Designing Orchestration Support for Collaboration and Knowledge Flows in a Knowledge Community

Bodong Chen, University of Minnesota, chenbd@umn.edu
Hong Shui, University of Minnesota, shui0003@umn.edu
Stian Håklev, Minerva Project, stian@minervaproject.com

Abstract: This paper introduces orchestration support designed to enact the Knowledge Community and Inquiry (KCI) model in a fully online graduate seminar. With support from a tool named FROG, we designed orchestration support for a range of collaborative activities such as collaborative reading, collaborative group projects, and synchronous virtual meetings. Design efforts were made to facilitate knowledge flows among these activities to enable collaboration across people, time, and space. Through a descriptive case study, we investigated the extent to which the KCI model was supported by the design and whether the design facilitated learning. Based on a rich dataset comprising system logs, student artifacts, and interviews, results showed with synergistic integrated support key principles of the KCI model were reflected in students' digital traces and accounts of learning experiences. This study contributes to a critical gap in the design and development of collaboration tools and has practical implications for online teaching.

Introduction

The next-generation digital learning environments for higher education are expected to address important areas such as collaboration, interoperability, integration, and analytics (Brown et al., 2015). However, supporting collaboration is often an after-thought for mainstream learning management systems (LMSs). Instructors interested in supporting student teamwork often need to seek general-purpose groupware (such as Google Docs, Wiki, Slack). These tools are versatile and powerful but are not built with the same level of pedagogical intentions, or pedagogical "biases" (Scardamalia & Bereiter, 2008), in comparison with technologies designed by learning scientists. They also tend to be locked in separate software ecosystems, operate in silos, and demand more effort from the instructor to facilitate knowledge flows across system boundaries. Thus, to support sophisticated collaboration scenarios using general-purpose tools, we need to pursue stronger technological interoperability and integration to orchestrate collaborative activities and knowledge flows in authentic knowledge spaces. The design challenge facing learning scientists is to orchestrate information flows across learning environments so that sophisticated knowledge practices necessitated by pedagogical needs could happen.

This paper introduces orchestration support designed to help a fully online graduate seminar function as a knowledge community to pursue emergent knowledge goals. Inspired by the *Knowledge Community and Inquiry* (KCI) model (Slotta, Quintana, & Moher, 2018), pedagogical designs were created to launch and maintain a knowledge base within the class community. A dedicated orchestration system—FROG (Fabricating and Running Orchestration Graphs; Håklev, Faucon, Hadzilacos, & Dillenbourg, 2017)—functioned as the technological backbone that connected various web environments where collaborative activities happened. With FROG, pedagogical designs were encoded into orchestration graphs to orchestrate collaboration practices (e.g., grouping learners for discussion activities) as well as knowledge flows across time and space (e.g., feeding posts made before class into real-time group discussions). Through a descriptive case study of the enactment of the designed orchestration support in the seminar, we report the extent to which the KCI model was supported by the design and the extent to which community knowledge flows were facilitated by the introduced orchestration support. Below, we first introduce theoretical perspectives guiding the study, particularly the KCI model, before describing key features of the FROG environment designed to support classroom orchestration and knowledge flows. We then move on to introduce the research context and methods. Finally, we report key findings from the case study and discuss their implications.

Facilitating collaboration in knowledge communities

Knowledge Community and Inquiry

Knowledge Community and Inquiry (KCI) is a pedagogical model for designing effective support for collective inquiry in a knowledge community. It was inspired by community-based approaches to learning including Knowledge Building Communities (Scardamalia & Bereiter, 2006) and Communities of Learners (Brown & Campione, 1994), and added an emphasis on designing *macro-scripts* that specify sequences of activities to scaffold collaboration (Dillenbourg & Hong, 2008). Over the past several years KCI has been tested in K-12 settings through multiple design-based research projects, leading to the articulation of four design principles, including: (1) Students work collectively as a knowledge community, creating a knowledge base that is indexed to a specific content domain; (2) The knowledge base is accessible for use as a resource as well as for editing and improvement by all members; (3) Collaborative inquiry activities are designed to address the targeted domain learning goals, using the knowledge base as a primary resource and producing assessable outcomes; and (4) The teacher's role must be clearly specified within the inquiry script, in addition to a general orchestrational responsibility (Slotta, Quintana, & Moher, 2018). These principles are used to guide the design and enactment of future KCI models, as well as the macro-scripts used to orchestrate specific collaborative activities.

