

Co-Design of an Orchestration Tool: Supporting Engineering Teaching Assistants as they Facilitate Collaborative Learning.

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Abstract. This paper describes a design-based implementation research (DBIR) project, focused on the co-design and implementation of an orchestration tool for teaching assistants (TAs) in required engineering classes. Building on our collaboration with the engineering department, we identified a need for a tool that provides insight into groups to help TAs intervene in real-time. This paper presents two phases of our iterative co-design process. The first phase includes the initial design of the tool from design workshops with TAs. The second phase focuses on a 16-week implementation of the orchestration tool and reports on interviews with TAs to understand how they used the tool. Findings indicate that the impact of the tool varies and that the uptake of the tool differs by TA. Finally, we reflect on the co-design process and discuss future directions for the creation of this technology.

Keywords: Co-design; orchestration tools; data analytics; collaboration.

1 Introduction

Technology provides a range of possibilities to change the nature of learning and collaborative learning in classroom contexts [1]. An emerging area of research is tools for teachers to orchestrate computer-supported activities in their classrooms, which takes advantage of the data available when students use technology to provide insight to teachers about the learning processes [2]. Of particular interest, are tools that can be used in the orchestration of collaborative learning that accounts for the complex nature of managing and adapting content for multiple groups within a classroom [3]. Emphasized as a “*grand research challenge*” (p. 3) in the field of Technology Enhanced Learning (TEL) [4], classroom orchestration has gained traction in the field, leading to calls to leverage co-design practices in order to create the most impactful technology for teachers. In this paper, we report on the co-design of an orchestration tool, created for Teaching Assistants (TAs; graduate engineering students) and Course Assistants (CAs; undergraduate engineering students) as they teach groups in engineering discussion sections. Two phases are presented, the design of the tool (phase 1) and the implementation (phase 2), to answer the research question:

1. How can co-design with TAs and CAs be shaped for meaningful co-creation of orchestration tools?
2. What are the benefits and challenges of the process?

In the first phase, we describe two rounds of design workshops with TAs and CAs that we used to elicit the needs and challenges in the classroom (see Table 1). In the second phase, we describe observations from a semester-long implementation of the orchestration tool called [software name removed for blind review] and responses from two TAs and four CAs who used the tool. We will reflect on the findings and challenges of our concrete co-design case.

	Phase 1		Phase 2
	<i>Workshops Round 1</i>	<i>Workshops Round 2</i>	<i>Implementation</i>
<i>Timeline</i>	Spring 2017		Fall 2017
<i>Data</i>	Notes and audio recordings of workshops using a semi-structured protocol		Notes and video recording of interviews using a semi-structured protocol
<i>Participants</i>	TAs $N = 6$ CAs $N = 2$	TAs $N = 1$ CAs $N = 6$	TAs $N = 2$ CAs $N = 4$
<i>Analysis</i>	Thematic analysis of notes and recordings		

2 Related Work

2.1 Orchestration to Support Teachers

Efforts to increase the use of collaborative learning in engineering courses have been driven by research indicating that this form of pedagogy allows students to develop deep conceptual understandings and transfer their learning to novel contexts [5]. This work is situated in the assumption that learning takes place in the interaction between students, highlighting the importance of constructing a joint problem space between individuals [6]. This is important as the quality of a group's interaction affects problem-solving and the construction of a joint problem space [7]. Research shows that collaborative problem-solving can increase engagement and persistence in STEM fields [8] and responds to calls from industry to prepare the workforce for a future of teamwork. However, classroom research indicates that the experience of students engaged in collaborative learning is varied [9], and teachers are often inadequately prepared to support students during these activities [10]. Research has explored the role of teachers in supporting collaborative learning in classrooms [11]; this work indicates that teachers can identify groups who need immediate help and use live information about students provided by the orchestration tool to inform their intervention decisions.

Dillenbourg describes orchestration as the teacher's ability to manage learning in real-time while simultaneously considering all the context and constraints of a classroom [12]. While there are varying opinions about the interpretation of the word

orchestration [13, 14], Dillenbourg's definition grounds orchestration as a "technical concept" (p. 491) that empowers and supports the teacher [3]. However, some researchers argue that these tools to support the teacher's orchestration can put a strain on their cognitive load; therefore, not supporting but adding unnecessary management time during class [15]. Time is a critical determinant of uptake when implementing orchestration tools; teachers are managing several components of the classroom and if the technology becomes strenuous the teacher will stop using it [16]. To design tools that optimize the teacher's time, their participation in the design process is crucial [2]. Orchestration tools have the capabilities to lessen the load of the teacher and allow them to adapt to unexpected situations in real-time, but to do so, the design of these tools needs to be intentional and consider the goals and needs of the teachers [3].

