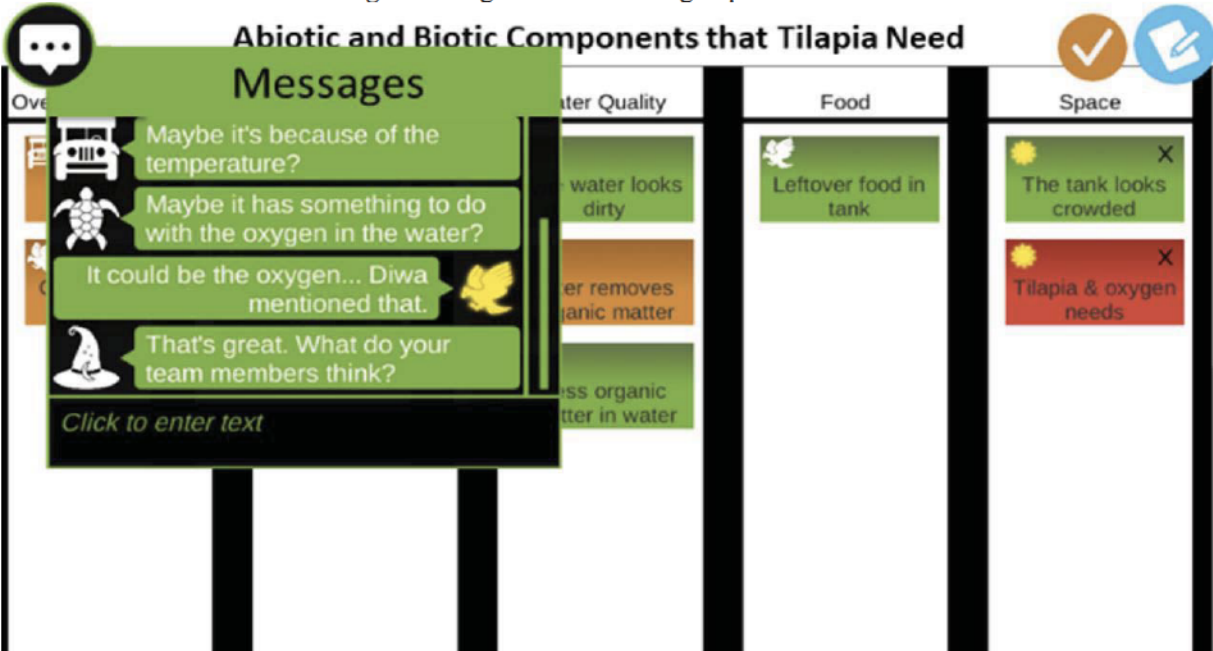


Figure 2. In-game chat box for group discussions



4.4. Data analysis

The chat logs derived from small-group PBL discussions were analyzed using Conversation Analysis (CA; Giles et al., 2015). This methodology calls for a participant-driven approach, particularly suited for exploring and unpacking interactions during the learning process. In addition, given the nuanced and dynamic interaction in PBL facilitation, CA allows us to understand the highly contextualized multiple-turn exchanges in the chat to reveal the development of facilitation strategies for SSRL along the discussion.

Following the CA iterative analytical procedures as suggested by Hutchby and Wooffitt (2008), our analysis process was methodically structured in three intertwined stages: (1) Unmotivated Reading and Reviewing: Before diving into the depth of the content, we approached the chat logs with an open mind, allowing the messages to speak for themselves. This initial phase was about immersing ourselves. Such unhindered reading granted us a panoramic view of the data, setting the stage for the subsequent in-depth analysis. (2) Identification and Highlighting: With a foundational understanding established, we began to zoom in with attention to facilitation utterances in chat. Overall, we identified 1229 facilitators' utterances from seven groups. We identified interactions of interest and started developing a chat log with highlights on socially shared regulation. During this phase, we considered existing SSRL facilitation literature but opted against using formal coding typically associated with top-down, theory-driven, and quantitative methods. The reason behind this decision was to avoid reducing the intricate dynamics of human conversation into simplistic categories. Our primary goal was not to quantify but to understand the nature of facilitation strategies and their influence on small-group PBL discussions. (3) Pattern Generation and Strategy Explanation: Patterns began to emerge, not as isolated fragments but as parts of a cohesive representation of interactions. The strategies were not about the "what" but also the "how." Therefore, our emergent facilitation strategies are highly contextualized based on the close monitoring and understanding of group interaction.

