Instructional Science (2018) 46:533–561
https://doi.org/10.1007/s11251-018-9463-3

Supporting communities of learners in the elementary classroom: the common knowledge learning environment

Cresencia Fong[1] · **James D. Slotta**[1]

Received: 19 September 2016 / Accepted: 18 June 2018 / Published online: 2 July 2018

Abstract

We report on a multi-year design study of a technology environment called Common Knowledge (CK), designed to support learning communities in K-12 classrooms. Students represent their ideas in the form of notes, add their ideas to a collective knowledge base, and use this knowledge base as a resource for their subsequent inquiries. CK supports teachers' orchestration of inquiry in blended learning environments, scaffolding the learning community as it progresses through a complex inquiry script. A community knowledge base is dynamically visualized on the classroom's interactive whiteboard, serving as a persistent visual reference that allows teachers to gauge the progress of the class, identify patterns, gaps or conflicts, and engage the students in extemporaneous or planned discussions of their ideas. We present enactments of two design iterations in which CK was integrated within broader elementary science units where the curriculum was guided by a theoretical framework called Knowledge Community and Inquiry (KCI). For each version, we analyzed the role of CK in scaffolding student inquiry, with a focus on teachers' facilitation of productive whole-class discussions. Analysis of teachers' orchestration patterns revealed a "3R" orchestration cycle (Reflect–Refocus–Release) that teachers used repeatedly within a single class session, to guide reflective community discussion and refocus students' inquiry. We also identified four distinct teacher discourse orientations, finding that these were invoked in different proportions depending on the orchestrational needs of the inquiry script. Synthesizing our findings, we discuss the role of CK within a classroom activity system for learning communities.

Keywords Orchestration · Scripting · Discourse · Collective inquiry · Collaboration · Blended learning · Technology-enhanced learning

✉ Cresencia Fong
cresencia.fong@utoronto.ca

[1] Curriculum, Teaching and Learning Department, Ontario Institute for Studies in Education (OISE), University of Toronto, 252 Bloor Street West, Toronto, ON M5S 1V6, Canada

Introduction

Responding to our VUCA (volatile, uncertain, complex and ambiguous) times, there is an ever increasing call for innovation in K-12 learning and teaching, to foster global competence—a person's capacity to examine and appreciate multiple world views of complex issues situated in local, global, and intercultural contexts; and collaboratively act for collective well-being and sustainable development (Asia Society Center for Global Education & OECD 2018; National Research Council 2012; OECD 2015, 2017; Partnership for 21st Century Skills 2011). The International Society for Technology in Education (2016) has articulated new standards for learning in an evolving technological landscape, identifying seven roles that embody global competencies and promote student-driven learning: Empowered Learner, Digital Citizen, Knowledge Constructor, Innovative Designer, Computational Thinker, Creative Communicator, Global Collaborator. To achieve these goals, learning scientists have proposed an approach in which classrooms are re-conceived as learning communities where students collaboratively co-construct knowledge, contribute to collective goals, and determine their own learning trajectories (Palincsar and Brown 1984; Scardamalia and Bereiter 1996; Brown and Campione 1996; Bielaczyc and Collins 1999; Slotta and Najafi 2010). Students within such a community adopt new epistemological perspectives, taking initiative to build on the ideas of peers and advance knowledge within the community (Bielaczyc and Collins 2006; De Jong 2006). Scardamalia and Bereiter (2006) have argued for the need "to enculturate youth into this knowledge-creating civilization and to help them find a place in it" (p. 97).

Some researchers have explored the role of social media (e.g., wikis, blogs, podcasting, social networks) in supporting collective forms of inquiry where knowledge is co-constructed by groups of learners, serving as both a product of and a resource for inquiry (Hod et al. 2018; Lee et al. 2008; Peters and Slotta 2010; Cress and Kimmerle 2013; Forte 2015). Such projects have shown that collective inquiry can engage students and teachers in dynamic, social forms of learning where students feel that their work is contributing to the progress of their peer community. A primary role of the teacher in such an approach is to enable pathways for learners to articulate their own ideas and advance those of the wider community (Jenkins 2009; Slotta 2010).

The process of engaging a classroom as a learning community relies heavily on guided oral discourse, where the teacher must respond to student ideas as they emerge, and guide individual learners and the class as a whole, along productive paths of inquiry (Slotta and Najafi 2010). This presents an ongoing challenge for teachers to decide when to intervene, how to identify relevant ideas and connect those ideas to productive classroom discussions—all while allowing learners to retain a sense of autonomy.

