TechTrends
https://doi.org/10.1007/s11528-023-00903-4

ORIGINAL PAPER

Co-designing a Classroom Orchestration Assistant for Game-based PBL Environments

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Accepted: 10 October 2023

Abstract
Because implementing and orchestrating collaborative problem-based learning (PBL) in K-12 classrooms requires teachers to manage multiple activities and access various teaching resources at the same time, this is an exceptionally complex task for designers to develop tools for orchestration support as well as for teachers to coordinate. The aim of the present study was to explore what classroom teachers perceived to be essential to support orchestration in PBL, but also to surface potential areas of tension between teacher and designer goals through a co-design approach. Thirteen K-12 classroom teachers were interviewed to find out what teachers consider integral to support orchestration in game-based PBL environments. We present the primary features that were identified as essential from the teacher interviews, which include the ability to 1) conduct assessment, 2) intervene and scaffold in different ways, and 3) visualize information. In addition, we discuss the design tensions between the goals of the teachers and designers as we work together on a shared view of what it means to design an intelligent assistant for classroom orchestration and present the design documents with implications.

Keywords Classroom orchestration · Collaborative inquiry · Problem-based learning · Teacher dashboard · Intelligent orchestration assistants · Co-design

Introduction

Problem-based learning (PBL) is a student-led instructional approach in which students learn through solving authentic problems and reflecting on their experiences (Barrows & Tamblyn, 1980; Hmelo-Silver et al., 2019). In PBL, student learning is driven by posing complex questions, problems, or scenarios (Hmelo-Silver et al., 2007; Savery, 2015). These problems do not have a single definitive answer or a pathway to resolve. Students are required to consider various alternatives, deliberate about evidence, and negotiate multiple perspectives as a group. For instance, students can engage in a problem of "Why tilapia fish are falling sick at alarming rates?" Student groups can work to solve such an aquatic ecosystems' problem using various sets of data (Saleh et al., 2019). In PBL, students solve problems as a small group, engaging in collaborative knowledge construction, as they develop and justify solutions to problems (Hmelo-Silver, 2004; Hmelo-Silver & Barrows, 2008). Thus, PBL affords students opportunities to learn both the content knowledge as well as other essential skills and practices by collaboratively engaging in investigations while exchanging their

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Published online: 08 November 2023

ideas with their group members (Hmelo-Silver et al., 2007). Various studies have shown that students can gain deep content knowledge about a subject (Yadav et al., 2011) while simultaneously developing their problem-solving and self-directed learning skills (Barrows, 2002; Yew & Schmidt, 2012; Wilson et al., 2010).

Although PBL and other forms of collaborative inquiry have positive effects on student learning (e.g., Brush & Saye, 2000; Furtak et al., 2012; Pedersen & Liu, 2003; Walker et al., 2015), PBL has not been widely adopted in K-12 contexts (Glazewski et al., 2014; Hmelo-Silver, 2004). Because PBL originated from the pedagogy of a facilitator-led small group setting usually involving five to nine students (Savery, 2015), scaling up this learning activity to a whole classroom filled with students (i.e., K-12 classrooms) imposes great challenges for a teacher to implement PBL in everyday classrooms (Hmelo-Silver et al., 2009). As class size increases, it becomes challenging for teachers to monitor interactions of multiple groups of students and the inquiry progress (Bae et al., 2021; Chen et al., 2021; Dobber et al., 2017). In PBL, students often track their progress using a structured whiteboard which provides a representation of the problem-solving and learning activity. The whiteboard represents one resource that makes student thinking visible while also enabling teachers to track and manage multiple groups in larger classes (e.g., Bae et al., 2021; Hmelo-Silver, 2000; Hmelo-Silver et al., 2009). These representations supported expert facilitators in monitoring multiple small groups in many higher education contexts. As such, it is crucial for teachers to track students' learning activities and provide contingent and adaptive support while orchestrating PBL.

Classroom orchestration refers to how teachers can productively organize and manage multi-plane interventions across various learning activities involving various range of activities (e.g., individuals, group, and whole class activities) (Dillenbourg et al., 2009). Because it requires teachers to monitor and coordinate an array of teaching resources and activities at the same time, multiplane classroom orchestration is a challenging and complex task (Prieto et al., 2018b). Teacher professional development (PD) can provide support for teachers to learn different strategies to orchestrate the classroom; however, PD alone will not reduce the cognitive load that classroom orchestration requires and provide just-in-time support for teachers to manage the complexity of a PBL classroom (Siko & Hess, 2014). We suggest technological resources may offer potential assistance for classroom orchestration. Such resources, if they are capable of capturing individual and group activity, can be developed to provide just-in-time support by capturing learning analytics and making them actionable for teachers. Such an orchestration assistant (OA) could provide teachers with opportunities to track student learning activities at the individual and group levels and extend instructional capacity to support contingent and adaptive teaching (Davies et al., 2017; Ferguson, 2012). Although resources exist that can provide individual or group insights, such as dashboard analytics or group progress reports (e.g., Do-Lenh, 2012; Martinez Maldonado et al., 2012), these applications tend to be limited in scope.

One approach to designing meaningful instructional support for successful classroom orchestration is engaging teachers in the process of co-design in which various stakeholders are actively involved from the beginning of the process in ways that are directly valuable to them (DiSalvo et al., 2017; Gomez et al., 2018). However, it is important to recognize the fact that all stakeholders participating in the process can have different goals and needs. Given its complexities, this is especially the case with classroom orchestration where teacher practice is often tacit (Toom, 2012). Thus, the purpose of this study is to understand what teachers characterize as the necessary supportive resources and guidance for classroom orchestration and what they identify as potential areas of tension between researcher/designer and teacher goals. In turn, this can surface implications for a collective vision of designing an intelligent assistant for classroom orchestration while addressing how teachers perceive as essential to support classroom orchestration in PBL.