In Conversation Analysis, validity is not merely a static measure of accuracy; it is a dynamic reflection of how authentically participants' interactions represent their intentions and understandings. Every chat message, with its unique phrasing and timing, provides a window into the intricate interplay of participants' contributions to the evolving dialogue (Waring, 2014). Given the richness of text-based chat data, extracting genuine patterns requires a meticulous approach. To strengthen our claims of validity, two external qualitative researchers well-versed in CA techniques worked collaboratively alongside each other. These researchers were tasked with independently sifting through the logs, focusing on discerning the patterns and rhythms of conversation that arose organically in the data. The challenge lay not just in identifying what was explicitly stated, but also in deciphering the implicit, reading between the lines to uncover underlying intentions and beliefs. When contrasting analyses emerged, they weren't seen as discrepancies but as opportunities. The research team convened, discussing and debating each difference, converging on interpretations that best honored the participants' voices.

While text-based chat data offers clarity devoid of transcription errors, it simultaneously presents the challenge of ensuring consistent interpretation across vast volumes of interactions. Reliability, in this setting, is about more than replicability. It's about maintaining a steadfast commitment to the integrity of the data, ensuring that every analytical decision is rooted in evidence and not swayed by external biases (Hammersley & Atkinson, 2007). To guarantee this level of rigor, our research process was characterized by continuous collaboration. Chat logs weren't analyzed in isolation; they were repeatedly shared, dissected, and debated among a group of qualitative researchers. This collaborative framework served a dual purpose: not only did it provide multiple perspectives on each chat segment, but it also established a system of checks and balances. Each researcher played a pivotal role, ensuring that interpretations weren't just plausible, but were deeply anchored in the data. Through this iterative review process, even subtle linguistic nuances - be they in the choice of a word, the structure of a sentence, or the timing of a response - were highlighted and interpreted, cementing the reliability of our findings.

While patterns and strategies are invaluable, they are, at times, abstract. To bridge the gap between our academic findings and their tangible manifestations, we curated select excerpts from the chat logs. These were not chosen at random; they were the epitomes of the patterns and strategies we had unearthed. Through these excerpts, we aimed to offer readers a firsthand experience of our findings, making the abstract palpably real.

5. Findings

Our analysis highlighted three categories of strategies that facilitators adopted to support SSRL in group discussions (see Table 1). The first category is a direct approach to modeling regulation talk, including

performing regulative processes, promoting group awareness, and considering contingency. The second category is the indirect prompting of regulation for the group, appearing in the conversation as prompting questions and acknowledgment of regulation behaviors. Last, the action of fading facilitation is just as critical as providing them at the right moment. In what follows, we provide some examples from facilitators to highlight the three categories of strategies in action and how students reacted to them.

In the excerpts, students are represented by the names of in-game characters: “Sun,” “Jeepney,” “Turtle,” and “Eagle,” while the facilitator is referred to as “Wizard.” As the students were referring to each other with the in-game names in their chat, we used pseudonyms here to maintain student confidentiality.

In the game, students were expected to place their collected notes on the shared collaborative board, make decisions about their relevance to the suggested hypothesis, and click on the notes to vote on their relevance to the problem. If they agree that a certain hypothesis is not the reason why fish are sick, they can remove it.

Table 1. Categories of facilitation strategies to promote SSRL

Category	Sub-category	Explanation
Direct modeling	Performing regulative processes	Demonstrate shared regulation moves in the phase of planning, monitoring, and evaluating
	Promoting group awareness	Value group members’ contribution and highlight importance of group agreement
Indirect approach	Dealing with contingency	Navigate group discussion when contingency happens
	Prompting questions	Provide hints to elicit shared regulation moves
	Acknowledging regulation	Express acknowledgment and appreciation when shared regulation moves occurred
Fading facilitation	Withdrawing facilitation	Fade facilitation by group dynamics to allow students fully take the regulation tasks

5.1. Direct approach: Modeling shared regulation talk

Modeling is a common facilitation strategy in PBL where students learn by watching how facilitators tackle certain challenges and mimic the behavior (Savery, 2006). The following modeling of regulation occurred at the first whiteboard discussion in Group A (see Excerpt 1) when the facilitator led the group to reach agreements while ensuring every group member had opportunities to speak up.