Design collaboration scripts and orchestration support for KCI

The script theory of guidance for collaborative learning is proposed with the promise that by designing *external* collaboration scripts educators can shape collaboration practices on a social plane and also influence the development of *internal* collaboration scripts used by individuals to guide their actions in collaborative practices (Fischer, Kollar, Stegmann, & Wecker, 2013; Kollar, Fischer, & Slotta, 2007). For external scripts, *micro-scripts* are dialogue/interaction models built in the environment to guide specific actions, while *macro-scripts* specify a sequence of activities reflecting a particular pedagogical model (Dillenbourg & Hong, 2008). *Orchestration graph* is one of the most recent innovations to support collaboration in the digital learning contexts. Specifically, Dillenbourg (2015) proposes to present collaboration scripts in the form of an orchestration graph—with its vertices/nodes representing learning activities and the edges/links capturing the pedagogical relationship between artifacts, individuals, teams, and class-wide activities. The orchestration graph does not only specify social configurations (e.g., student grouping) using "social operators," but also orchestrate data flows using "data operators" across collaboration activities and across social planes (Dillenbourg, 2015; Håklev, et al., 2017). These design ideas were implemented in an open-source orchestration system named FROG to support the authoring and execution of orchestration graphs (see more details below; Håklev, et al., 2017).

To enact KCI in classrooms, macro-scripts can be designed to engage students in working on three social planes—as individuals, in small groups, and as a whole class—to produce artifacts reflecting curricula goals. Inquiry activities in KCI designs typically carry on over several months, providing the community ample chance to grow a collective knowledge space and continually draw ideas from the knowledge base to advance lines of inquiry (e.g., Lui & Slotta, 2014). Novel technology has been built in smart classrooms to scaffold rich interactions amongst people, materials, tools, and environments (Slotta, Tissenbaum, & Lui, 2013). However, these studies and orchestrational support have been focused primarily on hybrid spaces (e.g., smart classrooms) in K-12 settings. More work could be done to support the implementation of the KCI in fully online spaces in higher education.

The present study

The present study's goals were to: (a) design orchestration support to implement the KCI model in an online graduate seminar; and (b) investigate the extent to which KCI principles were enacted in the course context. Based on these research goals, we developed the following questions in light of the KCI principles to guide data collection and analysis:

1. In which ways did the class work together to create, use, and improve the community knowledge base?
2. To what extent did the designed inquiry activities facilitate domain learning goals?
3. In which ways did the instructor participate?

We chose case study as the methodology because it allows researchers to consider nuanced realities surrounding a phenomenon while maintaining the potential to generalize to other contexts (Stake, 1978). By conducting a descriptive case study, we attempted to carefully scrutinize the novel study context and generate holistic descriptions of the pedagogical design and its enactment in light of the KCI model. In this section, we describe the research context, technological support, pedagogical design, data sources, and data analyses.

Context and participants

The present study was contextualized in a fully-online graduate seminar on a topic related to data analytics in education. As a typical graduate seminar, this course featured critical reading of texts, in-class discussions, and group projects. Participants of this study included the instructor and nine (out of 14) graduate students with diverse academic background (e.g., educational psychology, second language education, educational technology). The instructor had rich experiences in online teaching and was comfortable with incorporating digital technologies in teaching. He had a strong interest in support inquiry, teamwork, and authentic knowledge practices in his classes. This was the second time the instructor was teaching the course so he was familiar with the course content.

Technological support

To make learning experiences in this online course social and interactive, several digital tools were used. A course website was created to host course announcements, instructional videos, and reading materials; Hypothes.is (a web annotation tool) was adopted to support collaborative annotation of course readings (see Figure 1); Zoom (a virtual meeting tool) was adopted to host weekly online meetings; Slack (a group communication tool) was introduced to facilitate course communication and group work. Together, these general-purpose tools created a learning environment that was collaborative, had multiple entry points (e.g., course website, Slack chats), and supported various modes of engagement (e.g., annotating a reading, discussing with peers in Zoom). This was accomplished without the presence of a traditional LMS (Chen, 2019).