To design an authentic and complex problem scenario that students can engage in class, we developed game-based learning (GBL) environments that afford students the opportunity to immerse themselves in collaborative problem solving (Gee, 2003; Klopfer et al., 2017; Squire, 2006). In this interactive and narrative centered game environment, we can support targeted learning interactions by implementing instructional features to engage students in learning resources in a more enjoyable and motivational way (Qian & Clark, 2016). In addition, these GBL environments can set up foundational structure to collect data from individual and group activity in order to provide just-in-time support with teachers through analyzing, synthesizing, and representing multiple data sources (Bae et al., 2019; Ferguson, 2012). In other words, the game-based PBL environments afford to capture the necessary data to process meaningful analytics and provide actionable guidance for the teacher for a fuller platform of orchestration assistance that can reduce teacher orchestration load.

Designing an Orchestration Assistant (OA) to Support Complex Activity Structures

As students are often asked to work together on a complex problem in a PBL classroom, a crucial element is the teacher's timely and contingent support (Puntambekar, 2015). PBL classrooms integrate multi-plane activities including individual activities (e.g., independent research), groupwork (e.g., discussion), and whole class activities (e.g., mini-lectures and presentations), which may be face-to-face or computer-supported. When this complex pedagogical scenario involves different tools distributed over multiple social planes, real-time management is challenged to productively coordinate supportive interventions (Dillenbourg et al., 2009). Supporting collaborative problem solving requires a teacher to simultaneously coordinate multiple activities and access diverse classroom resources. Thus, classroom orchestration is an exceptionally demanding task not only for teachers to undertake, but for designers and researchers to design for in ways that would reduce load (Dillenbourg et al., 2018; Prieto et al., 2018a, 2018b; Slotta et al., 2013). Especially when innovative technological tools are designed for collaborative learning, they do not provide a simple item of software to support a separate activity but a complex program offering a rich set of activities to be orchestrated by a teacher (Dillenbourg, 2013). In other words, teacher facilitation and ability to optimize classroom time under the multiple constraints of real-world classrooms are considered critical factors affecting student learning (e.g., Onrubia & Engel, 2012; Song & Looi, 2012).

In many teaching scenarios, the notion of orchestration is often associated with teachers' cognitive burden and frustration (Dillenbourg, 2013). Imagine a teacher who must facilitate five groups of four or more students and has to log into a learning system for a class activity. Even before the lesson begins there may be practical problems, such as the resources being located in multiple places within the platform or the analytics not providing the necessary insights. In this scenario, orchestration load can be described as "the effort necessary for the teacher – and other actors – to conduct learning activities" in a classroom (Cuendet et al., 2013, p. 558). Orchestration load includes attending to both physical and cognitive components of classroom and learning management (Prieto et al., 2015). The physical component is concerned with navigation of space and layout, both in terms of physical classroom itself and also with learning materials and interface. The cognitive side is involved with how teachers facilitate and support students' learning activities such as reminding them of information and processes, monitoring each groups' progress, asking appropriate questions, and providing necessary scaffolding. Therefore, research on orchestration load attends to the ways in which teachers handle the complexity of managing physical and cognitive components and using instructional resources in a constructive way for students. Concerns about ways to minimize teachers' orchestration load induced by managing students and using new tools while maximizing productive use of teaching time and teachers' energy are more salient than ever in instructional design research (Dillenbourg, 2013).

One way to support teacher orchestration is through teacher dashboard applications that leverage student interaction data from learning environments. While a common LMS feature for online or blended course delivery, such dashboards also offer the potential to promote the teacher's awareness of student actions and reflection of their practices through gathering, analyzing, and synthesizing different data sources into visualizations (Chen et al., 2021; Ferguson, 2012). Many efforts in the field have been made to the design phase of teacher dashboards, highlighting stakeholders' voices and foregrounding teachers' needs (Holstein et al., 2019; Martinez-Maldonado et al., 2012), while a few examined how dashboards can be applied in classrooms in action. For example, SAGLET (Schwarz et al., 2021) was designed allowing teachers to receive alerts through visual representations about critical learning moments in collaborative learning while monitoring several work groups simultaneously. It was applied in virtual classrooms where small groups explored and solved geometry problems. Another example is a dashboard situated in a 12-week curriculum, PLACE (Physics Learning Across Contexts and Environments), to show students' progress, alert teacher when intervention needed, and allow teacher to advance the class to the next phase (Tissenbaum & Slotta, 2019). Typically, these dashboards visualize the activity information on a large display while capturing learner performance and delivering the most relevant insight into collaborative learning among student groups using video, physical, and positioning traces of student performances. They place emphasis on supplying real-time, actionable data visualizations by leveraging information that can be instrumented and collected through in-game actions, including time spent, chat participation, or artifacts to help teachers determine when to intervene. However, in this study, we contend that supporting teacher orchestration should be beyond what dashboards offer – progress tracking and class management for multiple groups. It could also cover the fuller range of teacher's facilitation responsibilities and tasks to achieve their teaching goals (e.g., scaffolding a reasoning process, supporting group negotiation, and confronting naive scientific concepts).

