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ABSTRACT

Facilitating the collaboration of multiple groups is a critical element in problem-based learning (PBL). In face-to-face learning environments, PBL facilitators require sufficient information about a group's progress and collaboration in real time to make decisions about when and how to facilitate. The capacity of facilitator is limited as PBL scales up. Online PBL settings can mitigate this challenge by presenting data from multiple groups to support facilitators using orchestration technology. A learning analytics dashboard with visual displays is one type of orchestration technology. This study examined 10 PBL facilitators' use of such an orchestration technology to assess the collaboration patterns of multiple groups. Think-aloud protocols were collected from PBL facilitators as they used the technology to understand group collaboration patterns, which were illustrated through learning analytics visualizations. The think-aloud method enabled the PBL facilitators to verbalize their thought processes, and content analysis was conducted to analyze the transcripts. This study found that the expert facilitators made consistent formative assessments and strategically selected the most relevant visualizations to examine knowledge co-construction and group collaboration. In addition, they used multiple visualizations to calibrate and confirm their understanding of the students' learning and group processes, rather than relying on one visualization. Understanding how facilitators use the information generated from a learning analytics dashboard to assess collaboration in an online PBL environment is critical for better support of online facilitation and the design of orchestration technology

Keywords: problem-based learning (PBL), facilitation, teacher dashboard, online PBL, expertise, think-aloud protocol, content analysis

Using Teacher Dashboards to Assess Group Collaboration in Problem-Based Learning

Problem-based learning (PBL) relies on skilled facilitators working with small groups. A PBL facilitator supports students to help them understand ill-structured problem scenarios, engage in collaborative problem-solving, practice argumentation, and gradually take responsibility for their learning process (Hmelo-Silver & Barrows, 2006; Ertmer & Glazewski, 2019). PBL facilitators play a critical role in guiding students' reasoning by prompting discussion and supporting the collaborative learning process (Brush & Saye, 2000; Hmelo-Silver & Barrows, 2006). Experienced facilitators employ a variety of facilitation strategies to support students, such as revoicing and appropriate questioning (Hmelo-Silver et al., 2019). PBL facilitators generally rely on face-to-face interaction in a physical classroom (Ng et al., 2014). In shifting PBL into online learning environments, facilitators need to reconfigure the learning environment and adapt their PBL facilitation (Tsai & Chiang, 2013; Lajoie et al., 2014). Studies have shown that synchronous online PBL is as effective as traditional PBL in learning outcomes and can be used as an alternative to face-to-face PBL (Ng et al., 2014; Erickson et al., 2020). In an asynchronous online PBL setting, PBL facilitators require additional support to monitor multiple groups and provide facilitation; otherwise, they will not be able to access students' learning processes and collaboration (Lajoie et al., 2014; Chen et al., 2017). A teacher dashboard is one approach for supporting asynchronous facilitation through the provision of synthesized learning analytics data (Siemens & Baker, 2012; Martinez-Maldonado et al., 2012). Few empirical studies have examined how PBL facilitators adapt their facilitation strategies to different group dynamics through the use of a teacher dashboard in an asynchronous online PBL environment. Therefore, we designed an online asynchronous PBL learning environment featuring a teacher dashboard to support facilitators in managing multiple small groups (Chen et al., 2017; Zheng et al., 2021). Based on a previous implementation, we improved the teacher dashboard with a collection of revised visualizations focusing on group progress and dynamics (Hogaboam et al., 2016). In this study, we use the terms "facilitators" and "teachers" interchangeably. This research examined how PBL facilitators interpret dashboard information to understand multiple groups' learning processes, using think-aloud protocols. The remainder of this paper is organized into the following sections: (1) a presentation of the theoretical framework; (2) the method of the study; (3) the results of the study; (4) a discussion of the findings; and (5) the conclusion.

Theoretical Framework

Online PBL and Facilitation

The PBL approach requires students to work in small groups and collaboratively solve an authentic problem(s) by identifying learning issues, deconstructing problems, searching relevant resources, generating variable solutions, and testing their hypotheses (Azer, 2005; Hmelo-Silver & Barrows, 2006). During a PBL cycle, students in small groups need to develop a shared understanding, co-construct knowledge, and practice self-directed learning skills. PBL facilitators play a crucial role in scaffolding collaborative knowledge co-construction and promoting productive, in-depth discussion (Hmelo-Silver & Barrows, 2006; Ertmer & Glazewski, 2019). To facilitate multiple groups in this manner, PBL facilitators need to understand different groups' learning processes, evaluate their performance, decide which groups require support, prioritize their efforts, and determine appropriate actions. In a face-to-face environment with multiple groups, PBL facilitators may act as wandering facilitators who walk between groups in a class and provide contextual and contingent support according to students' needs (Hanney & Savin-Baden, 2013; Hmelo-Silver et al., 2019). As PBL scales up and the number of small groups increases, a low facilitator–student ratio limits a facilitator's capability to support multiple groups as needed. Moving PBL online can provide opportunities to make the learning processes of multiple small groups visible in ways that would not be possible in a face-to-face class, thus advancing facilitators' capabilities to manage and scaffold multiple groups. Teacher dashboards with visualizations have been used extensively in technology-supported learning environments to improve teachers' awareness of student learning and enhance their instructional capability (Charleer et al., 2014; Verbert et al., 2013)[1].

Teacher Dashboard and Challenges

Teacher dashboards present visualizations generated from students' learning data to help teachers "see" students' learning activity in real time and over extended periods, ultimately assisting teachers in instructional decision making (Abel & Evans, 2013; Schwendimann et al., 2016). Dashboards can empower teachers to extend their capability to work with multiple groups, as is often required in PBL contexts (Martinez-Maldonado et al., 2012). In computer-supported collaborative learning (CSCL), some researchers

1 We use the term "facilitation" here as distinct from orchestration because we focused on teacher scaffolding of learning processes through largely metacognitive prompts. Orchestration encompasses a larger context, including classroom management, the organization of curricular resources, facilitation, and technology (Dillenbourg & Jermann, 2010; Dillenbourg, 2013; Roschelle et al., 2013).

have explored teacher dashboards to understand collaboration and monitor group processes. Van Leeuwen et al. (2019) investigated how teachers interpreted relevant information about various collaborative activities to reveal teacher noticing processes. Martinez-Maldonado (2019) explored teachers' perspectives after using a teacher-facing dashboard in a technology-rich learning environment. However, research examining PBL facilitators' decision-making processes for understanding group learning and collaboration is scarce. A prerequisite to using these online environments to support decision-making is interpreting the often complex information presented to teachers. Studies of online PBL environments have demonstrated that tensions occur between the responsibility of PBL facilitators to provide timely and flexible facilitation and their need for information about student learning (Hew & Cheung, 2008; Hogaboam et al., 2016).

PBL facilitation is not simple or easy. Teachers can become frustrated when managing messy and complex classroom situations and have difficulty providing just-in-time support, particularly if they are novice facilitators (Ertmer et al., 2009). As PBL instruction is scaled up, facilitators must adjust their roles to a one-facilitator-per-many-groups model (Ertmer & Glazewski, 2019). Online PBL enables a facilitator to monitor multiple small groups by providing real-time access to collaborative activity and learning processes. Orchestration technologies such as teacher dashboards are designed to assist teachers in making a formative assessment and adapting their facilitation goals and strategies (Prieto et al., 2011; van Leeuwen & Rummel, 2019). In CSCL research, studies have explored how teachers interpret dashboard information and make instructional decisions (Schwarz & Asterhan, 2011; van Leeuwen et al., 2019).

