Designing Intelligent Cognitive Assistants With Teachers to Support Classroom Orchestration of Collaborative Inquiry

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Abstract: Because orchestration in collaborative inquiry learning requires teachers to coordinate multiple activities and access diverse resources at the same time, it is an exceptionally complex task, not only for teachers to engage in but for designers to develop orchestration supporting tools. The present study explored what classroom teachers perceived to be critical areas in classroom orchestration that require support and describes our initial design of an intelligent cognitive assistant through a participatory design approach. Thirteen classroom teachers were interviewed to address what teachers identify as integral to support orchestration in collaborative inquiry learning. We present the design tensions between teacher and designer goals in working toward a collective vision of what it means to design intelligent cognitive assistants for classroom orchestration and discuss the implications for our design.

Keywords: classroom orchestration, collaborative inquiry, problem-based learning, intelligent cognitive assistants, participatory design

Introduction

Computer-supported collaborative learning (CSCL) environments typically offer tools that can support collaborative sense-making (Schwarz, 2018). CSCL tools can be integrated into problem-based learning (PBL) to support learning and teaching (Hmelo-Silver & Barrows, 2006; Lu, Lajoie, & Wiseman, 2010). In PBL, the learning is complex, dynamic, and context-sensitive, so it emphasizes the collaborative knowledge construction process, while learners are meaningfully engaged in collaborative inquiry (Hmelo-Silver & Barrows, 2006). In PBL, learners engage in collaborative problem-solving activities such as planning, investigating, debating, and negotiating while communicating their ideas with peers. However, PBL has not been widely adopted by K-12 teachers (Kim, Belland, & Axelrod, 2019; Glazewski, Shuster, Brush, & Ellis, 2014). Because most PBL related studies originated from observations in a tutor-led small group setting usually involving 5-9 students in medical and dental schools (Savery, 2006), scaling up this learning activity to larger classrooms in primary and secondary school imposes great challenges for teachers to implement PBL in authentic classroom settings (Hmelo-Silver, Derry, Bitterman, & Hatrak, 2009). As class size increases, it is challenging for teachers to monitor the inquiry progress and interactions of multiple groups of students (Dobber, Zwart, Tanis, & van Oers, 2017).

In the context of classroom orchestration (Dillenbourg, Prieto, & Olsen, 2018), PBL can be supported by CSCL tools (Bae et al., 2019). Such tools for PBL can provide spaces for collaboration, rich problem contexts, and scaffolding. These tools can also make collaborative engagement visible to instructors. However, helping teachers use the information for teaching is a challenge. Recent work in CSCL has focused on supporting classroom orchestration, which refers to how teachers can productively coordinate interventions across multiple learning activities that occur at multiple social levels (Dillenbourg, Jarvela & Fischer, 2009). Because orchestration in collaborative inquiry learning requires teachers to coordinate multiple activities and access diverse resources at the same time, teacher orchestration is considered as an exceptionally complex task not only for teachers to engage in, but for designers to design for in ways that would reduce load (Dillenbourg, Prieto, & Olsen, 2018; Prieto, Sharma, Kidzinski, & Dillenbourg, 2017; Slotta, Tissenbaum, & Lui. 2013).

One approach to developing meaningful teacher support for successful classroom orchestration is involving teachers in participatory design, or the process of design in which stakeholders are actively involved in the design process in ways that are directly beneficial to them (Gomez, Kyza, & Mancevice, 2018; DiSalvo, Yip, Bonsignore, & Carl, 2017). However, one of the realities of participatory design is that all stakeholders involved can have different goals. This is especially the case with classroom orchestration given its complexities, where teacher practice is often tacit (Toom, 2012). In this paper, we present the first stage of our participatory design process where we interviewed teachers about their needs for supporting classroom orchestration. We aimed to address what teachers identify as integral to support orchestration in PBL, but also to surface potential areas of tension between teacher and designer goals. This, in turn, has implications for a collective vision of what it means to design intelligent cognitive assistants for classroom orchestration.

Designing intelligent cognitive assistants to support classroom orchestration

One of the challenges in orchestrating PBL within the classroom is the orchestration load, which includes attending to physical (i.e., classroom space) and cognitive components (Dillenbourg, 2013). In our project, we envision that intelligent cognitive assistants are deeply embedded in teacher workflows to support teacher performance by targeting three key areas of orchestration that involve cognitive aspects of teaching: prospective, concurrent, and retrospective guidance. This means supporting preparation before classroom teaching, facilitation during classroom implementation, and retrospective post-implementation reflection in order to evaluate and refine orchestration moves. In terms of physical space, the cognitive assistant will track how teachers and students engage in the classroom space to provide teachers with an overview of how they interacted with students. Additionally, the cognitive assistant will utilize multimodal data streams to understand classroom dynamics to provide guidance to teachers. However, in order to understand the types of guidance that teachers required, we had to first understand what teachers perceived as integral for improving classroom orchestration of a collaborative game-based PBL environment (Bae et al., 2019).