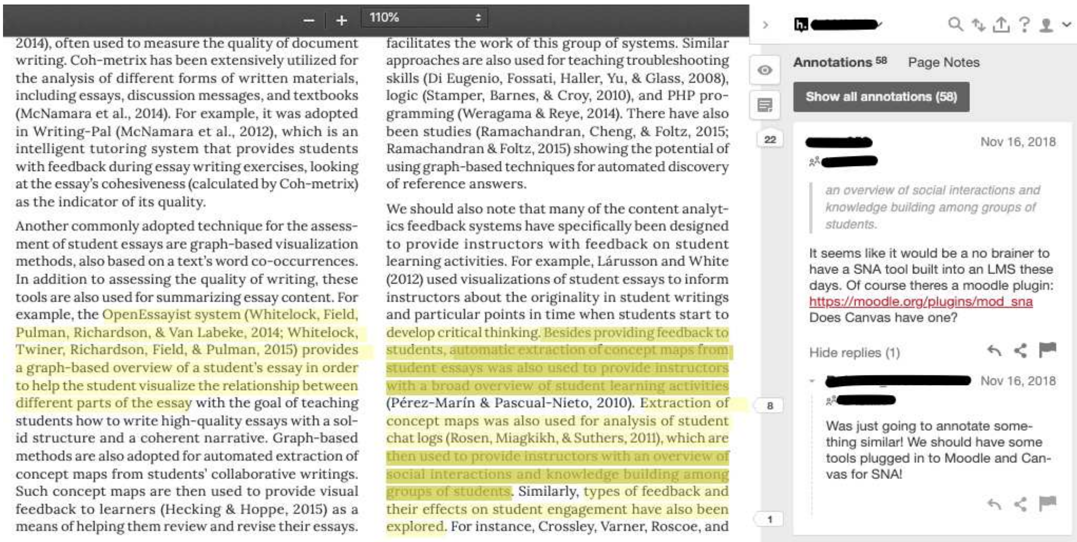

Figure 1. The class collaboratively annotated and discussed readings using Hypothes.is.

To support distributed and yet uncluttered collaboration experiences, orchestration and deeper integration among these technological tools were needed. Orchestration support—primarily enabled by FROG—was put in place to support sophisticated collaborative learning scenarios in the digital environment. As a learning technology, FROG was designed to support the authoring and execution of orchestration graphs. Specifically, FROG consists of (a) an authoring environment designed according to orchestration graphs (Dillenbourg, 2015), and (b) an execution environment that enables the instructor to run graphs, monitor progress through dashboards, and take orchestrational actions. Reflecting key components of an orchestration graph, FROG provides a range of activity types, such as video player, quiz, chat, and collaborative editing, which all support live collaboration and activity-specific dashboards. To support workflows in collaboration, FROG provides a set of operators that can create student groups, fetch data from external sources (e.g., via RSS feeds or APIs), transform data, route data from one activity/group/individual to another, and so forth. In the example orchestration graph presented in Figure 2(a), the rounded rectangles represent collaborative learning activities (such as reviewing web annotations presented in a "gallery," taking group notes in a shared "text area"); the circles represent two main types of operators that are in charge of grouping students (the social operator) and processing data (such as querying annotations, sending group notes to a class-wide "gallery" for debrief). Figure 2(b) shows more details of a group discussion activity. On the left side, a discussion group is presented with a collection of annotations made by its group members; students in the group can "star" or bookmark an annotation and search annotations by text to filter information pulled from the community knowledge base. On the right side, students take shared notes based on their collaborative sensemaking of the annotations. These types of activities and operators included within FROG are all designed as LTI-compliant plugins, enabling FROG to interoperate with other learning environments. Before the present study, FROG had been piloted in nascent educational contexts such as massive open online courses (MOOCs; Håklev, et al., 2017) and has demonstrated promise in facilitating rich collaboration activities. In this study, FROG was used during Zoom meetings to facilitate synchronous collaboration activities participated by learners and orchestrate knowledge flows across time and digital spaces.