2.2 Co-Design and the Role of the Teacher

Socio-cultural theory attends to the process and interactions of learning rather than merely focusing on outcomes; therefore, allowing researchers and designers to understand how cultural artifacts mediate learning [17]. Designers make decisions about external factors, while also considering how learning is affected by interactions with the setting, culture, and people. Considering the significance of these decisions on students and teachers, it is a crucial component of co-design to incorporate teachers' voices in this process. Research shows that co-design in TEL environments gives the teachers ownership over the technology and affords greater professional growth through the collaborative process [18]. Cober, Tan, Slotta, So, and Könings enacted a co-design process to design astronomy software and reported that teachers suggested design requirements and innovative pedagogy during the process [19]. Matuk, Linn, and Eylon co-designed curriculum materials with teachers that led to embedded customization for teachers which allowed them to leverage student work to better support their class [20]. Co-design can be a time-consuming process and may not always be easy to implement; however, the value of co-creation is the opportunity to build more effective tools, increasing their uptake and use in the classroom.

Design-Based Implementation Research (DBIR) is one methodology to integrate co-design practices into research-practice partnerships to ensure that interventions are effective and sustainable [21]. Stemming from the seminal articles from [22] and [23] on design experiments, DBIR has formed into a methodology that looks at the relationship between designed artifacts, theory, and practice [24]. Fishman and colleagues [21] describe the key principles of DBIR as (1) focusing on problems from multiple stakeholders, (2) designing through iterative, collaborative processes, (3) developing outcomes that build on both theory and practice, and (4) creating change in a system.

We enact these principles of DBIR in relation to our co-design to construct effective and sustainable orchestration technology for teachers. Many researchers in the orchestration literature have emphasized the importance of giving the teachers a voice during the design process [2, 3, 25]; there are multiple examples of orchestration tools that were either co-designed or incorporated teacher feedback into the creation of the tool [26, 28]. In addition to co-designing with teachers, the designers of collaborative TEL tools must reflect on the teacher's knowledge of implementing collaboration [29]. This requires designers to reflect on both the practical needs and knowledge of teachers and the theoretical underpinnings of

collaborative learning. While this may create tensions in the co-design process, we argue that bridging these perspectives will, in turn, create more effective technology.

3 Phase 1: Design of the Tool

The first phase of this work focused on the process of designing an orchestration tool based on expert teachers' experiences and TAs' and CAs' input. Focus groups were conducted with expert teachers to identify information that may be valuable in real-time to support collaboration. To test the validity of these identified categories, visualizations were created. These prototypical visualizations were leveraged to build the design with TAs and CAs and understand if and how they may implement them in their classrooms. Below we discuss workshops with TAs and CAs, where we introduced them to various visualizations. We asked them to reflect on their understanding of the visualizations and discuss what they need to support collaboration effectively. We address the following research questions:

1. What do TAs anticipate they need in order to support collaboration successfully?
2. How can their ideas be used to inform the design of an orchestration tool?

3.1 Study context

As described above, the designers of collaborative TEL tools must reflect on the teacher's knowledge of implementing collaboration [36]. Our orchestration tool was built in collaboration with engineering faculty and TAs; however, we also used insight from expert teachers and prior research, not only to support TAs in the classroom but to simultaneously teach them about collaboration. Many TAs in the engineering classes place a higher value on getting the right answer than the process in which the students worked on the problem [30, 31], and had little prior experience of collaboration, or knowledge about successful collaborative interactions. By developing this tool, we aimed to build on TAs' and CAs' knowledge of collaboration and support them as they enact collaborative learning. Simultaneously, we aim to teach them about collaborative processes to more effectively identify groups that may be struggling and intervene appropriately. These goals showcase the importance of co-design in this work, wherein we target both their goals as teachers and their needs as learners.

This work takes place in the context of the fourth year of a six-year DBIR project. Students in this class attend a one-hour lecture three times a week and attend one 50-minute discussion section. Enrollment in discussion sections was capped at 32 students, and students were required to attend the same section each week. One engineering graduate student teaching assistant (TA), and one or two undergraduate course assistants (CAs) were assigned to teach each section.

Prior to this project, the engineering college had begun a process of pedagogic reform, including adding collaborative problem-solving activities to discussion sections, and the majority of the faculty were keen to participate in these changes. During the first three years of our study, the research team worked with faculty to conduct a year of baseline research in five discussion sections each week. The team regularly attended faculty and TA meetings in order to understand more

about the context, taught two semester-long courses on teaching for TAs in these courses, and worked with the teaching teams to re-design the collaboration activities.

During the first phase of the study, the focus was on the design of tools to support students creating joint representations during collaborative activities. A tool that allows synchronization across tablets within a group was determined to be the most useful in this context [32]. In the second phase, the focus was on using the log files generated when students worked on the synchronized software, to provide information for an orchestration tool. This work, and the co-design process to create the orchestration tool is the focus of this paper.



Fig. 1. A group of four students working on synced tablets.

Each discussion section used a worksheet, which was distributed at the start of class, and groups worked through the worksheet, getting help from TAs as needed. Students were assigned to stable groups and worked in groups of three or four to complete the worksheets (Figure 1) using the [removed for blind review] software (Figure 2). The worksheets were designed to be authentic, ill-structured problems to promote collaboration within groups [33].