Classroom orchestration of PBL in collaborative game-based learning

To situate our design, we briefly provide an overview of the collaborative game-based environment that was designed based around PBL for middle school. As part of the PBL process, learners collaboratively engage in the process of scientific inquiry that emphasizes meaningful knowledge construction (Hmelo-Silver & Barrows, 2006). In our collaborative game-based PBL environment, students work in groups of four and solve an aquatic ecosystems problem that reflects grade six life science subject matter. Students engage in several phases of inquiry in the game, individual investigation where they collect data from the learning environment and collaborative brainstorming where students share notes and negotiate the relevance of the information to the overarching problem (See Figure 1). Students' interaction data as they engage with the learning environment are captured and can be surfaced to the teacher. This information is then available to the teacher in real-time or as reports at the end of the classroom session.

Figure 1. Screenshot of the collaborative game-based environment.

A key motivation for the collaborative game-based PBL environment was that PBL has not been widely adopted by K-12 teachers, even though in many circumstances it is linked to improvements in student learning, disciplinary reasoning, and problem-solving processes (e.g., problem finding, deliberation, argumentation; Glazewski et al., 2014). This is primarily because given the number of students in these settings, PBL requires coordinating multiple groups of students, which makes it challenging for teachers to monitor progress of multiple groups (Dobber et al., 2017). In classrooms, a primary issue concerns how teachers manage multiple activities at different social levels while using multiple teaching resources including technological tools (Dillenbourg et al., 2009; Roschelle, Dimitriadis, & Hoppe, 2013). This is compounded by the fact that PBL classrooms integrate a wide range of activities including individual tasks (e.g., independent research), group work (e.g., discussion), whole class activities (e.g., presentation, or lectures). Thus, it requires real time management to productively coordinate supportive interventions in these complex environments (Dillenbourg et al., 2009). Thus, there are many factors that teachers and designers must negotiate to design cognitive assistants that are useful and usable.

In summary, effective support for classroom orchestration of PBL in the form of game-based collaborative inquiry learning represents a complex interplay between the designed game-based learning environment, the teacher needs, and individual and group processes. One key to understanding this interplay is how we might be able to capture actionable individual and group analytics to surface learner performance during collaboration. This is essential in order to enable teachers to detect when and how to intervene in support of classroom orchestration. For example, a system could deliver insight into student collaboration using audio, physical, and positioning traces of student performance by providing real time data including social interaction, time spent, or students' artifacts. Our primary research goal is to inform a deeper understanding of this complex interplay by addressing the following question: *What do teachers identify as integral for improving classroom practices to support problem-based learning?* Given that we anticipated this question might surface differences between what teachers might want versus what is intended by designers, our design process also highlighted tensions between teacher and designer goals in working toward a collective vision of what it means to design intelligent cognitive assistants for classroom orchestration in PBL but also explore relevant design implications.

Methods

Research design and analytic approach

Participatory design is a process that guides how different stakeholders are engaged in collaboratively making design decisions that are directly beneficial to the user group (Gomez et al., 2018; DiSalvo et al., 2017). It positions researchers as designers and stakeholders, allowing them to negotiate the needs of other stakeholders, iterate toward more useful and usable designs, and develop the practitioner capacity in, and ownership of, the learning and teaching tools (Kyza & Georgiou, 2014; Lui & Slotta, 2014). In addition, participatory design can contribute to foundational understanding of learning processes and instructional design (DiSalvo et al., 2017). We framed this as a case study (Merriam, 1998) because we were interested in learning how teachers envisioned an intelligent cognitive assistant that can support their classroom orchestration to inform our design decisions. We analyzed interviews with teachers through inductive thematic analysis (Braun & Clarke, 2006). We first used open coding to obtain categories related to our research questions. Two researchers in the research team initially coded and discussed with the team to review codes and themes. Coding issues were resolved by discussion with the first author, with changes to categories as needed. Each theme was articulated into the sub-themes that form our primary findings. This analytic approach is not intended to yield conclusive design decisions, but to provide exploratory insights that can guide further development of cognitive assistants from the participants.