In our project, the intelligent assistant design aims to be deeply embedded in teacher workflow and supports teacher performance by providing guidance for three key phases of orchestration: prospective, concurrent, and retrospective guidance (Bae et al., 2019). This provides support for preparation before classroom teaching, facilitation during ongoing classroom teaching, and after class implementation reflection to evaluate and refine orchestration and facilitation moves. In terms of physical space, the OA will be able to track both who teachers engage with in addition to how students interact and engage materially with each other, the in-game characters, and the resources in the online problem space. Additionally, the OA will employ multimodal data streams to make sense of classroom dynamics to provide the most relevant guidance to teachers. However, it was critical for us to first understand what teachers considered as integral for supporting classroom orchestration in a technology-rich PBL environment to surface the types of guidance that teachers required.

Classroom Orchestration in Game-based PBL Environments

We situate the development of the OA in a particular narrative centered multiplayer PBL game environment that supports collaborative problem solving in middle school science. In this section, we provide an overview of the game-based PBL environment that was designed around collaborative problem solving. As part of the PBL process, students collaboratively engage in the scientific inquiry process that emphasizes meaningful knowledge construction (Hmelo-Silver & Barrows, 2008). Students work in groups of three or four and engage in a multiplayer game called [EcoJourneys] while solving an aquatic ecosystems problem that covers middle school life science standards. Students participate in various phases of inquiry in the game, such as individual exploration where they gather data from the game environment and collaboratively solve the problem in a structured virtual workspace where students share each other's notes and negotiate the relevance of the information to the overarching problem (See Fig. 1). As the OA is developed and refined, the students' interaction data that is captured in the game-based PBL environment will be shared in real-time with the teacher or as reports after the classroom session.

In summary, designing an OA for successful support for teacher orchestration in a game-based PBL environment needs to address the complex interplay between the collaborative learning environment, individual and group processes, and the teacher's needs. In order to understand this interplay, it is crucial to capture group analytics and actionable individual and surface learner performance during collaborative inquiry. Detecting when and how to intervene for which group or individual student is essential for teacher orchestration. For instance, an intelligent assistant could deliver insight into student participation and progress by providing real time data including group progress, participation patterns, time spent, or students' artifacts. In this paper, we inform a deeper understanding of this complex interplay by addressing the following research questions: (1) *What do teachers identify as integral for supporting their teaching practices reducing orchestration load in game-based, problem-based learning,* and *(2) What potential areas of tension were surfaced during the co-design sessions?* We frame this research as a case study (Merriam, 1998) to investigate how teachers envisioned an intelligent assistant that can support their PBL classroom and thus to inform our design decisions. Our primary goal was to explore relevant design implications as well as highlight any other issues, such as potential tensions between designer/researcher and teacher goals, in working toward a collective vision of supporting classroom orchestration and designing the OA, and introducing the co-design process was a means to achieve these two ends.

Methods

Co-Design

To arrive at the design implications and highlight the issues along with potential design tensions between teachers' goals and designers' goals, we engaged in a co-design process (Cavignaux-Bros & Cristol, 2020; DiSalvo et al., 2017; Gomez et al., 2018; Roschelle et al., 2006), which leverages the contributions and expertise of each stakeholder. Co-design is a process that leads different stakeholders engaging in collaborative design decisions that are directly valuable to the end user group. Because co-design positions researchers as designers and stakeholders in the collaborative process, it allows them to negotiate other stakeholders' needs and develop the practitioner ownership of the teaching and learning tools (Kyza & Georgiou, 2014; Lui & Slotta,

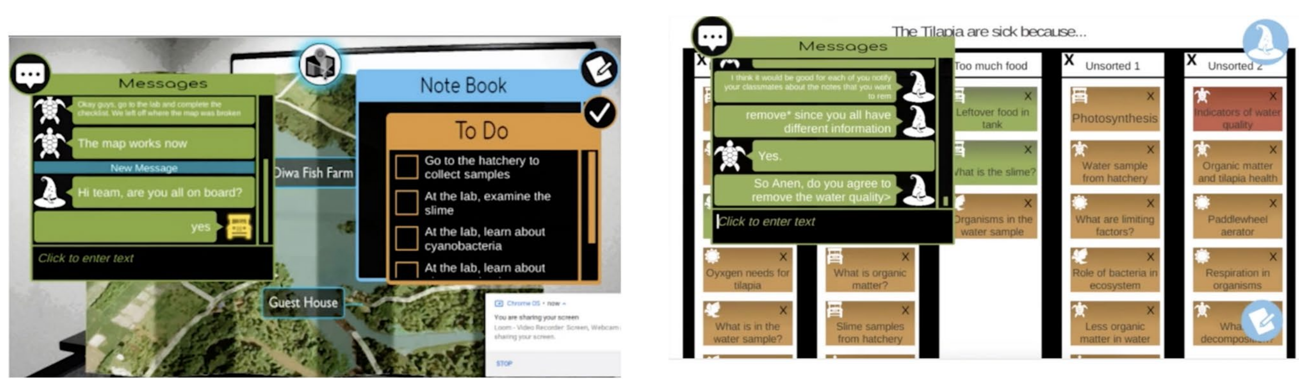

Fig. 1 Screenshots of the game-based PBL environment

2014). This process is successively iterated toward more useful and usable designs. Thus, co-design can contribute to understanding of foundational instructional design (DiSalvo et al., 2017).

Participants and Data Collection

The research team interviewed 13 partner K-12 teachers to gather information on teacher's perception of student analytics derived from game-based learning environments and how these analytics can be used to support learning. The participants had between 10 to 20 + years of teaching experience, especially with facilitating inquiry-focused activities in middle school classrooms. The purpose of the interview was to come up with as many design ideas as possible for the delivery of learning analytics for the OA. We explained to the teachers that we needed their ideas to understand the types of analysis, feedback, and prompts they might want to see from an intelligent assistant to support classroom orchestration in a collaborative game-based PBL environment.