The orchestration tool. The orchestration tool was not designed to replace in-person monitoring; rather, the goal of the tool was to provide insight into multiple groups (which may not always be easily visible to a teacher in a classroom) so that TAs can prioritize groups who need intervention. In addition, a secondary goal of this tool was to support the TAs and CAs who may lack the expertise to identify the quality of group processes and intervene effectively. Thus, by providing some insight into what is going on in the groups, TAs may approach the group with a better idea of what behaviors to look for before they intervene. Analysis of TAs and CAs using this orchestration tool in the classroom indicates that the use of this orchestration tool changed how TAs and CAs monitored and intervened with groups of students [31]. The tool was useful in getting the TAs and CAs to engage in more monitoring of groups and allowed them to initiate interventions with more concrete information rather than interrupting groups with general interventions that often interrupt discussions [34], as research shows this has been known to happen with TAs and CAs in this context [30]. While we know this orchestration tool was able to influence the TAs and CAs actions in the classroom, in this paper, we aim to explain the co-design process to develop this tool and discuss interviews with TAs and CAs.

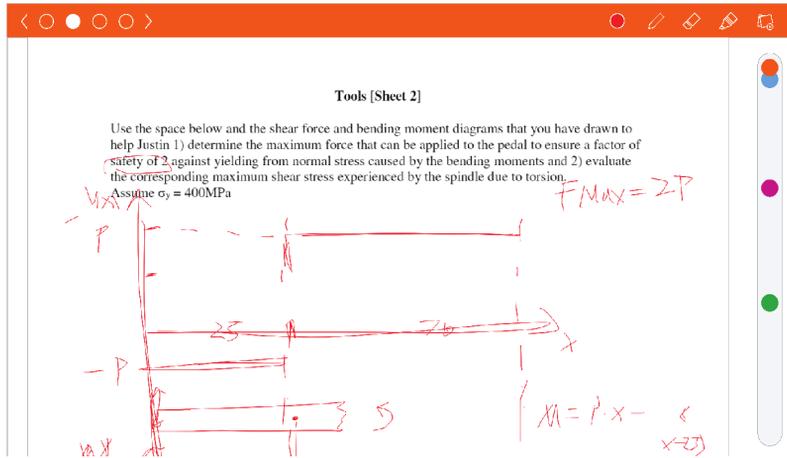


Fig. 2. Screenshot from synced student's software.

3.2 Methods

As a DBIR project, we conducted workshops using semi-structured prompts with TAs and CAs to design the visualization of the categorized information. Recognizing that many of the TAs had little experience teaching, we created a series of scenarios based on the insights from teachers. Scenario-based design is used to evoke discussion by presenting the participant with context that is flexible enough to encourage reflection while providing participants with the key functions of the design [35].

Through thematic analysis and researcher consensus, we identified three categories that were important to expert teachers when implementing collaboration: student activity, location on the task, and progress. Student activity was important to expert teachers to identify who is contributing to the task or not. They determined location is important to ensure students were working together and not separately (e.g., working on the same page or separate pages). Finally, progress was important to make sure all groups were progressing with the task at the same pace. We presented participants with scenarios visualizing the three categories from interviews with expert teachers.

Participants. Fourteen engineering TAs (graduate students) and CAs (undergraduate students) participated in this phase of the study. All participants were working as a TA or CA in at least one engineering discussion section at the time of the design workshop. Recruitment took place in their weekly meetings. Ten of the TAs and CAs were in their second semester of teaching; the remaining participants had completed between three and six semesters in their position.

Design workshops were conducted with one or two participants at a time, for a total of ten workshops. Multiple workshops were held to accommodate the participants in scheduling; additionally, to engage the participants in more discussions to validate design decisions across groups. Workshops were separated into two rounds, with changes to the scenarios between the two. Each round had five workshops. One participant from round 1 also participated in round 2; thus, there were eight participants in round 1, and seven in round 2.

3.3 Design Workshops Round 1

Protocol. Two members of the research team attended each workshop; data were collected through audio recording and notes. TAs and CAs were presented with a series of scenarios and asked questions to spark discussion. The questions focused on how they reflected on the categories and what they need in the classroom.

Initially, one group of students from the scenario was described, and each representation was explained (student activity, location, and progress) (see Figure 3). They were then given a full scenario with all eight groups (see Figure 4). TAs and CAs were told to take a few moments to analyze all eight groups, then asked to describe the scenario and explain what, if any, action is prompted from the information.



Fig. 3. One group represented in a scenario used to explain the categories.