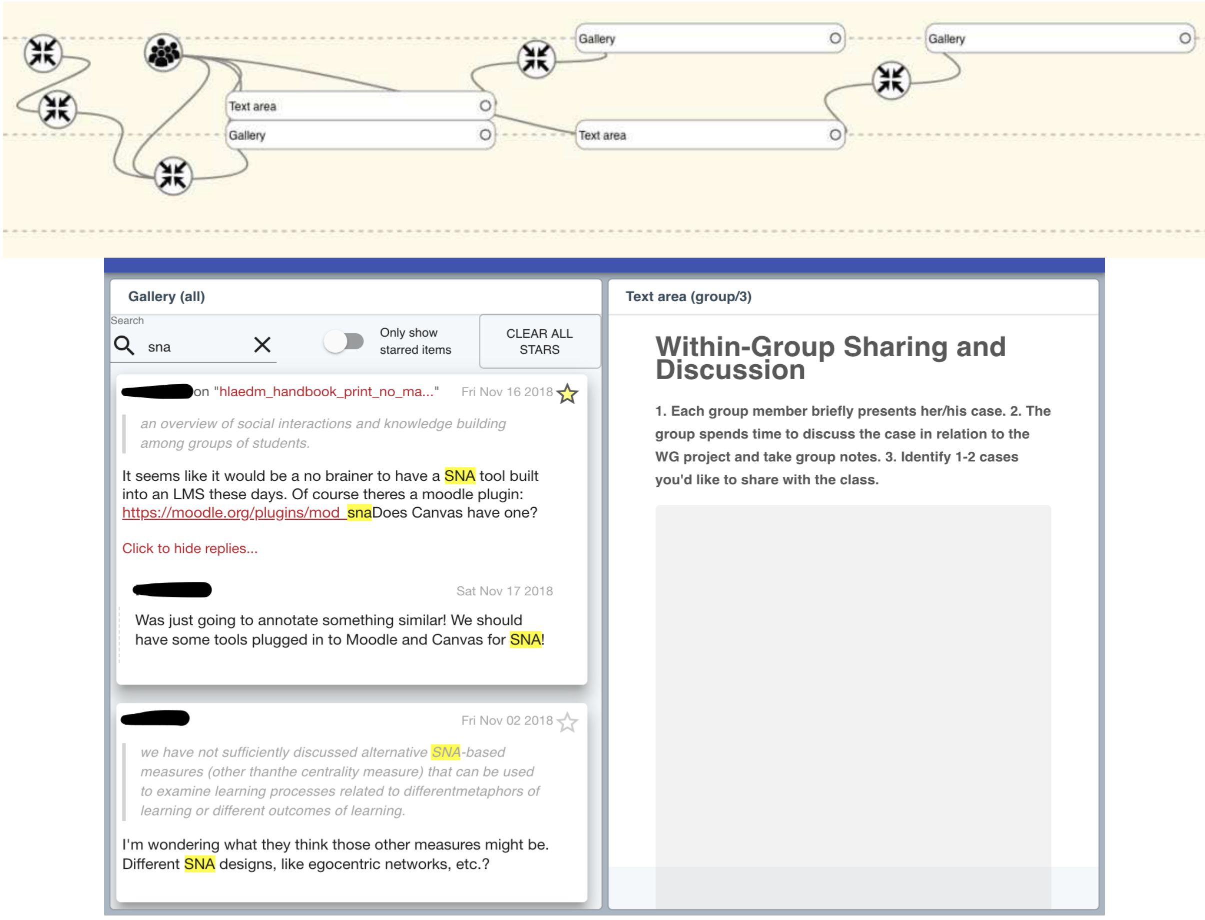

Figure 2. (a) Top: An example orchestration graph created on FROG. (b) Bottom: A group discussion activity.

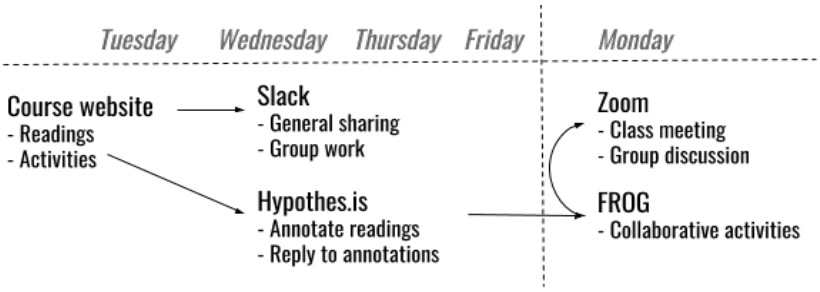

Figure 3. An illustration of the course design.