In Excerpt 1, students in Group A were on the collaborative whiteboard (see Figure 1), where they placed notes under each column and voted for if a certain note supports the column to be a relevant factor to the problem. Then their votes were shown as the color of each note, green for agreed supported, red for agreed unsupported, and orange for disagreement. If the group agrees that all the notes as evidence suggest that the column is not relevant to the problem, the facilitator will help remove the column as it is an irrelevant factor, therefore the students can focus on the rest hypothesis in the coming exploration. In order to do so, the group must reach agreement on their votes.

The conversation in Excerpt 1 happened when the group had voted for the notes but showed a discrepancy in one hypothesis. As a result, the group was stuck for several minutes. Then the facilitator intervened by posting this question “shall i remove it?” (line 1), to initiate the discussion in the chat instead of just voting in the game. Responding to the prompt, three students replied with their status in voting (lines 2, 3, & 4). By spotting Sun’s change of mind in line 3, the facilitator further invited a discussion from Sun to explain his thoughts on this problem.

The highlight of the regulation moves happened in the sequence of lines 8, 10, and 13, where the facilitator strategically restated the game rule that one hypothesis can be removed only if everyone in the group agrees to do so. Instead of relying on the in-game vote where students were mistakenly clicking around (lines 6 & 7 for Jeepney, and lines 9 & 11 for Turtle) or changing minds (line 3), the facilitator decided to collect the votes in chat (line 13) so that each student could speak up. By encouraging students to participate in chat discussion by voting 1 or 2, the facilitator later built up their votes and asked for deeper scientific discussion such as summarizing and reasoning.

This excerpt exhibits the modeling of regulation as a facilitation strategy in two aspects. First, it demonstrates how the facilitator modeled monitoring for the group by actively asking for sharing status and ideas on the given problem and collecting feedback beyond the limitation of the game mechanism where inadvertent clicks might

occur. Furthermore, the facilitator demonstrated the value of individual contributions within the discussion, not only by insisting on collecting everybody’s opinion but also by referring to specific group members to participate in the chat.

Excerpt 1. Modeling regulation at the initial whiteboard discussion in Group A

Line #	Timestamp	Speaker	Chat
1	13:25:17	Wizard	shall i remove it?
2	13:25:27	Eagle	yea the sun said yes
3	13:25:33	Sun	I did. I change my mind.
4	13:25:34	Jeepney	i revoted
5	13:25:46	Wizard	ok, you wanna discuss sun?
6	13:25:53	Jeepney	oops i clicked the wrong one
7	13:26:04	Jeepney	i meant to click no
8	13:26:04	Wizard	lol it's ok. i can just remove it if everyone agrees
9	13:26:09	Turtle	opps
10	13:26:12	Wizard	but everyone must agree
11	13:26:14	Turtle	i mean no
12	13:26:18	Jeepney	lets remove it
13	13:26:29	Wizard	ok vote 1, if remove, vote 2, if you don't want to remove

We have further observed facilitator modeling of regulation in the early stage of collaborative inquiry to demonstrate to students how shared regulation could be done. Nevertheless, sometimes facilitators might still need to model how to handle contingency when things are unexpected or unplanned. A contingency in CSCL might happen across the inquiry process, ranging from encountering technical issues to misconceptions about certain contents. In Excerpt 2, a new student Turtle in group B triggered a contingent situation by posting a capitalized chat “IM STILL CONFUSED” in the group discussion (line 1).