Prior to the interview, teachers were provided with an introduction video of the game-based PBL environment along with interview questions to review in advance. The aim of the introduction video was to present the narrative and specific features of the game and briefly describe the PBL activities in the game through recorded scenes and multiple screenshots. Using this video guided the teachers who did not know about the learning environment to effectively make sense of the research context and the goal and engage in the interview.

These semi-structured interviews were conducted using previously shared interview questions so that the teachers had enough time in advance to understand the learning context and review the content as much as they needed to elicit their design ideas (e.g., What information might be valuable to you as a classroom teacher supporting students in the learning environment? What would you do with this information? What would you want the dashboard to help you do with this information?). For example, teachers were asked to think about information they might find helpful to support their students when students engage in these PBL activities. They were encouraged to "dream" big, leaving the feasibility aside for the moment, and focusing on the functionality that they really want and need. All the interviews were conducted online and recorded with the participants' permission.

Data Analysis

The research team produced verbatim transcripts for all the interviews and transferred all the text into a research analysis software. We employed inductive thematic analysis (Braun & Clarke, 2006). We started an initial coding process that was inclusive, thorough, and systematic. When we had enough codes to capture the diversity and patterns, we shifted from codes to themes. A theme "captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set" (Braun & Clarke, 2006), p. 82). This stage was an active stage in which we tried to generate or construct themes by identifying areas of similarity and overlap between codes.

Next, we revisited the themes and codes and started to explore the relationship between themes and thought how these themes would work together in answering our design questions. After reviewing the full data set, two researchers independently annotated and created potential codes and discussed with the whole team to review codes and themes. After the researchers reviewed the codes together, we discussed our disagreements in codes until they achieved consensus (Harry et al., 2005). This analytic approach was not intended to yield conclusive design decisions, but to offer exploratory insights that can lead to further discussions regarding development of the OA from the research team and participants.

Findings from the Teacher Interviews

Three Substantial Features from the Teachers Interviews

The findings from the teacher interview data guided us to navigate the specific features that were identified as essential from the teacher interviews. There were three key themes from the interviews, the ability to 1) conduct assessment, 2) intervene and scaffold in different ways, and 3) visualize information. Further details of sub-themes and quotes from teachers are presented in Table 1.

Ability to Conduct Assessment The first theme centered on teachers' general obligation and external pressures for evaluation and assessment in learning. The teachers emphasized the importance of having the quantified information from assessment to check students' understanding. For example, many teachers wanted to include features to check students' domain knowledge level by setting up multiple choice or short answer questions as checkpoints in the game and some form of formative assessment that specifically addresses science standards. During the interview, one teacher even noted "[I]f I'm going to bring this in, I need to … know that it directly connects to the standards. And if it doesn't, I can't." It was important for them to ensure that students' domain learning meets the targeted standards. Even though all the teachers understood the collaborative and constructive inquiry nature of PBL approach after watching the provided introduction video of the game-based PBL environment,

Table 1 Themes identified from teacher interviews

Theme	Sub-theme	Example Quotes
Ability to conduct assessment	Set checkpoints and monitor	"See that they're working towards the tasks and see that their output is measuring up to where they should be."
	Formative assessment by the standards	"If there's a group of questions that are related to a certain standard, it will give me usage reports on those standards on how students are performing on them. Maybe at the end of a certain piece, you would put in some sort of formative assessment."
	Assess students' decisions	"I want to know that they're understanding why their hypothesis is wrong or what they can… what information they have to understand that their hypothesis is wrong."
Ability to intervene and scaffold in different ways	Send messages to either an individual student or a group	"Almost like a chat box I guess what I want to call it, click on them [group of students] and I could talk to them individually and then at the same time I could click on in the individual person."
	Control students' screens	"In one button I can click where everybody is frozen that they're not allowed to move. I can click a button where [it] mutes everybody."
	Provide incentives in game	"It can be something as simple as a virtual badge or any type… In *World of Warcraft* it might be at piece of armor or something they can put on themselves to distinguish themselves from other players."
Ability to visualize information	Real time progress	"You want to get a feeling for how are they progressing with the problem"
	Idea development	"… you can see if they're actually growing, if they're actually understanding it more, if they're understanding it better, if they're getting a clear and concise, concise idea of whatever problems they are trying to solve."
	Level of engagement	"How involved they are? Like are they fooling around and just clicking or they're really paying attention and really doing what they're supposed to be doing?"
	Individual contribution to a group	"It would be nice to know who's actually doing what, taken over by one child or you know everybody's laying back and do nothing."

they were compelled to assess if the students are "getting the correct answer" or at least closely monitor if they are "on the right track." They wanted the OA to notify them if their students misunderstand the key concepts and to deliver a summary on those assessment results with simply aggregated numbers like percentile.

Ability to Intervene and Scaffold in Different Ways The second theme is linked with providing actionable information that includes different ways to scaffold and intervene the learning activities instead of passively receiving delivery of the data feed. Displaying the information in a more consumable and actionable format can better support teachers in prioritizing their teaching tasks. The forms of teacher intervention were different from freezing learners' screens to providing prompts through in-game chat messages. Most teachers emphasized that the OA should allow them the flexibility to select who to send a chat message, such as an individual student, a specific group, or the whole class without disturbing the workflow in the student groups or embarrass certain students in the whole class. One teacher specifically described this feature "[H]aving a conversation with them and checking on them to see why they're not contributing." Additionally, some teachers wanted a feature to provide rewards (e.g., digital badges, points) in the game environment.