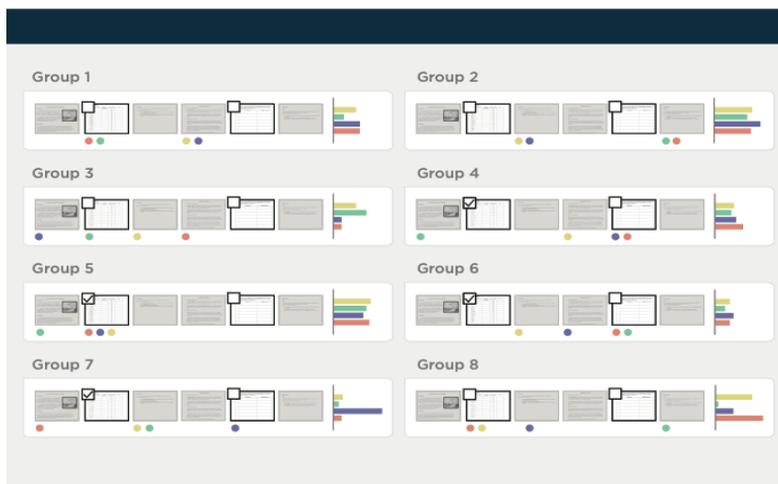


Fig. 4. Full scenario visualizing the categories for all eight groups at once in round one.

Once the scenario was familiar to the TAs and CAs, the moderator introduced the same scenario populated with different data. They were asked to give feedback on the representations and how the tool may or may not be useful in their classroom. TAs

and CAs were introduced to a total of five scenarios, followed by a wrap-up discussion that delved into their perceptions of the categories and discussion about their needs.

Analysis. Emergent themes were identified using notes and audio recordings from the workshops and discussed among the research team. The scenario identified as the best and the recommendations of additional features were analyzed from each workshop. We made changes to the visualizations based on their feedback.

Results. In order to address the first research question, the responses from the workshops were analyzed. We received a range of responses from workshops about additional features that the TAs and CAs suggested should be included in the tool. Many discussions were centered around viewing students' work to indicate correctness or to facilitate whole class discussions. During a discussion about their interactions in the classroom, one CA explained,

“When there are no questions, I walk around the classroom and check their worksheets without disturbing them. We couldn't do that with the tablets, I believe. Can... Can we look at what the students are doing? I think if [the tablet] could do that, I would look at the tablet more.”

This CA elaborated on this idea with the TA, who was in the workshop with him. The two discussed that being able to see the students' work would allow them to identify wrong answers or problems in the groups' process. There were many TAs and CAs who discussed viewing the students' work as a way to make sure the group had the correct answer. Two TAs in another workshop came up with another use for viewing the students' work. One TA explained,

“Could you play [the students' work] back to see how they approached a problem? It would be helpful in class to pause it and talk about [their work]. Something we try to do at the end of class, actually what you guys told us to do, is do a wrap-up at the end. An introduction and a wrap-up. And I wonder if some of this ability to display on the screen could be useful in doing a wrap-up. I could see that being a useful function during class.”

Similarly, other groups discussed including a function that allows the TAs and CAs to view and edit the work with the groups, adding another layer of functionality to viewing the students' work in addition to checking answers.

During the wrap-up part of the workshop, TAs and CAs were asked to identify which scenario would best fit into their discussion section. Findings show that there were two scenarios that the majority of TAs and CAs chose; see figure 5 for the top two visualizations. TAs and CAs explained that the primary reason for choosing these two scenarios was the use of the bar graphs as they were the most helpful when comparing activity within groups. When considering the location, participants indicated it was helpful, but the form of the representation could be more apparent. Finally, some TAs and CAs expressed that the ability to see a thumbnail of the pages as necessary. One TA said, “I would like to know, to have a picture of the page to know where the students are.” This TA and other TAs and CAs described that adding the thumbnails would not require them to memorize what was on each page of the worksheet.



Fig. 5. Top scenarios chosen in round one.

Common themes were identified from the workshops about the categories of information. First, there was some general confusion about student activity. One TA asked, “is this amount of blue [in group two] the same amount of blue [in group four]? Or is it a relative amount?” While the bar graphs alluded to relative comparisons between groups, they were intended to represent activity within groups. Many TAs and CAs indicated a desire for across group comparisons, one TA explained,

“I can compare and say if this bar is smaller than this bar, or all of their bars are significantly less than this group, maybe it means they are on their phones or maybe they’re doing something else, or they’re stuck, and they are trying to talk it out. Then it would be really helpful to see bars like this.”

Student activity was visualized using bar graphs, Gantt charts, and pie graphs; there was an overall consensus that the bar graphs afforded the most precise inferences about the activity. We also received suggestions to add group activity; a few participants suggested it be visualized with a line graph.

The TAs and CAs and researchers had lengthy discussions about the progress category regarding the logistics of identifying when a group has completed something. Suggestions to this included the technology identifying right or wrong answers, one group member indicating the group had finished the problem, or each group member approving work had been completed in order to determine if all members were progressing at the same speed or if some group members were progressing too quickly. Here we see a tension between the theoretical goals – to have students engaged in open-ended authentic problems where there is not a single correct answer – and the practical perspectives – that the TAs and CAs idea of success is still firmly rooted in task completion and achieving the right answer. Additional suggestions to the visualization included making the location more obvious and to including displays of the content of the pages on all visualizations moving forward so that TAs and CAs do not have to memorize the content of each page.