Excerpt 2. Modeling of handling contingency in Group B

Line #	Timestamp	Speaker	Chat
1	09:38:08	Turtle	IM STILL CONFUSED
2	09:38:15	Jeepney	So the fish don't have to compeat.
3	09:38:22	Wizard	what are you confused about, turtle?
4	09:38:26	Sun	I have an air bubbler for my axolotl named Pickle
5	09:38:28	Turtle	im kimmya
6	09:38:41	Turtle	i didnt do tis yesterday
7	09:38:48	Jeepney	Correction * I'm Kimmya.
8	09:39:04	Turtle	grammar schammar
9	09:39:06	Jeepney	*I did'nt do this yesterday.
10	09:39:11	Wizard	Ok, someone remind Vinny what we are doing
11	09:39:18	Wizard	Remember be respectful

This discussion occurred at the beginning of the second day of the gameplay, where students in this group were reviewing what they had learned yesterday and jumped into the next round of discussion. While the three group members were engaging in collaborative inquiry, Turtle in this group seemed to be really confused about the current situation (line 1). Instead of promoting content-based discussion, the facilitator decided to pause and address this urgent problem by asking “what are you confused about, turtle?” (line 3). Then, they found out that Turtle had newly joined today’s session without enough pre-knowledge about the game (line 6). In addition, there was another urgent issue: another student in the group, Jeepney, was continuously correcting their chat grammar (lines 7 & 9). The facilitator then leveraged this opportunity with a new group member to invite all the participants to jointly explain their in-game tasks (line 10) and remind the group of the collaboration norms set at the beginning (line 11).

This excerpt presents how the facilitator modeled dealing with contingency during group conversation while also emphasizing group awareness in the situation. Although not every group will experience late-joining members, different forms of contingency could happen during PBL and require certain levels of shared regulation strategies to employ, where the group work is expected collaboratively to tackle the problem. By facilitator’s modeling of handling unexpected scenarios, the students could learn shared regulation strategies in a situated authentic scenario, aligning with the social dimension of mentored learning in PBL (Bridges et al., 2016)

Facilitators in both excerpts demonstrated modeling SSRL in group discussions. While modeling general regulative behavior such as planning, monitoring, and evaluating often occurs at the start of collaborative inquiry, handling contingency only happens when groups are in unexpected scenarios, requiring facilitators’ immediate diagnosis and intervention to provide just-in-time support for the students. Besides, the group awareness was highly emphasized, explicitly or implicitly, in the facilitator’s move, therefore, setting the foundation layer to nurture SSRL in the group.

5.2. Indirect approach: Hinting for socially shared regulation

With students progressing in collaborative inquiry and becoming familiar with regulating their own learning, the facilitator took an indirect approach, instead of directly modeling in the conversation and yielded more responsibility to the students themselves to take over the regulation tasks. The discussion in Excerpt 3 occurred at the start of the second session of group A, the same group shown in Excerpt 1.

Compared to the direct modeling in Excerpt 1, here the facilitator took a more indirect approach by providing prompting questions such as “do we remember where we left off?” to elicit reflection among the students (line 3). When one student Sun took over the shared regulation task by asking for goals and plans (line 4), the facilitator instead of sticking with original prompts, quickly decided to support Sun’s behavior by acknowledging and soliciting group responses to Sun’s question (line 5). In the second half of the excerpt, the facilitator also intervened in the format of prompting questions (lines 9 & 13), so that the students were able to share their understanding of the tasks with the group. In terms of SSRL, such prompting questions are interpreted to support the externalization of students’ learning process and promote sharing and interaction.

Excerpt 3. Prompting and acknowledging shared planning in Group A

Line #	Timestamp	Speaker	Chat
1	12:24:10	Wizard	hi team, welcome back
2	12:24:16	Jeepney	werent we talking aout cyanobacteria
3	12:24:17	Wizard	do we remember where we left off?
4	12:24:20	Sun	What are our goals for today, what shall we get done?
5	12:24:42	Wizard	good question, team?
6	12:25:02	Sun	Let’s vote for the rest of the questions.
7	12:25:07	Jeepney	no clue i have zero ideas
8	12:25:16	Eagle	yes we need to continue voting
9	12:25:24	Wizard	remind me what we’re trying to do?
10	12:25:33	Jeepney	i think we were discussing cyanobacteria
11	12:25:34	Turtle	im done voting
12	12:25:47	Sun	We are voting on each topic, I hear.
13	12:25:48	Wizard	oh wait, did we get rid of space yesterday?
14	12:25:56	Eagle	yes

We also noticed the exceptionally long pause of 22 seconds between line 4 and line 5, before the facilitator jumped in to show acknowledgment and solicit group responses for Sun. Although online synchronized discussion does not follow the exact rules of face-to-face conversation where any silence over 1s would be considered intolerable (Jefferson, 1989), we can tell from the collected chat logs with five participants, 4 students and 1 facilitator, that normally the time gap between two turns of talk would not be more than 10 seconds within the conversation. Therefore, we can infer a deliberate move of waiting occurred on the facilitator’s end, expecting the rest of the group to jump in and join the regulation with Sun.