It was also recognized that using deliberate, simple, and informative visualizations for the huge amounts of trace data generated by students' actions within the environment could provide more immediately meaningful and, thus, actionable information. Such visualizations are necessary to effectively translate the current state of the classroom on behalf of the teacher. For example, alerting was often suggested as a simple way to communicate with students either by indirectly nudging students or by directly providing students an option, such as a panic button to summon a peer or a teacher when they struggle.

Ability to Visualize Information About Student Engagement The last theme represents teachers' needs to access essential information about the student performances. It is involved with visualizing the learning process so that the most needed information is readily accessible for teachers. It includes indicators of real time progress of students, the level of engagement in the class, and how students thought processes during the activity are evolving over time. For example, one teacher described a feature "I would want to see any notes that they were making. I'd want access to what they'd already done in the past like if I could click on that real quick, just see something like that." Specifically speaking, teachers were interested in distinguishing the different levels of engagement with the learning activities, describing as "really paying attention" versus "fooling around and simply clicking through." Even if teachers acknowledge the collaborative nature of group engagement in PBL, one of the shared concerns teachers had in terms of the group work was to quickly understand which individual student and how much work each student is contributing to the group. One teacher mentioned that "if it's real time like that'll be a good thing to have to kind of see who's working on what, so I can go by." It was important for them to identify who is coming up with new ideas, who is building on each other's ideas, who is dominating the group conversation, and who is isolated by monitoring their in-game chat or any other problem-solving activities. Some teachers were interested in obtaining more information from multimodal data as signals of student engagement, including students' movement (e.g., the frequency of using the restroom or student's gaze), student facial expressions (e.g., frustration, concentration, or boredom), and volume of the classroom (e.g., chatter sound).

The critical element discussed in the interviews then was how to have the information communicated with the teachers so that the OA can provide the most pertinent and easily consumable feed that is beyond the teachers' direct classroom observation. Employing learning analytics can afford teachers opportunities to extend their instructional capacity while tracking students' inquiry learning activities and providing contingent and adaptive support (Mavroudi et al., 2021). In particular, it was important to determine how the information collected will be interpreted and presented to the teachers through the system. For example, teachers suggested features like quantified visualizations or color-coded data including content of chat, chat frequency, and chat distribution per student, progress bars, and remaining class time were.

Design Conjecture for the OA

Feasibility and Priorities The teacher interviews helped us surface the importance of having the ability to conduct assessment, to intervene in the inquiry process, and to view the real-time progress of individuals and groups. However, we also recognize that there is a tension between what the teachers might want versus what the designers' intentions are. Several design decisions were made to reconcile the tensions mentioned above for the OA, which are briefly introduced below.

To meet the needs of teachers and the goals of designers at the same time, we tailored the requirements of teachers into three different stages of guidance for OA: (1) prospective guidance, (2) concurrent guidance, and (3) retrospective guidance (Bae et al., 2019). Before the class, the OA should proactively suggest specific plans to support classroom orchestration, which serves as a "forward guide" for teachers to anticipate pre-identified obstacles, decrease orchestration load, and implement successful classes. The retrospective guidance provides a reflection space to make sense of their orchestration and facilitation moves and help them make successful ones stay.

During concurrent guidance, the OA will provide real-time support to help teachers decide what approaches are going to be the most successful in context. Because implementing technology-rich inquiry learning environments places an extremely high orchestration load on teachers, the design of OA during this stage must be more robust and actionable. This can help teachers with facilitation in terms of supporting initiating inquiry, supporting problem-solving process, and pushing for collaborative knowledge construction. The OA will be designed offer features to help teachers by tracking student interaction data as well as assessment data during student problem solving activities to quickly see where every group is.

Three Dimensions to Structure the Specific Features A key thread throughout the identified themes is the concept of accountability. Teachers wanted students to be held accountable and in turn, needed ways to monitor student learning progress and engagement through assessments and in turn, provide scaffolds as needed. Thus, teachers need robust visualizations of student progress, their participation in the learning environment and to the group, and the quality of scientific discussions. Drawing on the PBL framework and findings from the teacher interview data, we constructed three dimensions that can be utilized to categorize the design elements of the assistant and determine how it can be integrated into classroom orchestration.

The three dimensions were mapped from the collaborative inquiry processes in the game environment. Student actions were tracked in the game and provide an overview of 1) individual and group progress, 2) participation in the in-game activities, and 3) group scientific discussions. These dimensions helped us navigate the specific features that were identified from the teacher interviews. To track progress in this context, we identified major tasks that students needed to complete. Student contributions to in-game activities such as collecting data, analyzing data, or sharing explanations factored into their participation. The participation dimension is distinct from progress in that participation is a more fine-grained measure of student inquiry actions, whereas the progress reported whether major tasks such as the tutorial is completed by the student and/or group. Finally, tracking scientific discussions meant detecting when students were sharing their ideas as well as agreeing or disagreeing with one another using the in-game tools, whether they changed their ideas after talking to peers, and using sentence starters in the chat. These dimensions will be integrated into the OA so that the teacher will have direct access to diagnose which group needs immediate attention at the moment. For instance, Fig. 2 represents a red flag that signals unequal participation the OA has detected, and this feature will support the teacher to prioritize which group they should support next.