Participants and data collection

The research team conducted interviews with 13 teachers to gather information regarding relevant student analytics they perceive as useful to know to support PBL activities in their classrooms. The teachers were chosen specifically because they reflected a range of 10 to 20+ years of teaching experience with facilitating inquiry related activities in middle school classrooms. The goal of the interview was to generate as many ideas as possible for the design and delivery of student analytics during classroom orchestration. Teachers were informed that we needed input to understand the types of analytics, prompts, and feedback they might envision from an intelligent cognitive assistant to support orchestration of learning and collaboration in their classrooms while implementing the collaborative game-based PBL environment.

For the interviews, an introduction video of the game-based PBL environment and the interview questions were shared with the teachers ahead of time so that the teachers would have enough time to watch and review the content as needed. The goal of the video was to provide a brief description of PBL activities in the game showcasing the narrative and the specific features in the game with multiple screenshots and recorded scenes. Using this video helped the participating teachers who did not have prior experience with the game environment to effectively grasp the research context and move onto the interview. After the video, teachers were able to understand that we needed their input to understand the types of analytics, prompts, and the feedback they want to include in a designed intelligent cognitive assistant to support orchestration of learning and collaboration in the PBL environment. The interview was semi-structured using the previously shared interview questions, such as "If your students were engaged in this game in your classroom, what information might be helpful for you to have on the "dashboard" as they complete the game activities? What information might be helpful to you as a teacher supporting students in the game? Don't worry about whether you think your ideas are feasible right now. Let's discuss your "dream" dashboard. What would you want?" The goal here was to gather information from the participating teachers for the design and delivery of student analytics to support classroom orchestration of collaborative game-based PBL environments. All of the interviews were conducted through a video conferencing technology and recorded with the participants' permission.

Findings

The interview data were categorized into elements that could be utilized to determine how cognitive assistants could be integrated into classroom orchestration. There were three key themes from the interviews, the ability to 1) visualize information, 2) intervene and scaffold in different ways, and 3) conduct assessment. Further details of sub-themes and quotes from teachers are presented in Table 1.

Table 1: Themes identified from teacher interviews

Theme	Sub-theme	Example Quotes
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."
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 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."

The first theme, ability to visualize information, represents teachers' needs to obtain critical information about the learning process. It includes indicators of student real time progress, how their thought processes are evolving over time, the level of engagement in the game, described as "really paying attention" versus "fooling around and clicking," and an individual's contribution to the group. Even if teachers acknowledge that collaborative effort is critical in PBL, one of the common concerns that teachers had regarding the group work was to quickly grasp how much work each individual contributes to the group. They wanted to identify who is dominating the conversation, who is putting out new ideas, and who is being left back by monitoring their chat or any other learning activities. Interestingly, some teachers mentioned multimodal information as signals of student engagement, including volume of the classroom (e.g., chatter sound), students' movement (e.g., the frequency of using the restroom or student's gaze), or student facial expressions. The critical concern discussed in the interviews then was how to have the information communicated with the teachers so that the cognitive assistant can provide the most pertinent and easily consumable feed that is beyond the teachers' direct classroom observation. For example, features like progress bars and color-coded or quantified data visualizations including chat frequency and content of chat were suggested by the teachers.

The second theme is linked with the ability to react to the perceived information. Teachers suggested different ways to intervene and scaffold the learning process instead of passively receiving the data feed. The forms of intervention varied from providing prompts through chat messages to freezing learners' screens, along with the authority to give out rewards (e.g., digital badges) in the game setting. The teachers strongly suggested that the cognitive assistant should afford them the flexibly choose who to talk to, such as an individual student, a specific group, or the whole class so that they would not disturb the group workflow or embarrass certain students in public. On the subject of means of alerting, the concept of a button was often mentioned as a simple way to interact with students either by cueing/nudging students or by giving students an option, like a panic button to summon a teacher when they are stuck.

Lastly, the theme on conducting assessment pertained to teachers' general anxiety of evaluation in learning. Many participants wished to include features to monitor students' domain knowledge level by setting up checkpoints with multiple choice questions in the game and some type of formative assessment that addresses science standards. One teacher even mentioned "If I'm going to purchase this, if I'm going to bring this in, I need to quantify budget-wise, why we're spending the money that we're spending on it, because I know that it directly connects to the standards. And if it doesn't, I can't." Even though the teachers understood the constructive and collaborative inquiry nature of PBL approach, where there is no single right or wrong answer, they could not resist the urge to evaluate if the students are "getting the correct answer" or at least "on the right track." They wanted the cognitive assistant to let them know if their students understand the key concepts that are being taught in the particular unit and to report on those assessment results with aggregated numbers like percentile.