The strategy of indirect prompts followed by acknowledging shared regulation behavior was commonly adopted during the shared monitoring process. For example, in Excerpt 4, two students in group C were playing Tic-Tac-Toe with each other taking over more than ten lines taking around 1 minute in chat, when they were supposed to negotiate ideas. In response to this, the facilitator delivered an indirect prompt, “Remember what you have discussed about group norms” (line 1). Another student, Jeepney, followed up by referencing rules that the group had discussed in class and mentioned “rule 7 no spamming” (line 6). As a context, at the very beginning of the class, prior to the gameplay, each group of students was asked to negotiate and generate rules for their group to follow during the game. This was a critical move because the students had only generated six rules at the beginning of class, and Jeepney added a new rule that was important in monitoring chat discussions. Whereas the facilitator was less indirect in their reminder, Jeepney took an explicit and direct approach to respond to disruptive talk and redirect the group conversation. The facilitator then expressed acknowledgment and appreciation (line 8) by directly referring to Jeepney’s name.

Excerpt 4. Prompting and acknowledging shared monitoring in Group C

Line #	Timestamp	Speaker	Chat
1	12:38:25	Wizard	Remeber what you have discussed about group norms
2	12:38:29	Turtle	0/x
3	12:38:30	Turtle	///
4	12:38:31	Turtle	//x
5	12:38:35	Wizard	Please focus on task
6	12:38:46	Jeepney	rule 7 no spamming
7	12:38:56	Turtle	were playing a mind active game
8	12:39:00	Wizard	Thanks, Jeepney~
9	12:39:09	Jeepney	:)

Both Excerpts 3 and 4 demonstrate how the facilitator adopted the combination of indirect prompts and follow-up deliberate acknowledgment to promote socially shared regulation of learning. Such patterns often appeared after the initial modeling stage, where students had already gained some techniques and started to perform on their own.

5.3. Fading facilitation: Withdrawing facilitation with the transfer of responsibility

One critical feature of facilitation as adaptive scaffolding in PBL is that the facilitator can dynamically fade their support as students gradually grasp collaborative inquiry skills on their own. However, as the fading of facilitation happens over time, it is not easy to demonstrate the process in a short interaction episode. Therefore, we have cross-examined the three episodes from the same group, Excerpts 1, 3, and 5. They were captured chronologically in Group A, in the first session, the start of the second session, and nearly the end of the last session, which was also toward the end of gameplay.

Focusing on the facilitation moves, we noticed that it shifted from direct modeling (Excerpt 1) to indirect hinting (Excerpt 3), and then totally faded as students regulated their own discussion (Excerpt 5). In Excerpt 5, all four students in this group were able to perform the shared regulation strategies that they had learned along the way. For example, Turtle shared the status of voting to remind Eagle to complete the task (line 1), followed by Sun restating the game rule of reaching group agreement (line 3), and Jeepney assigned tasks for group members to double-check (line 9), building on which Eagle suggested plans for group discussion (line 10 & 11). With the group's demonstration of shared regulation, the facilitation was withdrawn quietly. In fact, this group was fully operating on their own for 8 minutes of discussion, and the students did not notice the absence of a facilitator in the conversation until they needed the facilitator's vote to proceed in the game. We also observed that with facilitation faded, the responsibilities of regulation were transferred to the students, where they took charge and practiced learned SSRL strategies, aligning with the facilitation goal in PBL (Bae et al., 2021).