When the OA alerts teachers using the message center as a pop-up message, they will have different options to choose how to intervene with the groups. The OA will provide guidance for teachers to decide which student in the group needs support with the highest priority and offer recommended prompts which include what types of support will be the most successful, and when they need to pause the activity to give a mini lecture, either to particular individuals, to specific student groups, or the whole class. For example, once the OA identifies that group 2 needs support with the highest priority, the teacher can choose from three options (see Fig. 2). Furthermore, the OA will provide pre-designed recommended prompts that can be immediately used to support the group. Teachers may set up different preferences for the notifications—a text-based assistant that delivers guidance in text messages, or an audio-based assistant that delivers spoken recommendations. The important goal of the design at this stage is to provide actionable recommendations that can be easily adopted by the teachers to support productive group collaboration. The OA should help with basic classroom management, simple prompting, and detecting the specific needs of the student based on the student's responses. This will eventually provide teachers with time to engage in discipline-based discussions that are otherwise demanding to engage in. It is described this as a necessary thinking space required to form a supportive response and gather the necessary resources after the student's initial response (Kim et al., 2019; Saye & Brush, 2002; Shyr & Chen, 2018).

Finally, after each class, the OA will provide two forms of support that include support for reflection on their facilitation strategies and orchestration patterns and guidance for future considerations for their teaching. Teachers will access more detailed information on how the class was implemented by groups by reviewing the purposefully structured information, such as student group chat messages, artifacts, and history of used teacher prompts. In addition, this stage will allow teachers to notice their orchestration and facilitation patterns that would be hard to recognize on their own without looking at data that directly show their tacit practices. For example, this map of the classroom shows interaction geography (see Fig. 3) that represents teachers' interaction as they move across and spend time in multiple groups within the classroom (Shapiro et al., 2017). It can provide an integrative and multi-dimensional view (e.g., teachers'