In particular, PBL researchers have designed teacher dashboards or other orchestration technologies to discover ways to expand PBL facilitators' capabilities. For example, Rojas et al. (2012) employed awareness mechanisms to build a real-time web-based tool for supporting teachers and students in PBL lab sessions. They designed a teacher interface that included a general view for observing students' learning processes as well as a detailed view for intervening and providing formative feedback to students. Pan et al. (2020) examined machine-learning models to understand students' argumentation and track their problem-solving status in PBL, which informed the design of a learning analytics dashboard for teachers. Nevertheless, more research is required to understand how PBL facilitators use teacher dashboards to assess multiple groups collaborating in an asynchronous online PBL environment and how they adapt their strategies to interpret and respond to information from visualizations. This study served as a testbed for researching how PBL facilitators develop an understanding of group collaboration in an online learning environment by using a teacher dashboard. We designed an asynchronous online PBL learning context and implemented the Helping Others with Argumentation and Reasoning Dashboard (HOWARD; described below) to study how PBL facilitators use a teacher dashboard to support multiple small groups (Lajoie et al., 2014; Hogaboam et al., 2016).

In this paper, we investigated the differences between novice teachers and expert teachers in interpreting dashboard information about group collaboration. Expert teachers have more complex mental representations about their classroom and perceive and process information differently compared with novice teachers (Abernethy & Russell 1987; Westerman, 1991). Studies have examined expert and novice teachers' practices in technology-rich learning environments and various dimensions of their decision-making process to explain the difference in expertise in classroom settings (e.g., Brinkerhoff & Glazewski, 2004; Wolff et al., 2020). In our study, the "problem" the facilitators faced was to understand each visualization and interpret the information concerning group collaboration. We addressed the following research question: how do expert and novice PBL facilitators interpret the different visualizations presented by the HOWARD teacher dashboard when assessing multiple PBL groups' collaboration? To answer this question, we invited 10 PBL facilitators to think aloud while interacting with HOWARD.

Method

Participants

We invited 10 PBL facilitators to participate individually in a 1-hour online session. This population was divided naturally into two groups: expert facilitators (n = 6) and novice facilitators (n = 4). Six participants were recruited from the PBL Special Interest Group of the American Educational Research Association. These participants were university professors who studied PBL or educators who had advanced teaching experience and actively explored PBL in their practice. They had at least four years of teaching experience using PBL, with a maximum of 18 years. Because these participants had advanced knowledge of PBL and rich experience in implementation, they became the expert group of our study. Four participants were Ph.D. students from a midwestern American university. The student facilitators either took a course on PBL or had engaged in projects using PBL. They had all worked as assistant instructors at the university. Three student facilitators had worked as teachers before attending graduate school, with a range of 3 to 5 years of experience, but none had implemented PBL in their classrooms. These four participants became the novice group. The distinction between the expert group and the novice group helped us to explore the differences among facilitators with different levels of PBL expertise in their use of teacher dashboards.

The Context: HOWARD

HOWARD is an asynchronous online PBL learning environment initially designed for medical students (Hogaboam et al., 2016). Students solve an ill-structured problem in HOWARD using the student interface, while facilitators use a built-in teacher dashboard that presents student-generated data to inform their instruction. In this study, we focused on the facilitators' interpretation of the teacher dashboard. Figure 1 illustrates the central platform that students use to communicate and learn in HOWARD. Each group has its workspace within the student interface for their learning activity. The group workspace provides access to the ongoing activity of all groups.

In a prior implementation, the visualizations presented by HOWARD did not adequately address PBL facilitators' need for particular indicators of student learning and activity (Hogaboam et al., 2016). Facilitators required contextual information about students' conversations to make

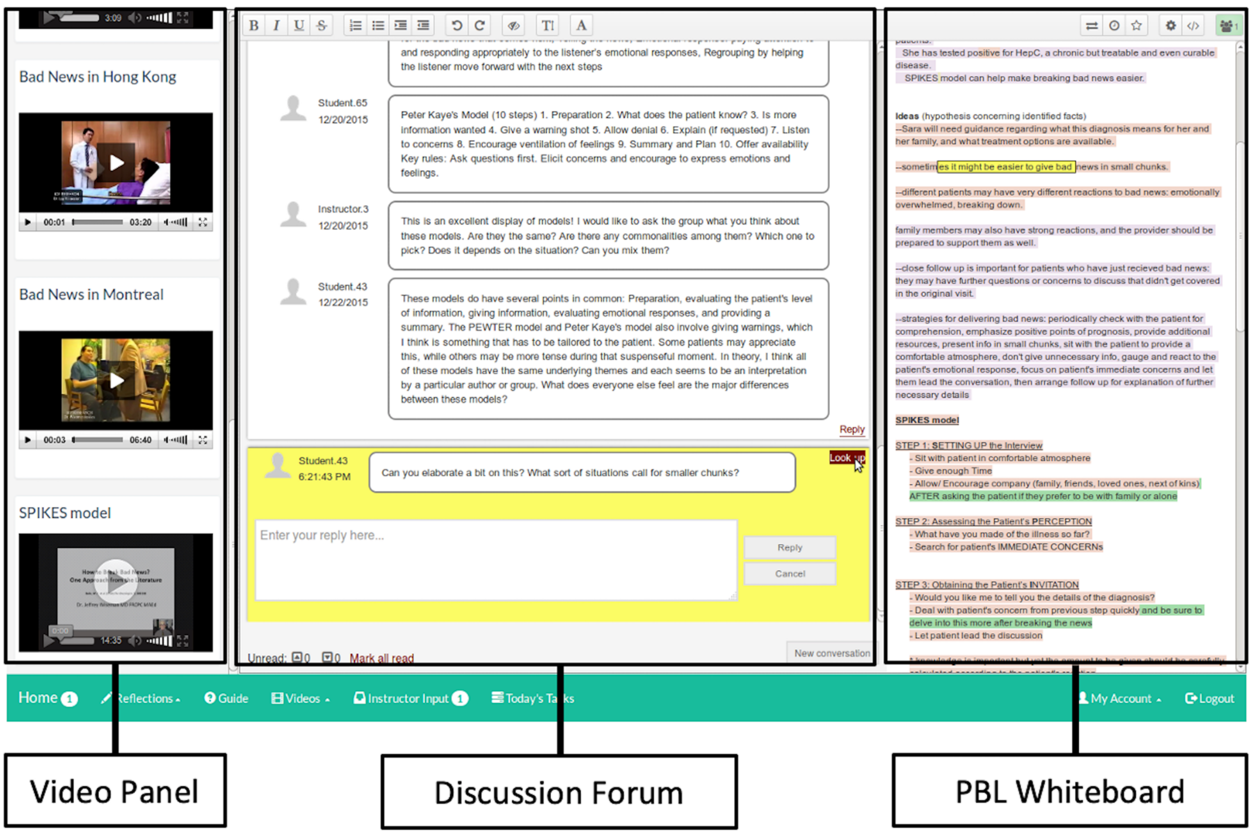


Figure 1. The HOWARD Student Interface

sense of the visualizations and wanted to see exactly what students were talking about. They noted that knowing how students developed their group discussions was essential for fully accessing students' group learning and collaboration. As the original teacher dashboard mainly displayed activity-level data (i.e., counts of words and frequency of posts), we redesigned the HOWARD teacher dashboard to address the facilitators' concerns. Figure 2 illustrates the current iteration of HOWARD teacher dashboard with the four visualizations labeled.