Excerpt 5. Prompting and acknowledging shared monitoring in Group C

Line #	Timestamp	Speaker	Chat
1	12:45:44	Turtle	i just noticed eagle hasent finished voting
2	12:45:59	Jeepney	because the dirty water is probably a countereffect of organic matter
3	12:45:59	Sun	We must agree on the topucs.
4	12:46:20	Sun	*Topics, not Topucs.
5	12:46:26	Eagle	no i have voted on everything
6	12:46:51	Turtle	oh never mind
7	12:46:55	Jeepney	everyone should go through and vote on everything
8	12:46:58	Eagle	lol
9	12:47:03	Jeepney	double check each one
10	12:47:08	Eagle	we need to agree on a few things
11	12:47:17	Eagle	2 things

6. Discussion

In this study, we explored the strategies that facilitators adopted to support the development of socially shared regulation in a game-based PBL context. We have identified how facilitators adapted the strategies from direct modeling to indirect hints and fully withdrawing intervention when students were able to perform regulative tasks without the facilitators' support. However, not all facilitation would fade in the same direction, and groups

now with faded facilitation still might need facilitation as the collaborative inquiry develops. It, therefore, requires facilitators to closely monitor the group discussion thus providing just-in-time scaffolding.

6.1. Connection between identified facilitation strategies and SSRL literature

The introduction of the categories of facilitation strategies to promote SSRL, as shown in Table 1, heralds an important step forward in comprehending how teachers can augment shared regulation in CSCL environments. Drawing comparisons with previous literature, we can identify both overlaps and novel insights that contribute to the SSRL literature. Starting with Järvelä's et al. (2015) design principles for supporting SSRL, there's a discernible alignment with the strategies presented in the table. For instance, their emphasis on "increasing learners' awareness of their own and others' learning process" is consistent with our identified strategy of "Direct Modeling" where promoting group awareness plays a crucial role. The parallel strategy of "Performing regulative processes" maps out closely with their recommendation to support "the externalization of students' and others' learning process" while facilitators' strategy of "Prompting questions" under the "Indirect Approach" category addresses their call for "prompting the acquisition and activation of regulatory processes." However, beyond these design guidelines, the novelty of our work lies in the expansion of the SSRL strategies toolbox. For instance, the "Fading Facilitation" category, where facilitation is deliberately reduced, affords learners the opportunity to spontaneously engage in SSRL.

Further, while the usefulness of CSCL tools is emphasized in bolstering collective regulation from planning to evaluation (Zheng et al., 2017), the strategies that we identified delve deeper into the nuanced dynamics of group interactions. The focus on "Dealing with contingency" and "Acknowledging regulation" marks a clear departure from just leveraging tools, advocating for a more responsive and adaptive facilitation approach. The challenges and constraints of technology-rich environments for SSRL have been discussed in the field (Savin-Baden, 2007; Lobczowski et al., 2022), including concerns about limited strategies in virtual interactions and the difficulty of garnering peer attention using text-based messages, which is countered by the identified facilitation strategy of "Dealing with contingency," which emphasizes navigating group discussions when unexpected situations arise. This also ties back to the early concern of missing physical cues in virtual platforms (Garcia & Jacobs, 1999), hinting at the necessity of such strategies. In PBL facilitation, our strategies address the concerns raised in over-intervening to inhibit student agency (Hmelo-silver, 2006; Järvelä et al., 2015) by providing a structured way to achieve this balance through our identified "Fading Facilitation" approach.

Our work has expanded on and supplemented existing knowledge by introducing a comprehensive set of strategies, considering both direct and indirect approaches, to nurture SSRL in technology-rich PBL environments. While the existing literature has shed light on tool design and systemic support, our study advances the understanding of SSRL from the facilitator's perspective, offering them a robust strategy repertoire for various CSCL settings.

6.2. Interplay of facilitation and embedded scaffolding in the PBL game

We also found that facilitation moves of SSRL through adaptive scaffolding from facilitators, under the game-based PBL context, interacted with the embedded hard scaffolding designed within the game, including the collaborative whiteboard and game rules. In the game, students were required to vote on the notes placed under a certain hypothesis and the color of the notes changed according to the status of their agreement. It was designed to support the externalization of students' learning processes, allowing students to view each other's stand on the specific notes. While the facilitators were referring to the voted notes, they had also gone beyond the game design by inviting students to directly express their opinions and focus on the knowledge and collaborative inquiry processes in case there were voting mis-clicks. Furthermore, the game rule that students could not proceed without group consensus also forced them to pause, discuss, and closely regulate their own learning. The facilitator utilized this rule by keeping reminding students of it as modeling regulation (Excerpt 1), which had later been internalized and carried out by the students when they were regulating for themselves (Excerpt 5).