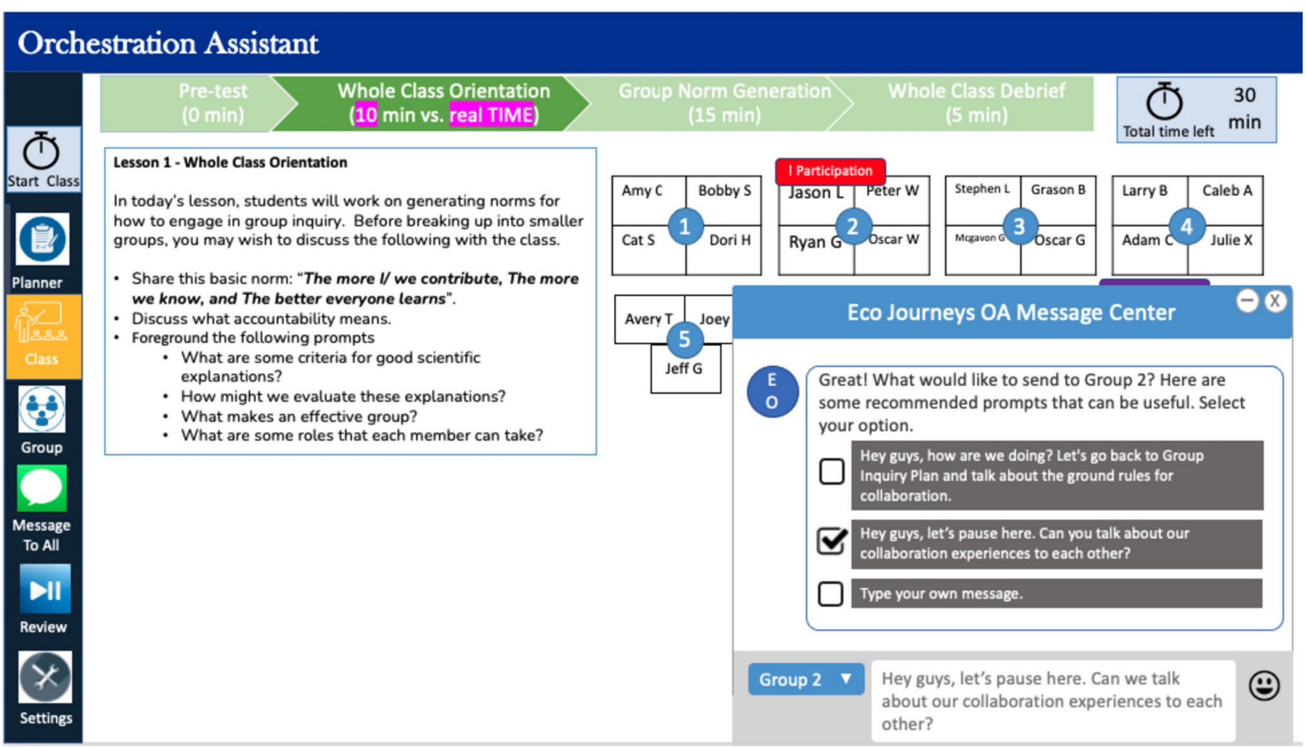

Fig. 2 Design of the orchestration assistant for concurrent stage

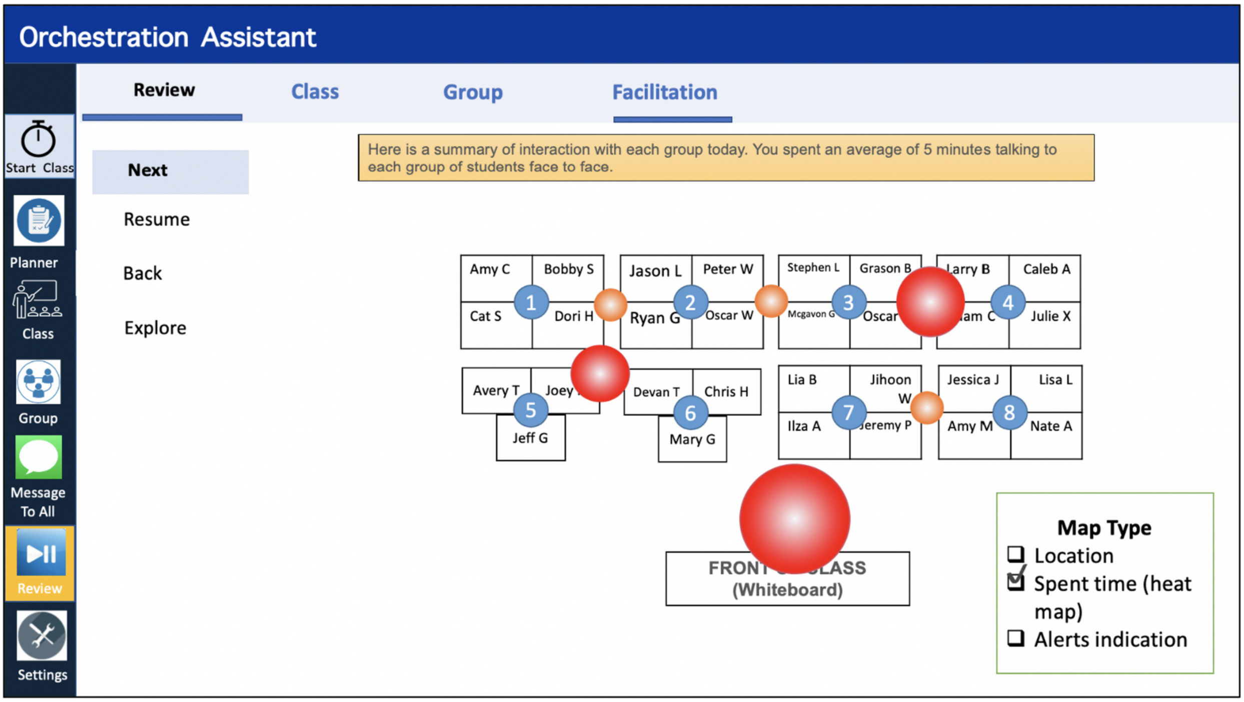

Fig. 3 Design of the orchestration assistant retrospective stage

location, time spent, and notified alerts) to characterize teacher-student and student–student interaction in relation to the space. This stage was considered as a critical step in creating a useful reflection opportunity to make sense of what part of class went well, what did not, how the prompts were taken up by the students, and why and prepare for the next lesson.

Discussion

In this study, we examined the implications of a collective vision for designing an intelligent assistant for classroom orchestration, while addressing the perceptions of teachers regarding crucial support for classroom orchestration in a game-based PBL environment. More specifically, in eliciting teacher perceptions, we surfaced areas of alignment and agreement as well as areas of tension among both designers/researchers and teachers. Both groups acknowledged that implementing a PBL unit in a whole classroom can impose a higher orchestration burden on teachers, as they must effectively manage and scaffold the learning process. They both further recognized the importance of nurturing reasoning and collaboration skills in middle school PBL classrooms. Some common challenges that both agreed on included navigating the complexities of overseeing multiple groups within a classroom, promoting equitable participation, allocating tasks, and resolving conflicts were identified as challenges. The use of differentiated instructional strategies alongside emerging technological tools was identified as a necessary approach by both researchers and teachers. This study focused on designing a meaningful intelligent assistant for successful classroom orchestration, involving teachers in the co-design process from the beginning in ways that hold direct value for them. Addressing the intricate interplay between the collaborative learning environment, individual and group processes, and the teacher's needs was crucial during the co-design process to capture both group and individual analytics, while also representing learner performance during collaborative inquiry. In particular, the exploration of relevant design implications and the highlighting design tensions between designer/researcher and teacher goals were integral steps to achieving our goal.

The concept of design tensions can advance design decisions by considering various perspectives and balancing considerations in generating the outcome (Tatar, 2007). The goal is to surface users' tacit knowledge (Tabak, 2004) and skills and integrate them into the research and design process so that researchers can collaborate with and learn from potential users (e.g., K-12 teachers) and negotiate 'needs and wants/preferences.' We were able to identify three different tensions that existed between the practitioners (i.e., teachers) and designers (i.e., researchers) goals (see Fig. 5) by sharing the opportunity for classroom teachers to engage in the decision-making process that will directly benefit them through co-design (DiSalvo et al., 2017).

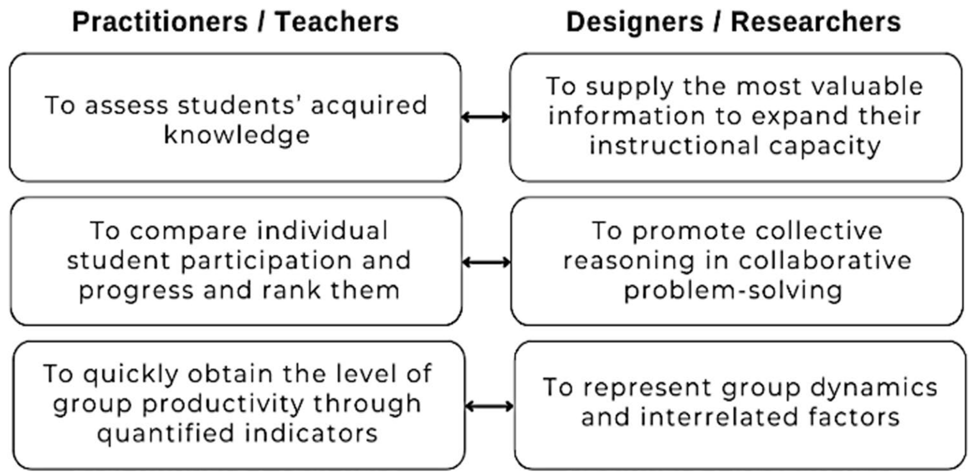

Fig. 5 Design tensions in the goals of the OA

When asked to consider ideas to support classroom orchestration in a collaborative game-based learning environment constructed around PBL, teachers mostly described suggestions for assessing, intervening, and monitoring. However, not every suggestion can be actualized in the actual design, and expectations may or may not meet the design criteria that teachers recommended. As such, the emergent themes manifested several inevitable tensions between being a facilitator of PBL in student-centered pedagogy that promotes student independence and collaborative inquiry versus being a conventional classroom teacher who attends to the practical responsibility of classroom management in everyday classrooms.