In this current design, each group space on the teacher dashboard includes a Conversation Explorer, a Social Network Analysis (SNA) Graph, a Task Progress View, and an Activity View (see Table 1). This new visualization set involves three aspects of learning that are key to PBL: knowledge co-construction, group participation, and learning activity. The

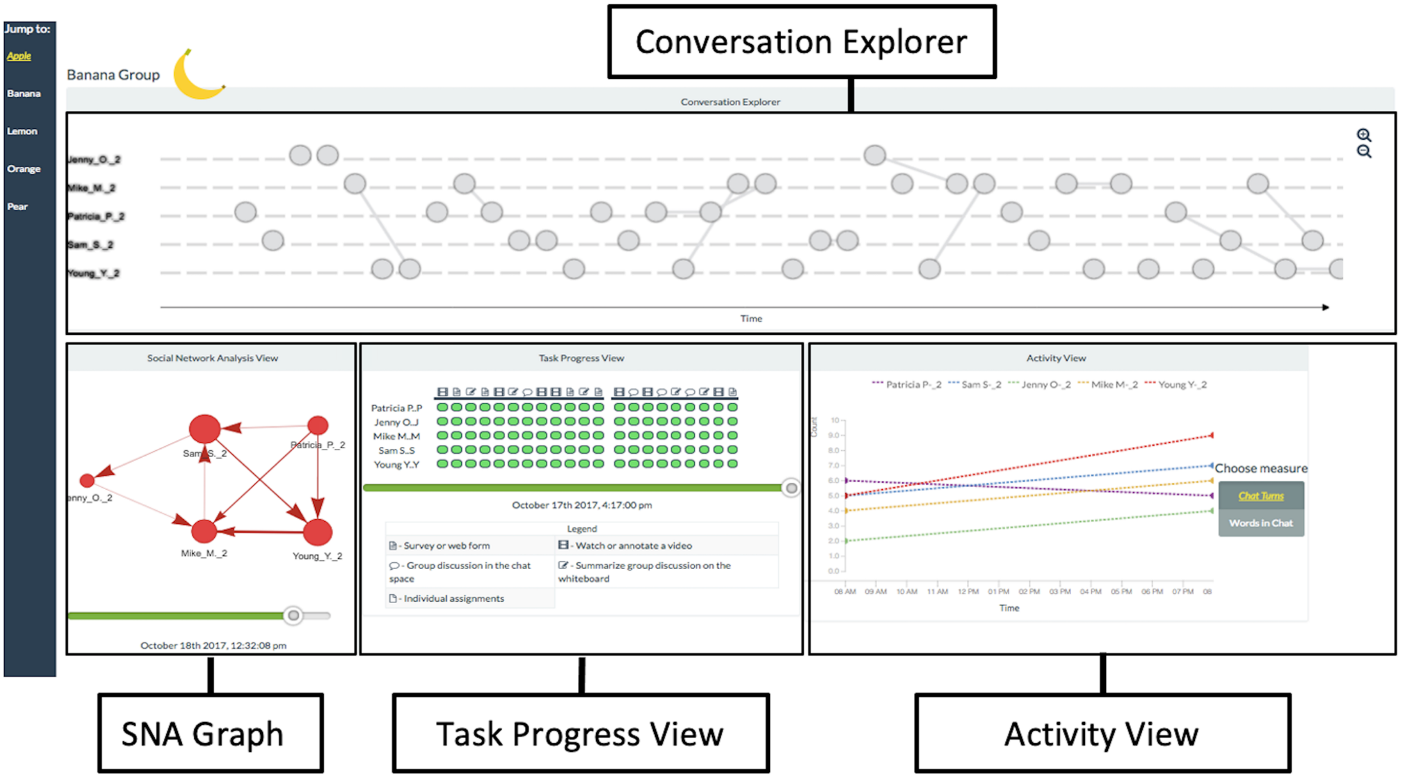


Figure 2. Screenshot of One Group Space of the HOWARD Teacher Dashboard

functions of each visualization are described in detail in Table 1. Facilitators are expected to use all visualizations to fully develop and calibrate their understanding of student learning and collaboration. We conjectured that these visualizations would aid facilitators in understanding the social dynamics and individual participation in the group as well as the overall progress. In the following sections, we will use HOWARD specifically to refer the teacher dashboard

Designing Simulated Groups

We created simulated groups to elicit teachers' understanding of collaboration dynamics, which epitomized five different PBL collaboration patterns. Howard Barrows (1968), the founder of PBL, developed the approach of using simulated patients to train and assess medical students' clinical skills. Simulated or standardized patients are not real patients but rather people who have been specially trained to act as patients (Barrows, 1968; Barrows & Tamblyn, 1976). The use of simulated patients enables students to conduct a thorough examination and provide careful evaluations without other concerns such as time constraints and patient reactions to information (Lane & Rollnick, 2007). Inspired by this approach, we introduced a similar method: five simulated student groups were presented to the teachers that exhibited different types of collaboration facilitators may encounter throughout a PBL cycle. The purpose of creating and using simulated groups is to present diverse patterns of group collaborative learning. In our previous studies, we needed to process information from both student activity and facilitator activity; the simulated groups allowed us to have an adequate number of groups to test the system and allowed all facilitator participants to see the same groups, thus eliminating some unknown variables. The graduate assistants on the project wrote scripts for the five simulated groups to be used as data points to generate the group spaces.

Before the scripts were written, we first explored the existing literature on group dynamics and leadership as well as social psychology research on group performance. We identified five types of groups featured in different collaborative structures and referenced some critical elements of productive collaborative learning and successful PBL groups (Johnson & Johnson, 1999). The five group patterns are not exhaustive, but they are representative of a significant range of collaboration patterns. Table 2 provides descriptions for each simulated group. One group was the group with a dominant individual, who volunteered to lead the group

Types of Visualization	Functionality	Use
Conversation Explorer	Presents the content of threaded conversations from the student chat space	Each dot is clickable and represents a post from a student. A line of linked dots refers to a complete conversation thread. The dots are connected sequentially from an initial post to the last reply.
Social Network Analysis Graph	Displays group structure and relations among group members	Each node represents a student, and the edge indicates the interaction between two students. The size of the node is proportional to the number of student posts; the weight of the edges is the density between two students' interactions. A progress bar below can be dragged to see how the graph is formed over time.
Task Progress View	Indicates the task completion status of individual students	Each box is a task. A box turns green when a student checks the task list. A progress bar below can be dragged to see when and what tasks students have completed.
Activity View	Reports simple statistics based on students input in the chat space	Two modes can be selected. "Chat Turns" indicates how many times a student posted and replied in the chat space; "Words in Chat" reports the total characters of a student's word input.

Table 1. Functionalities of Visualizations in the HOWARD Teacher Dashboard

but dominated with personal opinions, putting others in a submissive position, and took over the group's entire process (Yamaguchi, 2001). A group with a dominant individual may exhibit decreased overall performance and group participation (Miller et al., 2013). The second group was the parallel-play group, in which group members functioned as "solitary players," and had little collaboration. Smith (1978) observed kindergarten children who tended to play by themselves and interact little with others, naming this phenomenon parallel play. Such a phenomenon was also observed in online group discussions in which students posted independently but without meaningfully interacting with others (Hogaboam et al., 2016). The third group was identified as the well-functioning group in which students engaged in equal participation and produced rich, in-depth discussions to generate viable solutions as they solved the problem collaboratively (Kelson & Distlehorst, 2000). The fourth group was the social-loafing group, in which some individuals let others do all of the work (Latané et al., 1979). Shiue et al. (2010) stated that social loafing has "weak social ties and strong perceived risk" and is a key obstacle for group cohesion in the online learning environment (p. 775). The fifth group was the off-task group, whose members engaged in irrelevant conversations and paid less attention to the tasks at hand. Individuals' off-task actions, either being "active" in a way that affects others or being "passive" and disengaged from learning activities, could be viewed as disruptive behaviors in a classroom, and these behaviors do not contribute to student learning (Hofer, 2007).