6.3. Opportunities and challenges in text-based chat

In addition, we highlight the impact of text-based streamed chat, compared to face-to-face communication, on supporting and challenging SSRL in PBL. As we can see in the excerpts above, the text-based chat messages could easily overlap with each other as they can be posted at the same time. As a result, the subsequent message did not always reply to the message before, which will cause intervals of messages in the chat, and also create

challenges for facilitators or any other teachers to read them after the play. It also allows multiple topics to occur in the same period of time, which in turn places demands on SSRL skills to manage the discussion. In addition, text-based chat can amplify disruptive talk, since each text message appears to have the same weight in the chat window. This makes shared monitoring challenging while providing students with the opportunities to support each other in the group as everyone's "voice" now has an equal opportunity to be read (Michaels et al., 2010). Similarly, teachers experience challenges when supporting students with shared monitoring, while providing the right amount of intervention and supporting student agency in monitoring their own learning (Järvelä et al., 2015). In addition, facilitators should also consider the typing speed of each student when adopting online text-based chat as the major discussion channel in learning, which will highly influence engagement in collaborative inquiry.

6.4. Implications for practice and research

The findings from this study offer a robust foundation from which we can draw both practical and research-based implications. This is particularly vital when we consider the growing emphasis on collaborative learning and its consequent need for socially shared regulation. In practice, the need for facilitation to support SSRL is critical. It is important to understand that SSRL is not just about individual regulation but involves the interplay between group members. The role of facilitators in modeling such regulation is particularly significant. As this study shows, facilitators are not just passive actors but play a pivotal role in guiding group dynamics. Their strategies and interventions are contingent on the specific requirements of various scenarios. They need to be equipped to handle the multifaceted challenges that come with supporting SSRL in collaborative learning environments. While facilitators are actively involved in monitoring group discussions, they should also recognize when to step back and transfer the responsibilities of learning to students (Bae et al., 2021). This allows students the opportunity to self-regulate and take charge of their learning processes. It is a delicate balance between intervening when necessary and allowing students the agency they need to develop their skills (Johnson & Tawfik, 2022; Bae et al., 2021).

CSCL environments need to be designed with an understanding of the evolution of group dynamics and according to evolving needs for facilitation. An effective CSCL system should provide the tools and features necessary to promote healthy group discussions. It should be capable of mitigating challenges like spamming or off-task conversations. Informed by the findings from this study, we conjecture that adaptive scaffolding mechanisms in such environments can be implemented in steps. Initial interventions could be subtle, nudging students towards task-relevant discussions. If such indirect prompts are unsuccessful, more direct interventions might be necessary. This layered approach ensures that students are given ample opportunity to self-regulate before facilitators step in. In larger classroom settings, especially in K-12 environments where a single teacher might be responsible for multiple groups, the design of intelligent tools becomes even more essential. These tools should aid teachers in monitoring and facilitating without overwhelming them. Such tools can be invaluable in ensuring that facilitators can provide consistent and effective support across multiple groups (Dillenbourg et al., 2018).

7. Conclusion

In this study, we investigate the nuances of facilitation strategies to support SSRL in technology-rich problem-based learning groups. Three major strategies have been identified through CA including direct modeling, indirect prompting, and the strategic deployment of fading facilitation, as they organically unfolded in real-time in text-based chat interactions of a game-based PBL scenario. For research, this empirical study fills the gap by focusing on the facilitator's role in supporting SSRL in PBL. For the design of educational technology, by identifying the strategies, we pave the way for the development of sophisticated, automated adaptive scaffolding systems embedded within technology-rich learning platforms, by proactively offering tailored prompts to nudge student groups towards richer collaborative interactions. Concurrently, for practice, teachers armed with this knowledge can craft and refine their facilitation techniques, supporting them in guiding students through the PBL journey and developing students' agency and responsibility in their own learning.

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