First, the teachers emphasized the importance of comparing individual students to others. They wanted to apply the quantified results of assessment to their formative assessment to monitor if the students' acquired content knowledge meets the standards. In addition, many teachers recommended that these reports be shared with students to motivate students by stimulating their competition. However, they also noted the downside of using the concept of competition as a motivator in class, thus they suggested the OA allow them to flexibly decide which specific parts of the summary could be selectively presented to the students. However, our intention was not solely focused on building an assessment/classroom management tool that will be used to compare student participation and progress and rank them. Furthermore, we were concerned that doing so would reflect an inequitable practice, even if unintentional, that reinscribes a norm of "faster" groups being rewarded and "slower" groups labeled or even called out as such (Uttamchandani et al., 2022). Rather, our intention was to build a support environment for teachers that can supply the most valuable information so that they are empowered to make the most supportive decisions for their students based on just-in-time needs rather than rankings. Thus, our emphasis was on collaboration not competition.

Second, there was a tension between the amount of data that should be collected from individual student contributions to understand the productivity and interaction of the entire group. Teachers wanted the ability to quickly obtain the indicators of group productivity by looking at the level of individual contributions and the level of group interactions such as how much time they spent talking about a hypothesis and how they arrived at their argument. The most commonly mentioned concern involved disinterested students, not only when dominant students control the entire conversation, but also when one or more students in a group have little contribution to the collective goals (Hall & Buzwell, 2013). Therefore, the teachers wanted to know who contributed to what, based on chat messages or the number of tasks completed. Although teachers wanted this information, research suggests that this is not straightforward as group dynamics and success are highly complex issues, and with many interrelated factors. For example, McCorkle et al. (1999) showed that lack of group norms and communication difficulties can lead to an unequal amount of participation in comparison to other group members. Börjesson et al. (2006) also found that when a particular student is deemed incapable of performing assigned tasks, other group members may encourage free riding. Thus, simply presenting quantified numbers of completed tasks or chat messages may not meet the need to understand group dynamics in the collaborative problem-solving environment.

Conclusion

Our goal in this work was to create a design document to support classroom orchestration. Our focus was on designing an actionable intelligent assistant that can foster and support collaborative inquiry in PBL environments rather than building an assessment tool, or information provider that reflects standards and simply supply summarized reports. Thus, the most challenging design tension identified during the co-design process was related to assessment. As we consider the practical needs from teachers, we returned to our design considerations that prioritize teacher understanding of collaborative inquiry processes and learning outcomes, which is not entirely different from assessment but not the exact same thing as assessment tools.

In our prioritization, we chose to bring the thinking process in students' collaborative inquiry process to the surface and propose suggestions that provide the most valuable and pertinent information. This information includes how student groups operate and what support they need. A compromised area can be intermittent milestones that can trigger a set of notifications and pre-designed recommendations when students are articulating what they know about the content during conversation or when students are not making progress rather than having explicit domain knowledge checks such as multiple-choice questions. In other words, we empower teachers to make the instructional decisions they need to make about student learning and collaborative processes without offering standards-based checklists. We suggest that this can help teachers with making various decisions they need to encourage deep learning.

Co-designing a platform for classroom implementation is an invitation to resolution development by including key stakeholders (e.g., researchers, teachers, software designers), and participatory design shows the importance of stakeholder collaboration in a way to advance usefulness and impact in the community (Philip et al., 2018). In the beginning of the process, researchers may pay more attention to theory-led decisions, and teachers may put forward their practical and realistic views on how instructional decisions can be realized in practice (Gomez et al., 2018).

However, collaboration between researchers and practitioners can provide opportunities to address the needs of both parties, accounting for expectations and goals, as well as the constraints of the actual classroom environment through reiterative negotiations. Our next step is to evaluate our OA design in the classroom, receive feedback on how it worked with their teaching and how it can better support teachers to implement PBL, and refine our initial design documents to ensure that our design decisions meet the needs of the end users. In particular, the suggestions delivered by the OA may appear to be prescriptive, but they are not entirely deterministic. Therefore, we need to better understand how teachers interpret the structure and the suggested instructional information and investigate how they were usable and useful to decrease orchestration load in everyday classrooms.

Acknowledgements This research was supported by the National Science Foundation through grants DRL-1561655, DRL-1561486, IIS-1839966, and SES-1840120. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors, and do not necessarily represent the official views, opinions, or policy of the National Science Foundation.

This paper is an expanded and updated version of a conference proceeding of a paper "Designing Intelligent Cognitive Assistants with Teachers to Support Classroom Orchestration of Collaborative Inquiry" at the International Conference on Computer Supported Collaborative Learning in 2020.

Declarations

Ethical Approval All procedures followed were in accordance with the ethical standards of the Human Subjects & Institutional Review Boards at Indiana University. Informed consent and assent were obtained from all individual participants including the teacher and students who were included in the study, and they were informed they could elect to withdraw participation at any time.

Conflict of interest The authors declare that they have no conflict of interest.

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