Discussion

When asked to consider ideas for support of classroom orchestration in a collaborative game-based learning environment designed around PBL, teachers mostly described suggestions for monitoring, intervening, and assessing. However, it is important to note that not every suggestion can be realized in the final design, and expectations may or may not satisfy the design criteria that teachers prefer. As such, the emerged themes manifested a number of inevitable tensions between being a facilitator of PBL in learner-centered pedagogy that entails student independence and collaborative nature and being a conventional classroom teacher who cannot neglect the practical responsibility of classroom management in authentic classrooms.

The concept of design tensions can advance design decisions by taking into account many different perspectives and balancing considerations in producing the outcome (Tatar, 2007). The goal is to bring users' tacit knowledge (Tabak, 2004) and skills into the research and design process and collaborate with and learn from potential users and negotiate 'needs and wants/preferences.' By granting classroom teachers the opportunity to participate in the decision-making process that will directly affect them through participatory design (DiSalvo, et al., 2017), the research team were able to identify different tensions that exist between the practitioners (i.e., teachers) and designers (i.e., researchers) goals.

First, the teachers stressed the importance of comparing individual students to others and having the quantified results for assessment. They wanted to apply these reports to their formative assessment to see if the students' acquired knowledge meets the standards. Additionally, many teachers suggested that these reports can be presented to students to motivate students by stimulating their competitive spirit such as who gets the most correct answers or which group is the fastest. However, they also recognized the downside of using competition as a motivator in class, thus they requested the cognitive assistant to allow them to flexibly decide which specific parts of the report can be shared with the students instead of showing entire reports. However, the design team's intention for the cognitive assistants was not solely focused on building an assessment tool that will be used to rank students. Rather, our intention is to build a support environment that can inform the *process* of PBL activities not the *outcome* of student learning. The emphasis was on the collaboration not competition.

Second, there was a tension between how much data from individual student contributions should be mapped out to understand the whole group productivity and interactions. The teachers wanted to quickly and immediately pick up the cues of productive and non-productive groups by looking at the level of individual contribution as well as the group level of interaction, such as hypothesis building or discussion. The most commonly mentioned problems were related to disinterested learners, which refer to the situation when one or more students in the group contribute almost nothing to the collective needs, as well as dominant learners who control the whole conversation (Hall & Buzwell, 2013). Thus, the teachers wanted to know who is contributing to what, based on the number of chat messages or completed tasks. However, research studies suggest that group dynamics and group success are highly complicated matters and the problems of group work are interrelated with various factors. For example, McCorkle et al. (1999) demonstrated that a lack of group norms and communication difficulties may cause an unequal amount of work in comparison to other group members. Börjesson et al. (2006) noted that free-riding may be encouraged by other group members if a particular member is believed to be not competent to complete the assigned tasks. Therefore, simply presenting numbers of chat messages or completed tasks might not satisfy the needs of understanding the group dynamics in collaborative problem-solving environments.

Implications for design: Priorities, feasibility, and tensions

From the teacher interviews, we identified the importance of having the ability to see the real-time progress of individuals and groups, to intervene in the learning process, and to conduct assessment to directly support classroom orchestration. However, we also recognized tensions that exist between what teachers might want versus what is intended by designers. In order to reconcile the tensions mentioned above, several design decisions were purposefully made for the cognitive assistants, which are briefly described below.

In order to meet the needs of teachers as well as designer goals, we matched teacher requests to three different phases of guidance from the cognitive assistants: (1) prospective guidance, (2) concurrent guidance, and (3) retrospective guidance (Bae et al., 2019). Prospectively, before class, the cognitive assistants will proactively suggest orchestration planning as “forward guidance” for teachers to anticipate potential obstacles, to manage orchestration load, and to implement successful classes.

Next, during class, the cognitive assistant will provide concurrent guidance to help teachers determine what approaches are going to be the most effective. Because classroom implementation of technology-rich inquiry learning places an extremely high orchestration load on teachers, the design of the cognitive assistant will be more robust and actionable during this stage. The assistant will have features to help teachers with facilitation such as initiating inquiry, scaffolding problem-solving process, and pushing for deep knowledge construction. For example, the cognitive assistant will track student interaction data as well as assessment data during the course of students’ problem solving to provide context-sensitive guidance. This will help teachers quickly see where every group is. The teacher will have access to immediately identify which group needs his or her attention at the moment. For example, Figure 2 shows bells that represents how many alerts the cognitive assistant has detected, and a raising hand icon which represents how many students need the teacher’s support. This feature will help the teacher prioritize which group he or she should attend to next.