Pedagogical design

Figure 3 delineates the course's weekly schedule and roles played by FROG and the other technological tools. On each Tuesday, the instructor would publish participation guidelines (with readings and pre-class activities) on the course website and make an announcement on Slack. For the rest of the week, students collaboratively annotated course readings using Hypothes.is, commented on each other's annotations, and engaged in emergent conversations on Slack. After nearly a week of asynchronous interactions on Hypothes.is and Slack, on Monday the class met virtually in Zoom for 1.5 hours. Zoom breakout rooms were used to support small-group discussions besides whole-class conversations. Informed by the KCI model, the instructor made explicit efforts to engage the class to function as a knowledge community, using words such as "community" and "our ideas," while also involving students to self-organize into interest groups and project teams to pursue various knowledge goals.

In Week 4, FROG was introduced to the class to orchestrate synchronous activities during Zoom meetings. In particular, the instructor designed orchestration graphs to feed students' Hypothes.is annotations into synchronous Zoom meetings to help students access ideas in annotations more easily. Figure 2(b) illustrates one collaborative activity, where students were organized based on project groups to make sense of their annotations (in the left panel) and develop ideas for their shared project in a shared notepad (in the right panel).

Data sources

To answer our research questions, a rich set of data were gathered. Data from students who did not consent to the study were excluded from data analysis.

- *Course materials.* The course syllabus and weekly course materials were collected to provide information about the pedagogical design and to guide interpretation of research findings.
- *Web annotation data on Hypothes.is.* Hypothes.is annotations of course readings made by participants were extracted. This dataset included the annotation content, reply structure, and meta-data (e.g., tags).
- *FROG log data.* System logs produced by the class's interaction on FROG during Zoom meetings were exported for log analysis.
- *Text chats and group notes from Zoom meetings.* Data generated during Zoom meetings, including text chats and group notes, were collected as well.
- *Student interviews.* We conducted semi-structured interviews with five students. Audio recordings of these interviews were transcribed verbatim and analyzed to examine student perspectives of their course experiences.

Data analysis

We adopted an open analysis approach in this descriptive case study to focus on the construction of high-level descriptions and *conceptual ordering* instead of theory building (Strauss & Corbin, 1998). Because of the multimodal nature of our research data, we did not depend on a single analytical technique. Instead, we departed from our research questions and engaged in *open coding* of multimodal data concerning each question. The coding process was iterative, and ended until holistic descriptions could be constructed based on data to sufficiently respond to initial research questions.

In response to the first research question about the community knowledge base, the Hypothes.is annotation data, group notes taken during Zoom meetings, and interview transcripts were scrutinized and cross examined. The Hypothes.is annotations, replies, and tags revealed the individual and collective contribution to the creation of the community knowledge base. To track the flow of community ideas, the annotations were classified based on project groups and then contrasted with group notes produced in Zoom meetings. By doing so, we could trace how students drew from resources from the community knowledge base to address project problems and contribute group artifacts back to the community. The interview scripts were analyzed to triangulate with findings from these two data sources.

The second research question regarding whether the designed activities facilitated learning goals was addressed using FROG log data and interview transcripts. Student interactions with FROG—such as starring an annotation, searching annotations, and contributing to group notes—revealed ways in which students used FROG to support their group sensemaking activities during synchronous meetings. The interview transcripts added insights into students' accounts of how orchestration support and inquiry activities facilitated their learning goals.

Finally, to answer the third research question about the participation of instructor, we analyzed Hypothes.is annotation data, Zoom meetings, FROG logo data, and interview transcripts to demonstrate the roles he played in this online seminar and the ways he contributed to the knowledge community.

Results

In which ways did students work together to create, use, and improve the community knowledge base?

The creation of a knowledge community

The course website, together with course readings organized by weekly topics, provided a mechanism to index the community knowledge base. Student annotations of course readings reflected their sensemaking efforts; through annotations, students related readings to personal experiences, interests, and/or group projects. The class created a total of 1,504 Hypothes.is annotations, with students on average making 54.1 (SD=38.9) annotations and 37.6 (SD=24.6) replies. These annotations and replies on Hypothes.is generated community knowledge that could have facilitated individual understanding. In a thread comprising one annotation with 6 replies, five members dived into the topic of intelligent tutoring systems. They contributed perspectives from different angles, touching upon cognitive modeling, artificial intelligence, and classic examples of intelligent tutoring systems. On

Hypothes.is, community members worked collectively via asynchronous conversations to deepen their understanding and contributed knowledge artifacts (i.e., web annotations) to the knowledge base.