This paper reports on research of a technology environment called Common Knowledge (CK), that was designed to support learning communities by enabling student contributions of inquiry notes to a collective knowledge base, which supports teacher-guided discourse and scaffolds the orchestration of inquiry sequences. Working closely with teachers who were experienced with knowledge building pedagogy, we investigated a sequence of CK designs, each of which was integrated into a 9-week inquiry curriculum for two grade 5–6 learning communities. Our subsequent design iterations aimed to better accommodate those patterns, gradually increasing the complexity of our curricular and technological environments. In our earliest versions of CK (including the first iteration presented in this paper), we examined a basic set of technological functions that allowed students to construct notes and synthesize their ideas in whole-class discussions. In later versions (including iteration two, presented in this paper) we include orchestration supports for more complex scripts, in which the community is guided through distinct phases of inquiry. Overall, the aim of this study was to elucidate what patterns of teacher orchestration and teacher-guided inquiry discourse occurred throughout enactments of these iterations.

Literature review

Knowledge community and inquiry

In attempting to bridge the complementary perspectives of Knowledge Building (Scardamalia 2002) and Fostering a Community of Learners (Brown 1994, 1997), Slotta and his colleagues (2010) have advanced a pedagogical model known as Knowledge Community and Inquiry (KCI—Slotta 2013; Slotta et al. 2013; Slotta and Najafi 2012). KCI places a strong emphasis on collective epistemology (i.e. community identity and orientation) and knowledge construction, but also emphasizes a carefully designed sequence of student activities, including structured collaboration scripts for distributing expertise (i.e., jigsaw designs), teacher-led benchmark lessons at pivotal points in the inquiry, and collaborative inquiry projects. Hence KCI adds a layer of collective inquiry and knowledge building to a scripted inquiry approach (Fischer et al. 2013; Raes et al. 2012). KCI curriculum typically spans multiple weeks or months, during which time learners are guided to identify and work as a learning community, traversing between individual, small group, and community "planes of learning" (Stahl 2012, p. 467). Students collaborate in a technology-enhanced learning environment to build a collective knowledge base that becomes a resource for subsequent inquiry activities, often incorporating a jigsaw approach to grouping and re-grouping students (Aronson 1978; Brown and Campione 1996). Another requirement of the KCI model is that the outcomes or artifacts of inquiry activities (e.g., student designs or project reports) must provide evidence of learning that is explicitly linked to targeted learning goals.

KCI curriculum and learning environments are developed through a sustained process of co-design (Roschelle and Penuel 2006) amongst researchers, teachers, and technologists. This results in a detailed pedagogical script that specifies curricular inquiry progression, in which students may be placed in certain groups or assigned certain materials or activity conditions depending on emergent student contributions (i.e. in response to real-time events), or mediated by teachers' spontaneous decisions. A persistent challenge in KCI designs is how to "create a sense of autonomy, creativity and inquiry, without 'overscripting'" (Slotta, quoted in Fischer et al. 2013, p. 570). For this reason, KCI activities and sequences are only partially specified, with some of the details (e.g., which groups, or the specifics of their activities) dependent on the nature of student-contributed ideas that emerge during the course of inquiry (Slotta 2013).

Four principles guide the design of KCI curriculum, which offer a theoretical and methodological foundation for the present research (Slotta 2013; Acosta and Slotta 2013; Slotta et al. 2013):

1. Students work collectively as a learning community to produce a knowledge base that is indexed to learning goals and pedagogical variables.
2. The knowledge base is accessible for editing and improvement by all members, and serves as a primary resource for ongoing inquiry.

3. Collaborative inquiry activities are designed that ensure the coverage of targeted science learning goals, including assessable outcomes.
4. The teacher plays a critical role defined within the inquiry script, but also a general orchestration role, scaffolded by the technology environment.

Scripting and orchestration

Prior research has shown that learners benefit from structured and scaffolded inquiry activities (Weinberger et al. 2010; Linn et al. 2004; Songer and Linn 1991). The structuring of inquiry designs to include sequences, roles, goals, allocation of materials, and the coordination of student grouping and learning activities, has been referred to as a "script" (Dillenbourg and Jermann 2007; Kollar et al. 2007; Kolodner 2007). The Script Theory of Guidance (Fischer et al. 2013) differentiates between *internal collaboration scripts*—participants' knowledge of how to collaborate in technology-enhanced settings, and *external collaboration scripts*—representations that may guide participants' application of internal collaboration scripts. Scripts vary in their degree of specificity, and many scholars have noted the potential negative impact of "overscripting" (Dillenbourg 2002) where activities and interactions of students and teachers are over-specified, challenging participants to stay on script, and reducing their level of autonomy. In a learning community script, the teacher plays a critical role, cultivating a collaborative learning environment, coordinating activities and resources, and fostering productive interactions amongst students.