Groups	Description
Dominant Student	One student tends to dominate group discussions; unequal participation.
Parallel-Play	Students post their ideas, but interaction with each other is limited; isolated participation.
Well-Functioning	Students are involved, respectful, and build on each other's ideas; equal participation, mutual interaction, and productive and meaningful discussion.
Social-Loafing	Some students gradually withdraw their participation and, assuming that others will do the work, make the less collective effort and depend on more competent group members.
Off-Task	Students engage in active discussion but frequently off-task; conversation constantly deviates from the main topic.

Table 2. Description of the Five Simulated Groups in HOWARD

Second, in reflection of our design of the asynchronous online learning environment, we considered students from different regions with different time zones in the scripts. We referenced the population of students from one of our previous studies, in which students were recruited from either Hong Kong or Canada, specifically Montreal (Hogaboam et al., 2016). In this study, we also identified students' regions as either Hong Kong or Montreal. Lastly, we populated the scripts to the teacher dashboard, and each group had its online space. In HOWARD, the five groups were presented in the following order: the dominant student group, the parallel-play group, the well-functioning group, the social-loafing group, and the off-task group. Visualizations in each teacher dashboard were aligned with the simulated data. For example, although students in the parallel-play group might have posted actively, the interaction among the group members was limited. Accordingly, their posts were not connected lines but isolated dots in the SNA graph. As another example, the off-task group might have had multiple interactions and continuous discussion among group members; however, they were frequently off-task and failed to produce topic-related conversations. Those off-task conversations would be reflected in the Conversation Explorer.

Data Collection

Think-aloud protocol

This study used the think-aloud protocol to access each facilitator's cognitive process while interacting with HOWARD teacher dashboards. The think-aloud method allows participants to verbalize whatever comes to mind and grants researchers access to participants' cognitive processes while they perform a task (Ericsson & Simon, 1980; Jääskeläinen, 2010). The think-aloud method is useful when studying the reasoning process (e.g., when determining what information to attend) (Fonteyn et al., 1993). For example, Wolff et al. (2016) used a verbal think-aloud protocol to elicit expert and novice teachers' perceptions of problematic classroom scenes regarding classroom management. Sheridan et al. (2019) conducted a think-aloud study to understand the reasoning of pre-service teachers' judgments on contextualized teaching scenarios. Wyss et al. (2020) conducted post-hoc think-aloud verbalizations between student teachers and teacher educators to identify and define the domains of teachers' professional visions on critical incidents. The data that results from these think-aloud sessions are written transcripts (Jääskeläinen, 2010). In the present study, the data collection was conducted separately for each facilitator; all facilitators attended online sessions at their own physical place and met with the researchers online.

Procedures

Before each round of data collection, we sent instructional materials to the facilitators, including an introductory video about HOWARD, instructions for using the think-aloud protocol, and a survey on teacher dashboard experience and knowledge. The video introduced the HOWARD system, the student interface, the teacher dashboard, group spaces, the learning context, the central problems to solve, and students' tasks and learning activities. The facilitators were told that the groups were simulated and populated by scripts, and each group was designed to solve the same PBL problem.

During the session, each facilitator logged into HOWARD separately and spent approximately 1 hour verbalizing their thoughts in a think-aloud session, working at their own pace. At the same time, two researchers were available online to assist the facilitator if needed. All facilitators interacted with the same teacher dashboard and the same five simulated groups. When some facilitators were silent for a long time, the researchers reminded them to say everything that came to their minds. Upon completion of the session, the facilitators debriefed their experience and posed their questions to the researchers. One hour of screen-recording video was collected from each facilitator. A trained undergraduate student made transcriptions of these screen recordings under the supervision of two graduate researchers. Due to technical issues, one of the screen recordings could not be heard clearly and transcribed; therefore, this video from an expert facilitator was excluded from the data. In total, we had nine think-aloud protocols from five expert PBL facilitators and four novice PBL facilitators.

Data Analysis

We used content analysis to understand facilitators' utterances when managing multiple groups to identify possible patterns between the two groups of facilitators. Content analysis is a method of analyzing and describing qualitative data to gain insights from phenomena and seek meaning from the contextual text (Hsieh & Shannon, 2005). Due to the small sample size and the exploratory nature of our analysis, we used an inductive approach to conduct content analysis (Elo & Kyngäs, 2008). Elo and Kyngäs (2008) identified three steps in the process of inductive content analysis, which are "open coding, creating categories and abstraction" (p. 109). Our analysis consisted of two main phases: initial coding and axial coding. Initial coding was conducted to understand emerging forms of utterances along with the first round of segmentation. Two think-aloud protocols were randomly selected from the expert facilitator group and two from the novice facilitator group for the initial coding. The facilitators usually indicated a visualization or multiple visualizations explicitly by bringing up the names or implicitly by describing the information from those visualizations. Therefore, we roughly segmented the think-aloud protocols based on the sequences of visualizations used. Two raters coded the four transcripts separately by generating summaries for each segment. The summaries were in the form of words, phrases, or short sentences. The raters reviewed each other's codes and then sat together to discuss the summaries one by one to generate a possible scheme for the second coding phase. Upon completing the initial coding, the raters identified five categories of facilitator utterance moves, illustrating the forms of their utterances (see Table 3). This coding scheme was used for the second coding phase. The descriptive moves were facilitators' general speech without any inference, such as when a facilitator read student posts. The evaluative moves were facilitators' comments on a student's learning progress, group process, and collaboration. The instructional moves were the facilitators' proposed possible facilitation strategies for student support. The regulative moves were coded when facilitators reflected and adjusted their strategies to interpret the teacher dashboards. The visualization relational moves concerned facilitators' interpretations of teacher dashboards and specific visualizations. Examples are presented in Table 3.

Utterance moves	Definition	Example
Descriptive	Facilitators talked about the content-based information they obtained from visualizations or read student posts without further inference.	"OK, so Trixie offers her initial hypothesis. Melissa responds. OK, continuing to dialogue with each other."
Evaluative	Facilitators evaluated group dynamics regarding identifying patterns of interaction, checking group progression, and detecting any critical issues.	"…if I were the facilitator, I would find this group a little bit more disconcerting because you don't see a lot of edges or kind of like connectors being done. You see kind of a lot of individual nodes, but a lack of response."

Table 3. Coding Scheme for Facilitators Utterance

Instructional	Facilitators talked about possible instructional moves for facilitating student learning and group collaboration.	"Looking at the Conversation Explorer, I can sort of imagining why, Group 2, obviously, everybody is less engaged, but in Group 1, everyone is more engaged. So, with this information, I will say, the facilitator will definitely have to take more time to facilitate Group 2 and to find out what the problem is in this group."
Regulative	Facilitators reflected on their pathways of exploring the dashboards or the strategies they used to interpret the visualizations and assess groups; then, they managed and adjusted their subsequent plans.	"Going [to] Group 2… Umm, there is a lot of detail in the Conversation Explorer, so as I am becoming more familiar with the dashboard, I mean I kind of start talking down…Let me take a look at task progress first. Just to get a sense of how the group is…."
Visualization relational	Facilitators generated thoughts on how to explore the dashboard and to look at different visualizations.	"If I am the facilitator, I will only look at it [Task Progression View] when they [students] actually completed everything at the end of the day. So, I don't really care about when they actually complete things at a certain time. I will just look at the view at the end and see what has been done and what hasn't been done."

Table 3 cont. Coding Scheme for Facilitators Utterance

In the second phase of axial coding, we parsed transcripts into smaller units of analysis and used chunks to define pieces of data (Elliott, 2018). A chunk is comprised of a cluster of sentences. We selected chunks of sentences as the unit of analysis because we found more nuance levels reflected within a facilitator's utterances on one visualization and across visualizations. Each chunk indicated that a facilitator assessed students' learning either at the individual or group level. For example, when one facilitator checked an SNA graph, he noticed an outlier student and described what he thought about that student's behavior compared with the rest of the group. Then, the facilitator checked the nodes for other students quickly and concluded on this group's interaction pattern. For this example of using the SNA graph, we segmented it into two chunks: the first chunk highlighted the facilitator's assessment of the outlier student, whereas the second chunk presented a group-level assessment. During the second phase, we excluded some chunks that were not relevant to our research questions—for example, when facilitators had questions for researchers or encountered technical issues. Two raters from the research team jointly coded 20% of each protocol, achieving a substantial level of interrater reliability (kappa = 0.85). Subsequently, the two raters coded the rest of the think-aloud protocols independently.