Following the instructor's participation guidelines, students tagged annotations with various tags such as "muddy points," "good points," and "useful points" to signal their interest in revisiting or reusing these ideas (see Figure 4(a)). The social tagging mechanism allowed students to index the community's knowledge base and then filter ideas by tags on Hypothes.is (Figure 4(b)). However, students made little effort to further index their annotations by topics. Domain-specific tags, such as "visualization" and "learning constructs," were used only sparsely (see Figure 4(b)). Overall, the class had developed an awareness of the knowledge base that existed in the form of web annotations; however, they did not take responsibility in properly indexing them by topics.

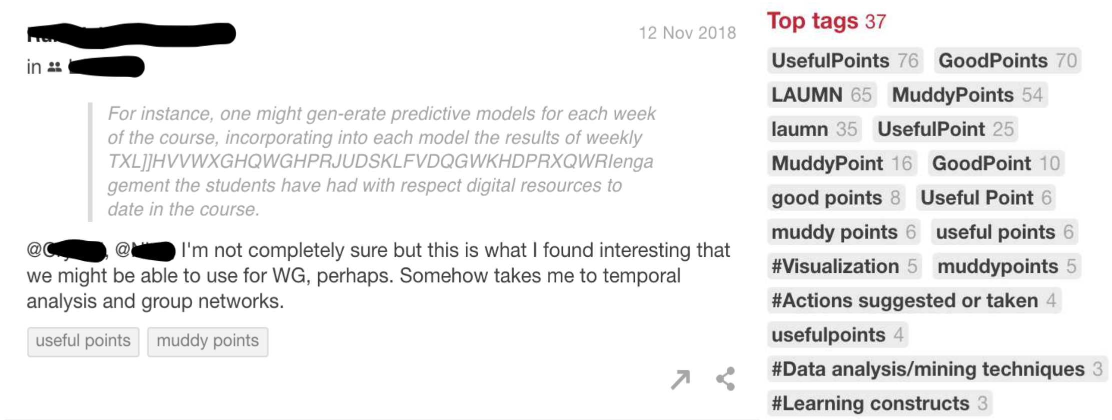

Figure 4. (a) A Hypothes.is annotation with two tags. (b) Top tags of the community.

The use and improvement of the knowledge base

The knowledge base—including Hypothes.is annotations and their replies created by the class—was accessible for all members to use and improve in two ways. First, community knowledge represented in annotations was processed during Zoom meetings to produce new artifacts such as group notes (see Figure 2(b)). In particular, group activities were specially designed using FROG to aggregate annotations tagged as "muddy points" for collaborative sensemaking; annotations tagged as "useful points" were aggregated to advance group projects. Using Week 5 as an example, the class were divided into 5 groups based on project teams. During the first activity, FROG aggregated and sent "muddy points" to each group to be discussed. Students were able to "star" or search annotations on FROG (see Figure 2(b)) and they did so 27 and 3 times respectively. For instance, the term "performativity" was tagged as a "muddy point" in annotations made by several members; during the FROG session, these annotations were starred by other students for further discussion. Analysis of group notepads indicated that during this group activity the understanding of "performativity" was further negotiated and solidified in three groups. For example, one group asked "Can performativity be used in a social network analysis?", while another group claimed "[analytics] tools aren't just objective." Notably, student groups drew from ideas archived in Hypothes.is annotations and attempted to further improve them or extend them to new contexts. During interviews, three students talked about their real-time sensemaking of annotations. Student A stated "it was nice having FROG bringing our Hypothes.is annotations…We could just go through what was confusing." Student B further commented: "What was helpful was pulling up and revisiting those questions, especially the ones that may not have been answered… The benefit of FROG is that you can identify those [questions] and pull them up for a live conversation." Student D shared that "I may [have] annotated something I don't understand, like muddy points… So when we came back together as a group, it was very interesting to see that somebody else had a different thought. It's all there in the FROG." As indicated by these examples, the knowledge base was used and revisited during synchronous group sensemaking activities.