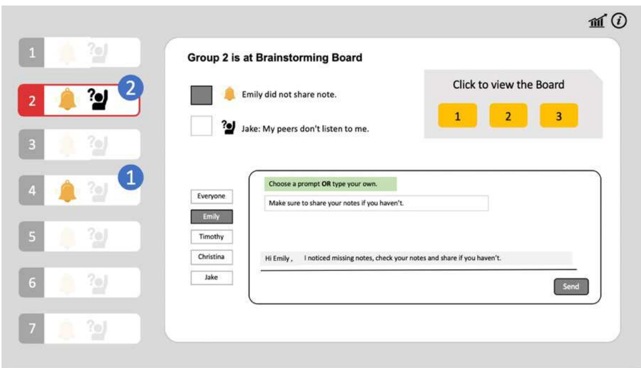

Figure 2. Group view (group number 2) of the cognitive assistants.

Secondly, when the cognitive assistant alerts teachers, they have various options to choose how to intervene with the groups. For example, once the cognitive assistant detected that group 2 needs support with the highest priority, the teacher can click group 2 and observe what has been going on during the collaboration (see Figure 2). In addition, the cognitive assistant will provide real-time recommendations and guidance to tell which student in the group needs additional support with the highest priority, what types of scaffolding will be the most effective, and when they need to pause the activity to provide a mini lecture, either to particular individuals, to specific groups of students, or the whole class. Teachers may choose a visually personified assistant—these visually embodied models will provide support to teachers—a text-based assistant that provides guidance in text messages, or an audio-based assistant that provides spoken recommendations. If they prefer, they may elect to have their assistants present guidance in different presentation modalities in different contexts (e.g., in-the-classroom vs. out-of-the-classroom). The important design goal in this stage is to offer actionable guidance that can support productive group collaboration. The assistant should support basic classroom management and simple prompting and identify the specific student needs based on student responses. This will ultimately provide time for teachers to engage in discipline-based interaction that is otherwise challenging to engage in. Saye and Brush (2002) characterized this as a necessary thinking space required to formulate a supportive response and collect the necessary resources following the students' initial response.

Lastly, after each class session, the cognitive assistants will offer two forms of support: 1) support for reflection on their orchestration moves and facilitation strategies and 2) guidance to help them consider future moves. In this stage, the teachers will have access to more detailed information of the class implementation. They can go back and read student groups' chat messages, artifacts, and history of prompts. We considered this stage as a critical step to provide useful reflection space to make sense of what went well, what did not, and why, and to plan for the next class. Further, the cognitive assistants' prospective, concurrent, and retrospective guidance will be improved with the same data that is collected during class time in a tight feedback loop.

The most challenging design tension identified in this study was about assessment. Our design goal is not simply to build an information provider, or assessment tools that reflect standards and supply reports, but rather an actionable cognitive assistant that can support classroom orchestration in collaborative inquiry learning. As we consider the fundamental teacher needs, what we returned to in our design consideration was the need to prioritize teacher understanding of collaborative processes and outcomes, which is not the same thing as assessment tools, but it is not entirely different from assessment. In our prioritization, we are choosing to surface thinking processes in students' collaborative problem-solving process and provide recommendations that will supply the most valuable information. This information involves how teams are doing and what they need. One area of compromise can be intermittent milestones that will trigger a set of recommendations when students are not making progress or articulating what they know about the content rather than having explicit knowledge checks. In other words, what we are giving teachers is the ability to make the kinds of decisions they would need to make about standards, learning, and collaborative processes, but without supplying standards-based checklists. We suggest this serves to empower teachers to make the kinds of decisions they need to foster deep learning.

Designing with teachers for classroom implementation is an invitation to solution development by involving key stakeholders (e.g., teachers, researchers, software designers), and participatory design demonstrates the power of stakeholder collaboration in a way to increase effectiveness and impact in the community (Philips, 2014). Initially, researchers might pay particular attention to theory-driven decisions, and teachers might bring their practical views on how instructional materials are realized in practice (Gomez et al., 2018). However, researcher-practitioner collaboration can pose opportunities to address the needs of both that consider expectations and goals, along with constraints of the practical context through multiple levels of negotiation. Our next step is to test our cognitive assistant design in classrooms, obtain feedback on how it can best help teachers orchestrate PBL, and refine our initial design decisions to ensure our design meets the needs of everyday users. Specifically, the recommendations that are made through the cognitive assistant may seem prescriptive, but they are not deterministic; thus, we need to better understand how teachers perceive the structure that we provided and the recommended instructional information, and whether they were useful and usable to reduce orchestration load in real classrooms.

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