Results

The results are discussed in two sections: (1) the distribution of codes by the two groups and the time allocated for each visualization; and (2) illustrative examples to display the differences in using visualizations between two groups of facilitators.

Descriptive Results of Facilitators' Utterances

We calculated the average time spent on each visualization across the different PBL groups to understand how the expert group and the novice group distributed their time and effort to check visualizations over the 1-hour sessions. This analysis of protocols helped us investigate the differences between expert and novice PBL facilitators' think-aloud processes while interacting with different visualizations in HOWARD. Analysis of the protocols revealed the descriptive statistics for the codes, which are presented in Table 4. Although the table shows that the expert group and the novice group had a high degree of similarity, the experts had more utterances coded as evaluative than the novices (34.3 per person versus 20.75 per person). Table 4 also reveals that the expert facilitators made 40% more evaluative statements than their novice counterparts. Because of these differences in evaluative statements between experts and novices, we investigated which visualizations facilitators drew upon most to inform their understanding. The results are discussed in the following sections.

Utterance moves	Expert Group (**n** = 5) *No. of codes* *(% within the group)*	Mean per Expert Facilitator	Novice Group (**n** = 4) *No. of codes* *(% within the group)*	Mean per Novice Facilitator
Descriptive	149 (31%)	29.80	114 (38%)	28.50
Evaluative	170 (36%)	34.30	83 (27%)	20.75
Instructional	20 (4%)	4.00	17 (5%)	4.25
Regulative	36 (8%)	7.20	24 (8%)	6.00
Visualization relational	100 (21%)	20.00	60 (20%)	15.00
Total	475	95.00	298	74.50

Table 4. cont. Distribution of Codes for the Expert and Novice Groups

All facilitators were given the same amount of time (1 hour) to use the dashboards, and we analyzed how they distributed their time on each visualization. By calculating the average time used by each group on all visualizations across the five PBL groups, we found that both groups spent a similar amount of time on visualizations: the Conversation Explorer was the most used among the four visualizations, followed by the SNA graph, the Activity View, and the Task Progress View. In Tables 5 and 6, the novices are shown to have spent more of the total time on the Conversation Explorer than the experts but less time on the other three visualizations. However, both groups spent nearly half of their total time on the Conversation Explorer (46% and 50% for the expert and novice groups, respectively). The experts spent twice as much time as the novices looking at the first group—the dominant-student group—whereas novices distributed the time comparatively equally over the first four groups. Both experts and novices spent the least amount of time exploring the off-task group, which was the last one they viewed. Although these findings suggested some general patterns of differences between the expert and novice facilitators, we still needed to examine how the facilitators leveraged specific visualizations to assess group collaboration.

Understanding the Use and Interpretation of Visualizations

Conversation Explorer

Because the Conversation Explorer was the most frequently used visualization, it helped the facilitators to identify the characteristics of students' discussion and served as the primary tool for accessing students' knowledge co-construction. We found that the expert facilitators carefully read students' posts, made connections among different threads, and made more precise evaluations regarding the quality of students' conversation and their knowledge-building processes. An example is presented in Table 7 in which one expert used the Conversation Explorer to evaluate the

Groups (n = 6)	CE[2] (minutes)	SNA (minutes)	TPV (minutes)	AV (minutes)	Other* (minutes)	Total (per group)
1. Dominant student	11.07 (22.48%)	2.82 (5.72%)	2.36 (4.79%)	2.11 (4.29%)	2.51 (5.10%)	20.87 (42.38%)
2. Parallel play	3.22 (6.54%)	1.43 (2.91%)	1.51 (3.07%)	1.93 (3.92%)	0.32 (0.65%)	8.41 (17.09%)
3. Well-functioning	2.53 (5.13%)	2.36 (4.80%)	1.1 (2.23%)	1.61 (3.27%)	0.32 (0.65%)	7.92 (16.08)
4. Social loafing	3.222 (6.54%)	1.13 (2.30%)	0.5 (1.02%)	1.14 (2.31%)	0.33 (0.68%)	6.322 (12.85%)
5. Off-topic	2.67 (5.42%)	1.18 (2.40%)	0.68 (1.38%)	1.18 (2.40%)	0	5.71 (11.60%)
Total (per visualization)	22.71 (46.11 %)	8.92 (18.1%)	6.15 (12.5%)	7.97 (16.2%)	3.48 (7.08%)	49.232 (100%)

[2]Abbreviations in Tables 5 and 6: CE = Conversation Explorer; SNA = Social Network Analysis Graph; TPV = Task Progress View; AV = Activity View.

Note: *Other refers to the time points when facilitators used multiple visualizations simultaneously or when verbalizations were unrelated to specific visualizations.

Table 5. Expert Group's Time Spent for All Visualizations Across the PBL Groups

Groups (n = 4)	CE (minutes)	SNA (minutes)	TPV (minutes)	AV (minutes)	Other* (minutes)	Total (per group)
1. Dominant student	4.9 (10.29%)	0.94 (1.97%)	1.42 (2.98%)	1.96 (4.12%)	1.06 (2.23%)	**10.28 (21.59%)**
2. Parallel play	5.15 (10.82%)	2.18 (4.58%)	0.9 (1.88%)	1.15 (2.41%)	2.69 (5.65%)	12.07 (25.34%)
3. Well-functioning	4.72 (9.91%)	1.71 (3.59%)	0.4 (0.83%)	1.13 (2.36%)	1.38 (2.89%)	9.34 (19.58%)
4. Social loafing	6.25 (13.14%)	0.9 (1.88%)	0.5 (1.05%)	1.29 (2.71%)	0.52 (1.09%)	9.46 (19.87%)
5. Off-topic	2.85 (6.00%)	1.29 (2.71%)	0.96 (2.01%)	0.56 (1.18%)	0.81 (1.71%)	6.47 (13.61%)
Total (per visualization)	23.87 (50.16%)	7.02 (14.7%)	4.18 (8.75%)	6.09 (12.8%)	6.46 (13.57 %)	47.62 (99.99%)