3.4 Design Workshops Round 2

Visualization Changes. We used the feedback from the first round to make changes to the visualizations. Due to TAs’ and CAs’ responses, we added group activity as an additional category. In round two, tags were added for the location, so

that it was easier to identify which page students were viewing. The students' color that was used on the teacher tool was also added to their personal tablet interface so that TAs and CAs could identify which color was which student when intervening with the group.

In round one, progress was visualized as checkboxes on the pages that were completed by the groups. Due to the flexibility of the scenarios, discussions were had during the workshop about the logistics of groups marking work as complete. A suggestion from one workshop that was agreed upon unanimously by the research team was to allow each student in the group to mark the page when they agree it has been completed, allowing the TAs and CAs to identify which groups were progressing together versus ones whom one member was completing the worksheet alone.

Protocol. The workshop was identical to round one but used new iterations of the scenarios created using the feedback received in round one. TAs and CAs were introduced to the scenarios the same way, with one group to explain each category (see Figure 6). They were then given a full teacher tool scenario with all eight groups (see Figure 7) and asked the same questions as the previous round to spark discussion. Five scenarios were presented in round two.

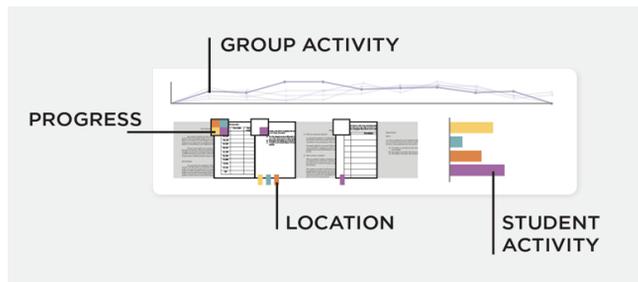


Fig. 6. One group from the scenarios to explain categories in round two.



Fig. 7. Full scenario visualizing the categories for all eight groups at once in round one.

Results. The scenario identified as the best and the recommendations of additional features were analyzed from each workshop. Findings show that when using the scenarios, the primary category discussed was progress. One TA explained the progress was helpful when knowing who needs assistant; he explained,

“The [progress] box is probably the most important out of [the categories]... I think knowing that they’ve completed something as a group is helpful when knowing who to check on.”

TAs and CAs identified that progress was a good indication of how the groups were doing, as they could identify which groups were not getting the work done or who were not working together. Another CA described,

“[Progress] would be at least one of the most useful to see where the group is as a whole. So that you could actually see these two have at least finished the first page, and then it’s also nice to see if someone is going too far ahead. You can use the [location and progress] data to see if they are spreading out and not working together.”

The emphasis on the outcome rather than process is not surprising that the TAs and CAs focused on progress, as they are not taught explicitly about collaborative learning.

Similar to the first round, there were several discussions about viewing and editing the students’ work in real-time to see if the groups have the correct answers. Many TAs and CAs discussed ideas that also emerged during the first round, such as playback or joining their group. One CA proposed a new idea. He explained,

“I would like to see inputs of numerical answers or algebraic answers [on the main screen]. You could have some sort of document where there is a box, and they have to write something inside the box, and then I could just quickly see a particular group. I then don’t have to interrupt them, but I only have to interrupt them when they’re wrong.”

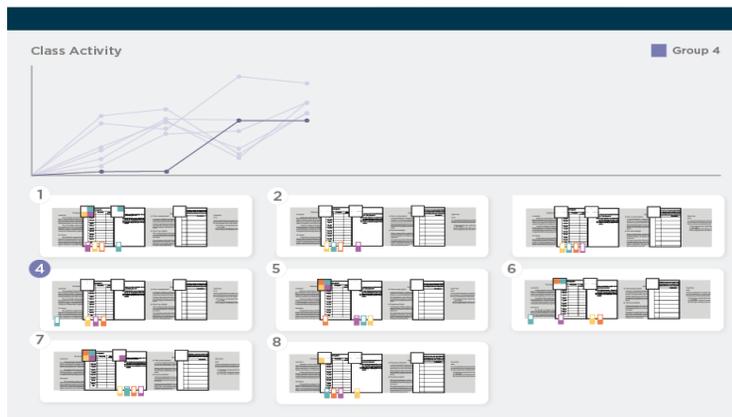


Fig. 8. Top visualization for round two.

During the wrap-up component of the workshop, participants were asked to identify which format would best fit into their discussion section. There was a unanimous preference for the tool shown in Figure 8. All TAs and CAs indicated this was the best format to use in their classroom because of the inclusion of the line graph for group activity comparison and the presentation of the progress. One CA explained that this option had the best use of space, especially with the combination of the location and student activity.

3.5 Conclusion

This phase set out to understand perceived needs in order to inform the development of an orchestration tool that would enable TAs and CAs to monitor group processes. Our overall findings from both phases of workshops suggest that the TAs and CAs perceived the information presented as helpful to determine which groups may need assistance.