Second, students also used annotations (and their related readings) from the knowledge base for personal learning and group projects. On the one hand, personal understanding of different concepts "was [informed] by the shared knowledge" (Student E), and learners reached out to others to "get more knowledge, comments, and support" (Student C). On the other hand, their web annotations reflected a propensity to "send" ideas from readings to their project's problem space through web annotations. Student D's project group explored the correlation between students' peer interaction and their course performance. During the study, their group members identified from readings ideas about network analysis (e.g., SNA tools, concepts) that were useful for their project; they also added relevant resources beyond course readings via Hypothes.is. During the synchronous meetings, the group pulled and discussed a range of community knowledge aggregated on FROG; as is reflected in their group notes, the group narrowed the research focus to ego-network and added temporal analysis to inspect the dynamic change of peer interactions. As Student D stated, her group project was "directly based on what we were learning every day" and "all the interactions on Slack, Zoom, Hypothes.is" (Student D). Overall, student engagement indicated that they had been purposefully constructing, using, and adding to the knowledge base.

In which ways did the designed inquiry activities facilitate learning goals?

At the course level, students formed groups to explore personal interests and tackle group projects. Over the lifespan of each group project, students worked in groups to craft the project idea, plan collaborative inquiry, feed ideas from the community to their evolving project, and developed project artifacts. Supporting structures for these group projects mostly included setting up check-points to ensure each group was making progress.

Zooming into each week, collaborative inquiry activities were composed of asynchronous social annotations and synchronous virtual meetings, which were bridged together via FROG. Students were provided ample opportunities to build on their personal experiences and ideas to develop domain knowledge pertinent to the course. Activities were socially constructive as students needed to nurture and rely on intersubjective sensemaking to unpack dense terms (e.g., performativity) and achieve inquiry goals.

During the interviews, students stated three levels of inquiry activities—the individual, group, and class levels—that assisted their learning. Individual learning mainly took place when engaging with course readings, during which students posted their personal reactions to these readings on Hypothes.is. Many students found collaborative activities at the group level were the most effective for accomplishing their learning goals. In particular, synchronous group discussions in Zoom breakout rooms helped the project group process multiple perspectives aggregated by FROG to address gaps of understanding and improve their group projects. At the class level, they were able to get informed by everyone's asynchronous contributions and other groups' synchronous debriefs after breakout discussions.

Digital tools used in the course played unique roles in facilitating collaborative inquiry activities. Based on student perspectives, Hypothes.is helped "learners do collaboration directly on [the] content so as to make deeper understanding" (Student B); it also "facilitated a lot of discussion of the reading" (Student E). Slack provided a channel for private and group communication, as well as the "home base" for the whole community where learners could share their thoughts and projects (Student E). The Zoom breakout rooms helped differentiated each group's discussion and offered each group more time to advance their projects (Student B). Finally, FROG helped the community bridge Hypothes.is annotations and Zoom conversations together, by feeding annotations into live Zoom activities (see Figure 2(b)) and providing real-time dashboards for the instructor to make informed orchestration moves (Students A, B, D).

In what ways did the teacher participate?

Based on the analysis of course materials and system logs, the instructor's role was clear in this course. During these weeks when FROG was used, he designed inquiry activities in advance, created the orchestration graph on FROG, and orchestrated class activities in Zoom. He also used FROG's dashboard to monitor note-taking progress in different groups and joined Zoom break-out rooms accordingly to provide conceptual or logistical support.

The instructor's participation on Hypothes.is reflected the role of a domain expert. He contributed 48 annotations in total; 42 of them were replies to students. These replies were mostly made to address common questions, suggest additional resources, or link a current annotation with earlier ones to foster collaboration.

From the perspective of learners, the instructor contributed greatly to the building of community by setting up the structure, keeping the inquiry activities open-ended, and offering immediate feedback. His proper degree of teaching presence gave students a strong sense of ownership of the knowledge community. During the interview, Student A described that the instructor "played a more passive role when we were in classes, but it was intentional... That helped [us to have a] sense of community. Like it wasn't that teacher-focused; it was definitely like class focused. We were controlling in a way."

Discussion and conclusions

The present study attempted to design orchestration support to help a graduate seminar to function as a knowledge community. Findings from the study indicated that with proper support, sophisticated collaborative learning experiences can be achieved in a fully online course. With synergistic support from pedagogical strategies and multiple tools, the principles of the Knowledge Community and Inquiry (KCI) model were reflected in students' digital traces and their accounts of learning experiences. The Hypothes.is annotation tool and its tagging system allowed students to critically engage with course readings and index information for future retrieval. Following orchestration graphs designed by the instructor, FROG imported Hypothes.is annotations into real-time group conversations for further idea improvement. Group notes were further fed into whole-class discussions, demonstrating a sophisticated scenario with information flow between social planes and across time points. The instructor played crucial roles in nurturing a sense of community and designing orchestration graphs but allowed students to “own” this course. Real-time dashboards on FROG enabled him to take prompt orchestrational actions. Overall, key principles of the KCI model were enacted in the course context. With the designed orchestration support, learners built an evolving knowledge base to tackle knowledge problems, experienced a strong sense of community, and developed group artifacts by constantly drawing on ideas from the community knowledge base.