Table 6. Novice Group's Time Spent for All Visualizations Across the PBL Groups

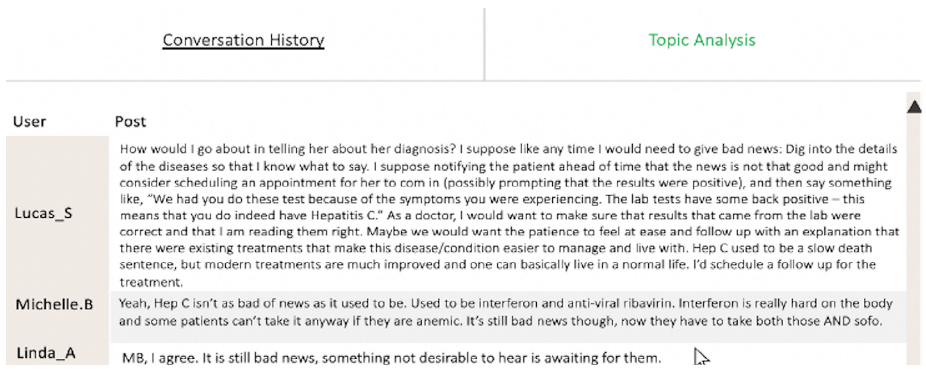
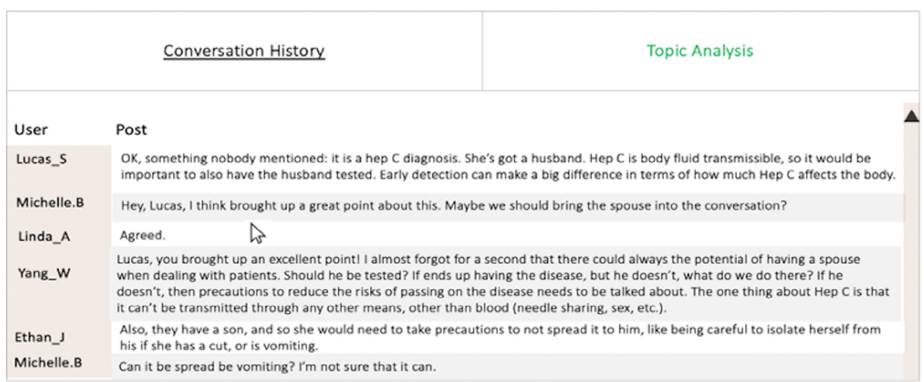
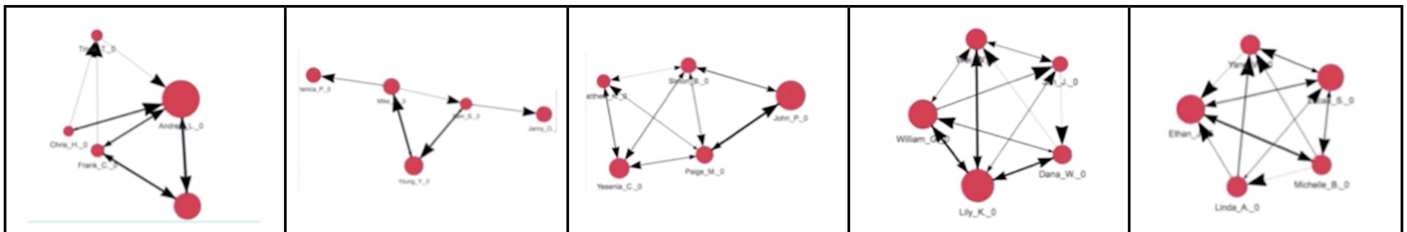
<table>
<tr><th>Actions</th><th>Screenshots</th><th>Utterances</th></tr>
<tr><td>1. Zoomed out the Conversation Explorer.</td><td></td><td>So, it seems here, like there is a lot, of kind of short interactions in spurts and when they are trying to diagnose the problem.</td></tr>
<tr><td>2. Clicked a conversation thread to zoom in and made several comments.</td><td>
</td><td>It seems like they are able to come to a consensus really easily, "Umm yeah, it isn't as bad as it used to be." And a one-sentence response and a "Yeah, I agree." So, there isn't a lot of kind of argumentation or challenging at a particular time, so it is really helpful to be able to have that.</td></tr>
<tr><td>3. Clicked another conversation and continued his evaluation.</td><td>
</td><td>Here, like I said, maybe in contrast with some of the other groups, you don't see as many kinds of, like, extended conversations when you zoom in on it. Once again, it is a lot of "I agree." It's interesting that this is kind of the last question, so it isn't like anyone is really responding and being able to address this person's concern and how to maybe build on that.</td></tr>
</table>

Table 7. An Example of Expert #3 Using the Conversation Explorer to Evaluate the Off-Task Group

off-topic group as a group with "short spurts of interaction and coming to consensus easily" (Actions 1–3). He finally concluded that this group exhibited much agreement but not many "confrontations" and "extended conversations" occurred among students. However, not all of the facilitators used the Conversation Explorer to evaluate the content of students learning.

Social Network Analysis Graph

We found that when some facilitators used SNA graphs as a major reference and considered students' patterns of interaction to be the critical indicator of group collaboration, they may have misidentified what actually happened in certain groups. Theoretically, an SNA graph helps people understand the formation of a group, the patterns of interaction, and the underlying social structure and dynamics (Dillenbourg & Jermann, 2010). Although SNA graphs' inherent graph-theoretic properties manifest in the positions of nodes and the shapes of edges, they do not necessarily relate the process of knowledge building to the development of social interaction. For example, the social-loafing phenomenon was reflected in students' decreased posts and less meaningful discussion in a group. As an SNA graph presents the current social structure based on students' cumulative interaction, a prior SNA shape could affect its later shape. As shown in Figure 3, the SNA graph of the social-loafing group indicated that all students engaged in multiple interactions with others, although their participation varied to certain degrees. However, to analyze the social-loafing group without examining the Conversation Explorer at the content level and understanding students' conversation, facilitators may have misunderstood the group's actual learning and collaborative process.



(a) Dominant-student group	(b) Parallel-play group	(c) Well-functioning group	(d) Social-loafing group	(e) Off-task group

Figure 3. Social Network Analysis Graphs Displayed in HOWARD

Table 8 presents an example of Novice No. 2, who depended mainly on the SNA graph to evaluate the social-loafing group and concluded that the group was doing well. To start her evaluation, she looked up the SNA graph first and then commented that the students had held a heated discussion. Then, she quickly checked the Task Progress and Activity View and confirmed the information that she had obtained from the SNA (Actions 2 & 3). Lastly, she returned to the SNA and summarized that "this group had a good discussion" (Action 4). Novice No. 2 spent nearly 2 minutes going through these three visualizations to evaluate the social-loafing group. We found three other facilitators (one expert and two novices) who also preferred the SNA graph over the Conversation Explorer for evaluating the social-loafing group. They all chose the SNA graph as the first visualization to check and used the Task Progress and Activity View to support their sense-making, commenting that this group was in good shape.

By contrast, Figure 4 displays an example of Novice No. 3, who successfully diagnosed the social-loafing group by looking up individual posts. She did this action by clicking dots in the Conversation Explorer and making inferences about how the students interacted with each other by reading their posts carefully. She found that the student Wei did not explain why he disagreed with Lily's idea and realized that other group members also provided shorter responses to a significant contributor without much elaboration. After selecting several other conversation threads, Novice No. 3 concluded that the students' methods of communication were problematic

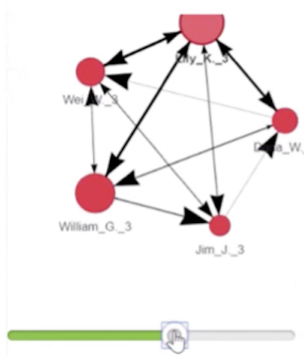
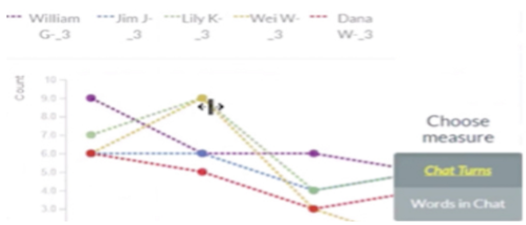
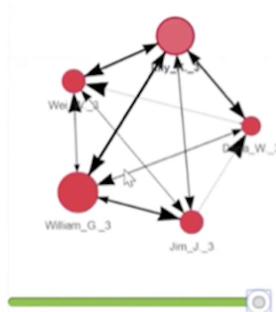
Actions	Screenshots	Utterances
1. Started by checking the SNA graph.		This [group] is interesting; it can be a very heated discussion. So, I also see a lot of dots are connected and umm lots of dots…so they always had this shape… Lily and William…I think Lily was the leader. Lily did the discussion, and William, Jim did talk to each other. I can see these two arrows there, so that's nice.
2. Moved mouse over quickly to Task Pro-gress View.		Everybody finished the homework.
3. Switched to the Activ-ity View and clicked specific stu-dents' chat turns to look at them.		Dana didn't talk a lot. It shows from here, too. Lily and Wei. William also talked a lot.
4. Moved back to the SNA graph and sum-marized her evalua-tion.		So, I think this group had a good discussion.