We also explored the TAs and CA's responses in light of our theoretical goals of the project. Our findings indicated that the majority of participants in the second phase selected the same visualization (Figure 8) as being the most informative and helpful in their classroom. Upon finishing the workshops, the research team, which included faculty from engineering and education, met and discussed findings and made final design decisions based on the literature to move forward with development. This tool visualizes three of the four categories of information recognized in the first phase of the project, student activity, group activity, and location on the task. While progress was indicated as an important category by expert teachers, TAs, and CAs, the research team decided it contradicted the theoretical foundations of the project. According to our theoretical views of collaboration, the components important to building a joint understanding as a group is not the answer to a problem but rather, is situated within the groups' processes. Therefore, the research team decided that the tools data should emphasize the joint contribution and location rather than introducing progress.

One additional feature was added to the tool so the teacher can join a group and either project their screen or interact with them directly. This was a function that was adapted from the suggestions from participants in Phase 1 that they wanted to be able to see what the students were working on. When a page is projected, any group member (including the TA or CA) can continue to work on the (projected) pages, allowing them to display work in progress to the whole class.

Finally, our findings indicated that TAs and CAs want to have access to information that tells them details about groups that may not be noticeable from simple observations, similar to suggested in the literature [3] and that these may change with teaching experience. Designing tools for classroom orchestration requires we consider not only the information we *can* provide, but the type of information that would be *most useful* to teachers, and the manner in which they can quickly review [2].

4 Phase 2: Implementation

In phase one of this paper, we presented the co-design workshops held with TAs and CAs. After these workshops, multiple rounds of software development took place as

well as several user testing sessions with small groups and large classroom tests; however, for the purpose of this paper, we only present findings from our co-design process. In the implementation phase, interviews with the TAs and CAs were conducted to understand how they used the tool. The research questions addressed here are:

1. What challenges arise when introducing an orchestration tool in classrooms?
2. How do TAs and CAs reflect on their experiences using an orchestration tool to support collaboration in their discussion section?

4.1 Context

Discussion sections were taught in a lab classroom for the entirety of the 16-week semester. One graduate student TA, and one or two undergraduate CAs taught in each discussion section. Seventy-five students in four discussion sections worked in groups of 3 or 4 on collaborative problems, using synced tablets (see Figure 2). Class size ranged from 12 to 29 students.

Orchestration Tool. Live information was collected from the tablets and appeared on the teacher interface (Figure 9), which was displayed on an Android tablet. TAs and CAs received a comprehensive two-hour training about the functions and information in the tool and were provided with a two to five-minute overview before class for several weeks starting the implementation to go over the tool and answer questions.



Fig. 9. Screenshot of the software implemented in discussion sections.

4.2 Methods

Participants. Two TAs and four CAs were interviewed as part of this study. One TA in each section was the lead teacher. There were two lead TAs in the four sections, one in the first two and one in the latter two sections. All participants were

working as TAs or CAs and used the tool in a lab classroom each week. Six interviews were conducted with one participant at a time at the end of the semester.

Protocol. The first author conducted all the interviews using a semi-structured interview protocol. Audio and video were recorded; consent was obtained from all participants. All participants in this round were interviewed immediately after teaching a discussion section and asked to reflect on the class.

Analysis. Emergent themes were identified using notes and video recordings from the interviews and discussed among the research team.

4.3 Results

Findings. To analyze the first research question, themes were identified in the interviews. TAs and CAs reported they either sought out the tool to identify groups that needed help or actively chose not to. One TA that did not regularly use the tool had a variety of reasons for his hesitation. The TA, who had previously given feedback in the design stage of the interviews, explained:

“[When there’s a problem with the tool] I get frustrated, and I’m like, well, I’m going to see what [a group is] actually doing. If it goes wrong once, I’m severely less likely to continue using it that day.”

The other TA who expressed that he used the tool semi-regularly during the class period reported that he could get a better sense of how a group was doing by watching over their shoulder for a short time to make sure they had the right answer, rather than drawing inferences from the visualizations on the tool.

Although the two TAs did not use the tool consistently, the remaining CAs reported that they used the information from the tool to identify which group may need help. One CA that used the tool consistently explained:

“I switch between groups [a function of the tool to compare activity] to see which one isn’t being active... Usually, they’re stuck or are talking to another TA.”

She went on to explain that her inferences from the tool were accurate most of the time and that groups she approached were usually stuck or had a question. Another CA that had positive experiences with the tool expressed that student activity in conjunction with the location on the page was a good indication that one student may not be participating or may have fallen behind in the activity.

To address the second research question, how do TAs and CAs reflect on their experiences using an orchestration tool to support collaboration in their discussion section, the wrap-up questions at the end of the interview were analyzed. Responses for the ranking question (How would you rate your overall experience using the orchestration tool during the discussions section on a scale from one to ten? Ten being very helpful; one being not at all helpful) were averaged, and feedback was analyzed. The ranking ranged from five to eight (out of ten), with an arithmetic mean of 6.5 ($SD = 1.05$). TAs and CAs were asked to describe the reasoning behind their rank. Two participants who gave lower rankings (five and six) explained that they thought the tool was more useful at the beginning of the semester but less so as time went, or that

they did not think that the tool was providing them with the information they could act on. One of the lead TAs who ranked the tool with a 6 described that he thought the tool was valuable for a larger class, but in his opinion, in the small class size of discussion sections, it may not be necessary. Participants who ranked the tool above the mean described that it displayed information that they could not identify by merely observing groups. One CA who valued the tool and ranked it an eight explained that he enjoyed the ability to see if the students were working together.