The study has strong practical implications. It provides a novel example of orchestrating sophisticated collaboration activities and knowledge flows across multiple environments. The provided case study is a response to the call for next-generation digital learning environments that feature collaboration, integration, and analytics (Brown et al., 2015). It also addresses several key challenges the field of computer-supported collaborative learning is currently facing (Wise & Schwarz, 2017). In particular, this study may have provided an example of promoting learner agency (by putting their own ideas and goals in the center) while harnessing orchestration support to make good use of the limited class time for intensive collaborative work. Orchestration support was designed to facilitate the flow of ideas and artifacts that were central to learners’ pursuit of their own knowledge goals. Realtime dashboards provided in FROG enabled the instructor to provide adaptive support to mitigate challenges facing group collaboration.

For future work, we first plan to expand on the case study by taking a deeper look at learning processes in the context. We also plan to continually refine the orchestration environment (i.e., FROG) and experiment with different collaboration scenarios. For instance, while the present study limited each orchestration graph to one class period, a future project is to experiment with orchestration graphs that execute over longer periods of time (e.g., a week). By doing so, we will be able to orchestrate new types of collaborative activities and scaffold learners to be reflective of and strategic about their participation in sophisticated collaboration scenarios.

References

Brown, A. L., & Campione, J. C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons Integrating cognitive theory and classroom practice* (pp. 229–270). MIT Press.

Brown, M., Dehoney, J., & Millichap, N. (2015). *The Next Generation Digital Learning Environment*. EDUCAUSE.

Chen, B. (2019). Designing for networked collaborative discourse: An unLMS approach. *TechTrends*, *63*(2), 194–201. https://doi.org/10.1007/s11528-018-0284-7

Dillenbourg, P. (2015). *Orchestration graphs*. EPFL Press.

Dillenbourg, P., & Hong, F. (2008). The mechanics of CSCL macro scripts. *International Journal of Computer-Supported Collaborative Learning*, *3*(1), 5–23. https://doi.org/10.1007/s11412-007-9033-1

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist*, *48*(1), 56–66. https://doi.org/10.1080/00461520.2012.748005

Håklev, S., Faucon, L., Hadzilacos, T., & Dillenbourg, P. (2017). *FROG: Rapid prototyping of collaborative learning scenarios*. European Conference on Technology-Enhanced Learning, Tallinn, 12-15.

Kollar, I., Fischer, F., & Slotta, J. D. (2007). Internal and external scripts in computer-supported collaborative inquiry learning. *Learning and Instruction*, *17*(6), 708–721. https://doi.org/10.1016/j.learninstruc.2007.09.021

Lui, M., & Slotta, J. D. (2014). Immersive simulations for smart classrooms: Exploring evolutionary concepts in secondary science. *Technology, Pedagogy and Education*, *23*(1), 57–80. https://doi.org/10.1080/1475939X.2013.838452

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97–115). Cambridge Univ. Press.

Scardamalia, M., & Bereiter, C. (2008). Pedagogical biases in educational technologies. *Educational Technology*, *45*(3), 3–11.

Slotta, J. D., Quintana, R. M., & Moher, T. (2018). Collective Inquiry in Communities of Learners. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International Handbook of the Learning Sciences* (1st ed., pp. 308–317). New York, NY : Routledge.

Slotta, J. D., Tissenbaum, M., & Lui, M. (2013). Orchestrating of complex inquiry: Three roles for learning analytics in a smart classroom infrastructure. *Proceedings of the Third International Conference on Learning Analytics and Knowledge - LAK ’13*, 270. https://doi.org/10.1145/2460296.2460352

Stake, R. E. (1978). The case study method in social inquiry. *Educational Researcher*, *7*(2), 5–8.

Wise, A. F., & Schwarz, B. B. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Journal of Computer-Supported Collaborative Learning*, *12*(4), 423–467.