Table 8. An Example of Novice #2 Evaluating the Social-Loafing Group

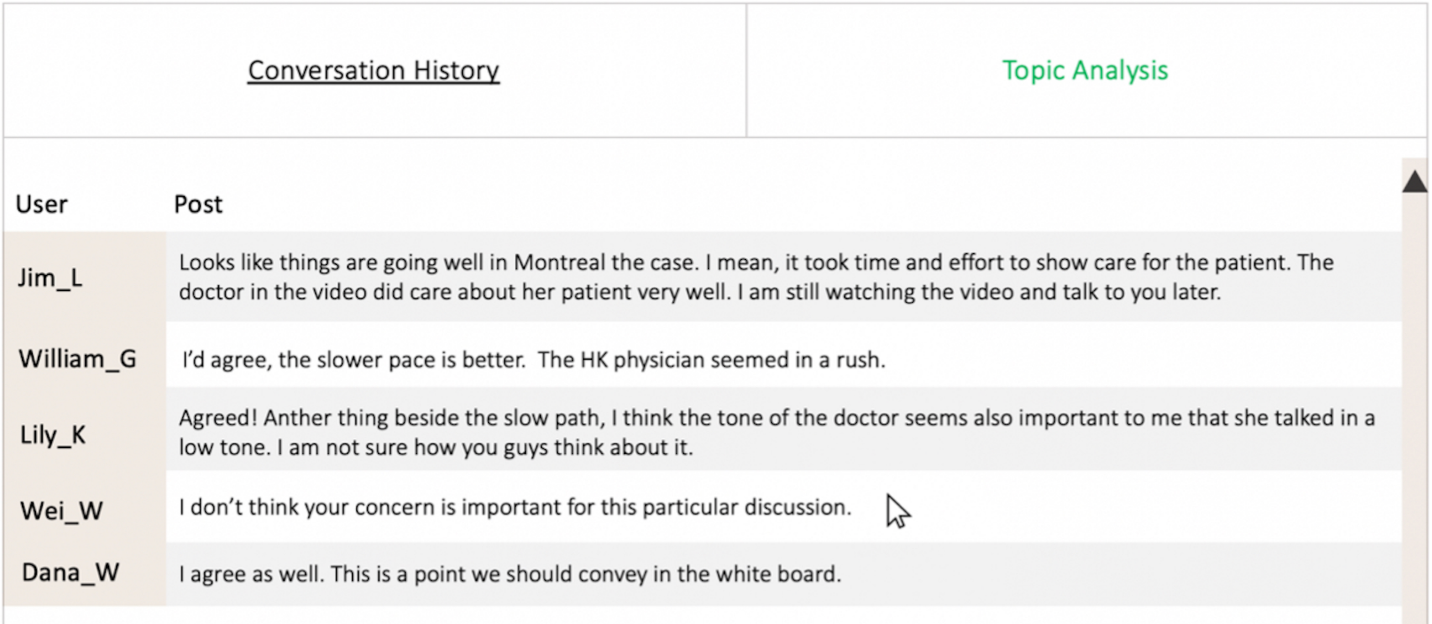


Figure 4. Screenshot Showing Where Novice #3 Identified the Problems in the Social-Loafing Group

Activity View

Most facilitators commented that the Activity View enabled them to identify the dynamics of participation in a group and orient their focus on specific students with apparent changes in participation. Although some facilitators felt that the Activity View was not particularly intuitive, they interpreted this visualization successfully once they understood the two modes of selection and the meaning of the numbers. Table 9 presents an example where Expert No. 1 began by looking at the chat turns of individual students and then switched to the words in chat mode (Actions 1 & 2). He confirmed that both modes revealed the same patterns of student participation, especially for Jenny, a student who participated slowly at the beginning but gradually increased her participation. Expert No. 1 further explained his assumption regarding Jenny's change in participation and finally decided to explore what the students had discussed in the Conversation Explorer (Action 3).

Task Progress View

Lastly, we found that half of the facilitators (two experts and three novices) commented that the Task Progress View was less valuable than other visualizations. The greatest problem with this view was the short period as it demonstrated student task completion within 2 days. Those facilitators explained that they were more interested in how students completed tasks over a more extended period (e.g., a week or a semester). Most facilitators used the Task Progress View as a checklist to understand each student's task completion status. Expert facilitators paid particular attention to students who lagged behind or completed all tasks at once. Table 10 demonstrates how one expert utilized the Task Progress View to evaluate the well-functioning group. Expert No. 3 started by dragging the slider to the far left and then moved forward to see how students had completed tasks in sequence. He made his first comment when he found that Paige and Simon had completed their tasks ahead of others (Action 1). Then, he noticed that the other two students—Matthew and John—had completed (i.e., checked off) their tasks at once and expressed concern about their patterns of participation (Action 2). Dragging the slider toward the end, the expert found one student who had not completed her tasks and commented that it was a red-flag situation in his mind.

Discussion

PBL facilitators guide students in moving through the various stages of PBL and monitor the group process (Hmelo-Silver et al., 2019). Successful facilitation requires teachers to engage in a continuous formative assessment of student learning and to make instructional decisions to support students as needed. As PBL has become widely used, working with multiple groups has introduced new challenges for facilitators. Moving PBL classes online offers facilitators opportunities to monitor multiple groups through the use of orchestration technologies, thereby accessing the learning activities of small groups as well as the individual

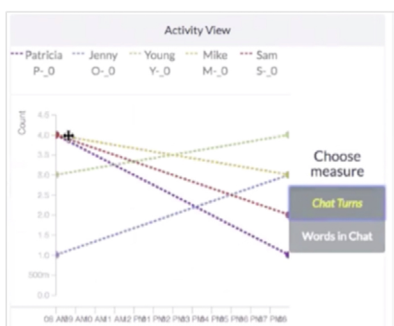
Actions	Screenshots	Utterances
1. Selected “Chat Turns” and clicked the student Young’s line.		I am seeing that student Young appears to be a little less engaged than everyone else in terms of completing tasks. Although the activity chart would indicate that she was staying engaged increasingly from the beginning, assuming that I am looking at this from the right direction.
2. Switched to “Words in Chat” and checked two students specifically, namely Patricia and Jenny.		…Well, that was Patricia. She began strong and then dropped off, had less to say over time, and then the opposite would be true for Jenny, who began quietly or at least with fewer words and then increased the volume of her conversation in the opposite direction…
3. Switched back to “Chat Turns” and looked up Jenny’s activity line.		The same pattern basically appears for chat turns. The number of times she [Jenny] contributed to the conversation increased from a slow start. There are people in the team who would be kind of lurkers figuring out what’s going on and then engaging as they become more comfortable with the conversation and probably that they had a place to contribute to it. So that would not be an atypical conversation. Let me go back up to look at the people themselves that are in the conversation.