Finally, participants were asked to identify additional features that could be added to the tool to support them as they implement collaborative learning. Two of the participants did not have ideas for additional features, and one interview did not get to the question due to a time restriction of the participant. Two participants explained that it would be helpful if the tool could indicate if the groups had the right or wrong answer, as this would allow them to know if they needed to intervene or not. Finally, one CA, who had an overall positive experience with the tool, expressed an interest in a function that allowed students to flag when they had questions. In his opinion, this would be a good way to indicate who needs help and gives him a reason to carry the tool with him at all times, as now he does not find it necessary to hold throughout the class period but would like to have a reason to.

4.4 Conclusions

This phase of the project set out to understand how a teacher orchestration tool was used by TAs and CAs to monitor group processes during engineering discussion sections. Our findings indicated that there is variability in TAs and CAs' use of the tool, as there is a somewhat even split of participants that used the tool and those that did not. One finding was that TAs and CAs that expressed they did not use the tool were primarily in the first two classes, with the same TA. However, one CA that taught in the first class did find the tool useful, in contrast to the views of the lead TA.

Designing a tool for classroom orchestration is challenging due to the differences in TAs' viewpoints on teaching, technology, and collaboration, among other factors. One significant implication when designing and implementing new technology in the classroom is the unpredictable technology issues that arise. As noted above, technology issues can impede the use of a tool entirely due to frustrations and the ongoing pressures in a real classroom environment. However, the technical issues that arose during class did not deter all participants, indicating that participants that are motivated to use the tool will push through and continue to use it.

During two of the interviews, we saw an emphasis on the correctness of answers rather than group processes. This shows a need for continued attention to the culture of the course and attention to explaining the purpose of ill-structured, authentic tasks. It may also indicate that additional prompts or visualizations may be necessary to help participants without collaborative expertise. We suggest that such supports need to be delivered in a way that is both useful and adaptable based on the teacher's needs.

5 Discussion

This paper set out to describe two phases of a DBIR project focused on the design and implementation of an orchestration tool for TAs and CAs to better understand how a

co-design process happens in context. To answer the research question, how can co-design with TAs and CAs be shaped for meaningful co-creation of orchestration tools, here we discuss the benefits and challenges that emerged during this process. This paper is grounded in the DBIR principles to work with stakeholders, engaged in a co-design process, building from theory and practice to create systemic change. We expanded on previous findings of this project, where we identified a need for an orchestration tool from working with engineering stakeholders over several years [30, 31]. The overarching goal of this project to work together with stakeholders to embed collaborative problem-solving in engineering courses toward pedagogical reform.

In the first phase of the present study, we identified three categories (student activity, location, and progress) using feedback from expert teachers. The TAs and CAs critical reflections about their needs in the classroom added value with contributions of how these categories would or would not work in their classrooms. In the first round of discussions, the consensus led to an additional category of group activity that was not presented by the expert teachers. Through iteration of these categories, using feedback from TAs and CAs and reflections on the literature, we were able to understand what may be beneficial when orchestrating collaboration in engineering discussion sections. After the second iteration, group activity, student activity, and location were the final categories implemented in the tool.

During these discussions, the primary challenge presented was the conflicting perspectives about what is learning in discussion sections. From a research angle, we view learning as encompassed within the interactions of the groups, which influence the purpose of the tool, whereas the majority of TAs and CAs clearly expressed a focus on the correct answer. This tension indicates that the purpose of the orchestration tools may not align with the pedagogic goals of the teacher. While this tension presented itself in the design phase, surprisingly, it did not appear when training TAs and CAs on the functions of the tool. We hypothesize this difference for a number of reasons. First, the tool was presented as an additional part of the classroom by the faculty running the course, leaving little room for dismissing the contents. Additionally, the tool was presented to TAs and CAs in a final form without progress as a category. While in the co-design process, progress was included as a category, with the context that it was a scenario not in its final form to prompt feedback.

During the implementation phase, we found that the TAs and CAs differed in the way they used the orchestration tool and the value they perceived in the tool. Differential uptake and use of orchestration tools by teachers have been reported elsewhere [36] indicating that teaching experience and comfort with technology may influence their uptake of a tool.

The tension that emerged during our co-design efforts was the TAs and CAs having different experiences and opinions with the goals of the tool, which then translated into the classroom implementation. We found that some TAs and CAs remained attached to the idea of a correct answer and wanted the tool to provide them with insight into the solution process or final answer of the worksheet. This highlights the importance of taking an ecological theoretical view of this type of work [30]. The issues that the TAs and CAs identified had more to do with their misunderstanding of the purpose of the learning activity as it had been designed (it was possible for groups to approach each task differently; therefore, no single right answer existed). This highlights the importance of continued education about the pedagogic reforms and understanding the entire context of the implementation of an orchestration tool when interpreting feedback on its use. The interaction of pedagogic goals of the teacher (whether they align with the pedagogic goals of the course or not) and the use of an orchestration tool is necessary to consider and may influence how and when the tool

is used. This evidence suggests that providing tools is not sufficient and that a teacher's beliefs and attitudes need to align with the pedagogic goals of a tool for them to be used effectively in a classroom context.