Table 9. Example of Expert #1 Using the Activity View to Evaluate the Parallel-Play Group

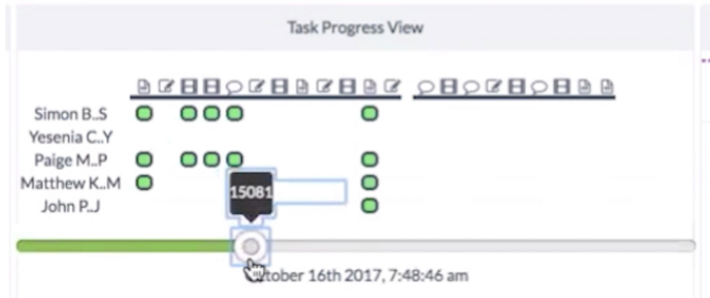
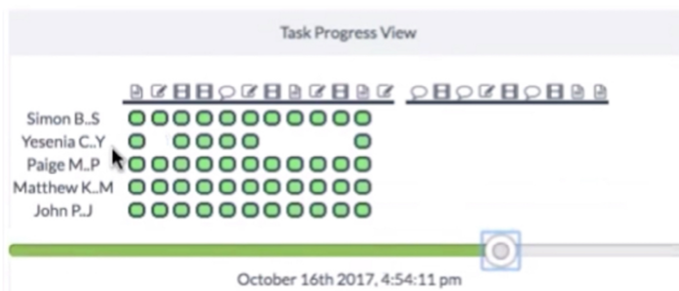
Actions	Screenshots	Utterances
1. Dragged the slider from the beginning, stopped for the first time, and commented on the 1st and 2nd students to complete the task.		It seems like that Paige and Simon are getting their tasks done early.
2. Moved on, stopped for the second time, and commented on the progress of a 3rd and a 4th student.		Matthew and John just kind of do it all at once; that to me would be a red flag. Like, why are you all of a sudden doing all of your tasks all at once? Or, are you the kind of participant contributing throughout, or are you just kind of just doing something at the end and just kind of, like, dumping a lot of information on your peers but not being consistent throughout? So, that would be a little bit concerning for me.
3. Dragged the slider to the end of Day 1 and commented on a 5th student.		Yeah, this is actually really helpful. Because it shows, you know, especially when everybody has something done. But you know, in this case, Yessenia doesn't have something done, but everyone else has been able to fill it in. I think that would be a problem.

Table 10. Example of Expert #3 Using the Task Progress View to Evaluate the Well-functioning Group

students within them. Although several studies have analyzed teachers' use of orchestration technologies in other learning contexts, research on how PBL facilitators interpret the information provided from orchestration technologies to assist PBL facilitation is limited. This study aimed to unpack how PBL facilitators interpret information presented to them from a teacher dashboard to assess different types of group collaboration. It also sought to determine whether a PBL facilitator's level of expertise in facilitation may affect how they use visualizations to assess multiple groups. The mixed population of experts and novices enabled us to conduct constant comparisons through our analysis. First, we explored PBL facilitators' use of a teacher dashboard by analyzing their think-aloud protocols and how they allocated time to check different visualizations within and among groups. We found that the facilitators generally made five types of utterances. The greatest difference between the groups was that the expert facilitators made more utterances about evaluating group collaboration than the novices.

We further analyzed the differences between the expert and novice groups regarding their think-aloud process for facilitation. As the dominant-student group was always presented first, it was the first time that facilitators saw the space and visualizations. Comparing the two groups, the expert facilitators spent twice as much time looking at the first group. Moreover, the expert facilitators scrutinized each visualization, attempting to figure out its functions and the information presented. Because they spent much time on the first group, which allowed them to gain understanding of how to use each visualization, the expert facilitators used the first group as a model when they moved to other group spaces to compare and contrast their knowledge. As for the practical use of each visualization, we found that the Conversation Explorer was the most frequently used visualization for both groups, both of which spent nearly half of the total time on the Conversation Explorer (46% for the experts and 50% for the novices). The Conversation Explorer became the primary tool for assessing a group's collaboration: it provided the content information from students' discussion forums and presented it in the form of linked threads, enabling the facilitators to probe the depths of students' knowledge and to understand the development of their conversation building. This finding suggests that the Conversation Explorer, as we designed it, can provide sufficient information to PBL facilitators for making a formative assessment based on the quality of posted content and the number of students who contribute to a shared conversation thread. This visualization thus allowed PBL facilitators to understand the group's problem solving, highlighting the construction of knowledge and the importance of eliciting multiple perspectives from students. In particular, we found that the content-level information was critical to facilitators for identifying specific types of PBL groups (i.e., the off-task and social-loafing groups). PBL facilitators who did not read students' posts carefully or misinterpreted information from the Conversation Explorer had an incomplete understanding of that group's collaboration.

The SNA graphs were the second most frequently used visualization. Facilitators used these graphs to identify the dynamics of group interaction and search for patterns by referring to the configurations of SNA (Goggins et al., 2011). Although no difference existed in the time allocated to use SNA graphs between the two groups, all experts used SNA as an auxiliary tool to help calibrate their understanding of a group's collaboration (along with other tools). By contrast, the novices sometimes used it as the primary tool for confirming their understanding of group dynamics. The Activity View and the Task View were reported to be helpful for understanding individuals' participation and task completion. These two visualizations played a complementary role in how the facilitators learned behavioral information regarding student learning.

To orient to the visualizations, the experts first understood each visualization's functions and then selectively used a particular visualization to seek specific information. However, the novices tended to use each visualization equally. In addition, the experts focused on both knowledge co-construction and group collaboration and strategically selected the most relevant visualizations. By contrast, the novices concentrated on how students interacted with each other in a group and paid less attention to how they built a shared understanding.

High-quality facilitation relies on interpreting information about group activity and knowledge building to decide appropriate facilitation moves (Hmelo-Silver & Barrows, 2006; 2008). This aspect is particularly challenging when facilitating multiple groups in a technology-rich learning environment. As Dillenbourg and Jermann (2010) stated, "teachers are not on the side, they are the conductor, they are driving the whole activity" (p. 527). To orchestrate the classroom and monitor multiple groups, PBL facilitators must provide, maintain, and modify facilitation on the fly. We hope our study provides some insights for designers and educators regarding the design and use of teacher dashboards for supporting teachers in managing student learning at the group level. Professional development may be essential for facilitators to become familiar with online teacher dashboards and develop and practice strategies for using visualizations, which will prepare them to facilitate multiple groups successfully.

Limitations

We acknowledge several limitations of this study. First, these groups were simulated, and the participants could not interact as freely as they would with real groups. Second, the group spaces were presented in a particular order, which began with the group with a dominant student and ended with the off-task group. The facilitators tended to use the first group as their model group and referenced the features of its visualizations to evaluate other groups. As the off-task group was last, the facilitators spent much less time observing and working with that group. Facilitators may have become fatigued toward the end of data collection; alternatively, they may have developed a good understanding of each visualization and known the system better, making the off-task group easier to diagnose quickly. Third, each facilitator only participated in a 1-hour session, resulting in limited time to work with the multiple groups' spaces and become familiar with the systems. In addition, in authentic environments, group collaboration would be more complex and variable. Finally, the sample population in our study was unique. All of the participants had some understanding of PBL and had used online learning technology before participating in this study. We anticipate that novice teachers who have less knowledge about and experience with PBL and/or online teaching may face more challenges than participants in this study.

Conclusions

This study investigated how PBL facilitators used teacher dashboards to assess PBL groups in online environments and to what extent their levels of expertise in facilitation might affect their interpretation of visualizations and understanding of group collaboration. Although an online learning environment provides teachers with abundant data about student learning, it is difficult to translate such data into actionable information to facilitate student learning. The design of orchestration technology can help serve teachers' needs to facilitate multiple groups. However, orchestration technologies should be usable and practical in a way that assists facilitators in enhancing their understanding and instructional decision making, eventually creating actionable scaffolds to support students. Without considering the pedagogical intent underlying the learning design and the rationale behind selecting tools, we may not be able to support facilitators with appropriate support and levels of recommendations (Gašević et al., 2015). The results of this study suggest that a critical consideration for teachers who wish to use a dashboard effectively for facilitating PBL: they need to learn how to interpret the visualizations and understand how functional visualizations can empower them to monitor multiple PBL groups. These steps are essential to support facilitators in the use of visualizations to advance their instructional capabilities.

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