This paper presents a relatively small study and co-design process of an orchestration tool. The design was based on 14 TAs/CAs, and interviews with six people using the tool; although, the tool was used for 16 weeks, adding value to the interviews. In addition, the orchestration tool was designed for a particular context, in which the teaching staff had less familiarity with collaboration, than may be seen in K-12 classrooms, or classroom contexts where teachers select their pedagogic practices and goals. Thus, the findings should be interpreted with caution, and future researchers need to consider the context within which their orchestration tools will be used when adapting the design decisions we made for this paper.

By carefully considering the design with users of the tool, and evaluating the effectiveness through interviews, we were able to attain an additional point of view as to why the TAs and CAs used this orchestration tool the way they did. This not only gives us a new perspective but allows us to evaluate what was not successful in our tool in order to inform design decisions for our next iteration of this tool. The design of the orchestration tool was intentional, considering the views of expert teachers, as well as those who were teaching in the context our design was to be used in. We tested the implementation of the tool over 16 weeks, allowing TAs and CAs to become familiar with the software and develop habits of use before we evaluated how they were using the tool. In this way, our designs were tested under real classroom conditions, and our findings indicate that there remain areas to adapt the interface, as well as continue to work on the pedagogic context and beliefs of the teachers.

The work presented in this paper indicates the value of using DBIR methods and engaging with experienced teachers and future users during an iterative design process. Ideas for what information should be shown on the orchestration tool were informed by the literature, expert teachers, current TAs and CAs, and the research team's theoretical approaches to this work. One limitation of DBIR work can be time constraints within this process. This study was conducted over a year, where the workshops were held over two weeks early spring 2017, with two weeks of iteration in between. The tool development and user testing occurred in the spring and summer, followed by the implementation in fall 2017. This means the co-design process was a short but rigorous process to work with TAs and CAs but lacked a full, in-depth analysis of the data before making final design decisions. This time constraint added pressure to the co-design component since we wanted to represent the users best but also move forward to meet implementation deadlines. While outcomes from the co-design were needed to make choices about the design quickly, more formal analysis of the co-design process and implementation continued past fall 2017. This analysis, presented here, was used to help the design team iterate on this software and identify areas of success and tension before beginning a new round of co-design.

Additionally, due to the time constraints on this project, students' voices were not included during this component of the co-design process, although there is a potential benefit of including them in the future. Other aspects of the project attend to their perspectives as stakeholders by introducing surveys to document their reflections about the technology and the class. These findings will inform future iterations of the project to understand how the students used the technology.

Working with the multiple groups provided a rich resource for the development of multiple dashboard views, which could be compared by current TAs and CAs. The use of scenarios was particularly important at this stage of the process, as it allowed the TAs and CAs to place themselves into a classroom situation and consider the way in which they would make sense of the data, while still allowing room for feedback

on the design [35]. However, implementation studies were also important to explore the range of how the orchestration tool was used in an actual classroom and the differences between how TAs and CAs adapted the tool for their use (or chose not to use it). The differences between TAs and CAs provide guidelines for future iterations of the tool, ensuring that the features in the next version will attend to the classroom use realities. This iterative process, drawing on multiple sources for ideas for use scenarios and interpretation of visualizations, as well as the implementation stages of the study, provide rich data for the development of orchestration tools, which should allow it to be more flexibly used by teachers in the future.

6 Overall Conclusions and Future Directions

This paper presented two phases of a DBIR project focused on the development of an orchestration tool that draws on data from student groups to inform TAs and CAs about the progress of groups. At this stage, the data is provided without any analysis, with only raw information on progress and location of the activity, but nothing more. Future iterations will draw on the analysis of the log file data in relation to video analysis of the quality of students' interactions to further inform the TAs and CAs about the groups' activity. In most cases, we expect to be able to provide TAs and CAs with a small range of possible behaviors to look for and select appropriate scripts to use to intervene in the groups. In this way, we aim to balance the use of scripts with the need to ensure they are not overly-structured and are implemented in a manner that considers the realities of the moment, as interpreted by the teacher, rather than merely being determined by an algorithm. Throughout the development of prompts, we will build on our co-design process, ensuring that the manner in which information is provided to the TAs and CAs is easy to interpret and act on. To do so, two TAs from these courses have become full-time members of the research team. This further engrains the co-design process into this work, as their viewpoints leverage the TAs and CAs perspectives more deeply into the next iteration of this software. From our experiences thus far, the iterative co-design process, coupled with interviews before and during implementation, provided valuable insight that influenced the choice and design of data that was included in the interface.

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