In KCI curricula, students engage in scripted inquiry activities individually or in groups that may be pre-defined, identified by the teacher in response to student-generated ideas, or self-selected—arising spontaneously from students' inquiry (Cober et al. 2013). The enactment of any inquiry script requires the "orchestration" of student interactions, activities, resources, technology, and time. Dillenbourg defines orchestration as "how a teacher manages, in real time, multi-layered activities in a multi-constraints context" (2013, p. 485). One objective for our design of CK was to help reduce what Dillenbourg (2013, p. 491) has called "orchestration load"—enabling the teacher to manage a complex inquiry script involving multiple student groupings, various forms of material and activity, and the need to monitor and help advance the ideas within the community. We are interested in how to represent the dynamic knowledge of individuals and the community as a whole, and how to make this knowledge accessible as a resource for discourse and inquiry, in order to facilitate further development of this knowledge (Slotta et al. 2013).

Inquiry discourse in learning communities

KCI gives rise to opportunities for inquiry discourse through its use of persistent, emergent representations of individual and community knowledge, often dynamically aggregated on large digital classroom displays (Slotta 2013). Common Knowledge (CK) was developed in recognition that teacher-facilitated discourse is essential to helping students access and make use of this knowledge to advance their inquiry.

Prior research of inquiry discourse has focused on the social process of meaning construction (Vygotsky 1962), including argumentation (Schwarz et al. 2004; Kuhn 1993), theory-building (Bereiter and Scardamalia 2012), or explanation building (Sandoval and Reiser 2004). Communication is an integral element of any learning community, supporting collaborative meaning-making, resolution of gaps or conflicts, and the generation of insights about next steps for inquiry (Sfard 2007). Wertsch and Smolka (1994) assert that thinking and learning within any learning community is mediated largely by language, and many researchers have studied the role of discourse in classrooms. Reciprocal Teaching (Palinscar and Brown 1984) was conceived as a transitional discourse structure to help students progress from teacher-mediated dialogue to independent small group discussion, with a gradual fading of teacher direction and structure. In Collaborative Reasoning (Anderson et al. 1997), the teacher moderates discussions amongst a group of children who publicly take positions on an issue and provide evidence to support their claims. Chinn et al. (2000) observed that in Collaborative Reasoning, children introduce argumentation stratagems within their group discourse, which are subsequently adopted by their peers. Bereiter and Scardamalia (2008) define five levels of classroom dialogue, along a continuum of *structure* (i.e. from recitation to problem-solving discourse) and *teacher directedness* (i.e. from teacher-directed to peer-mediated).

Mehan (1979) studied teacher–student interactions and identified a common sequence: a teacher's initiating speech act, followed by a student's response statement, and closing with the teacher's evaluative statement of the student's response; known as IRE (initiation, reply, evaluate) or IRF (initiation, reply, follow-up). More recently, this pattern has been referred to as Triadic Dialogue (Lemke 1990). Nassaji and Wells (2000) demonstrated that the teacher's choice of initiating discussions and follow-up questions influences the efficacy of triadic dialogue as a means of knowledge co-construction. They observed discourse in inquiry-oriented classrooms of nine elementary teachers over 6 years, and noticed that, of the three types of initiating questions teachers asked, the most substantive student responses resulted from teachers' initiating questions that elicited negotiation, debate, or multiple perspectives. Of the six observed follow-up moves, teacher requests for justification, connections, or counter-arguments yielded the richest student responses.

O'Connor and Michaels' (1996) analysis of "revoicing"—the oral or written rephrasing of a student's contribution by another participant (often the teacher)—reveals how teachers orchestrate group lessons, using language to socialize learners into intellectual practices. They found that teacher revoicing of student comments can advance discussion by (1) using student contributions to introduce new ideas or terminology, (2) reframing student contributions to steer the discussion toward a productive direction, (3) positioning a student in relation to the argument by attributing his or her comment to a stance, or (4) creating alignments and oppositions within an argument—thereby positioning students in relation to their peers. Revoicing thus offers a means for teachers to orchestrate classroom discourse and foster idea growth, reinforcing collective epistemology and guiding inquiry progression.

CK was developed to support teacher orchestration of KCI, with an emphasis on classroom discussions that serve to further the learning community's inquiry. We will present two iterations of CK design, which we discuss in terms of technology, inquiry, and discourse. Our goal is to understand the tensions between technology features, the activity scripts in which they are situated, and the forms of discourse and interaction that emerge during enactment. Thus, we examine what forms of teacher orchestration emerge from the particular configuration of technological features and activity script in each iteration, including the specific patterns of teacher discourse. Specifically, we focus on this research question: *How do teachers orchestrate a KCI script, leveraging CK; to achieve the desired progression of activities, maintain a collective epistemology, as well as help students access and work with their learning community's ideas?*

Method

Research context and approach

This study is part of a larger funded research project called Embedded Phenomena and Inquiry Communities (EPIC—see Moher and Slotta 2012) conducted by researchers and technologists from the Ontario Institute for Studies in Education of the University of Toronto and the University of Illinois at Chicago, and within a long-term research-practice partnership (RPP—Coburn and Penuel 2016) with the Dr. Eric Jackman Institute of Child Study Lab School in Toronto, Canada. The goal of EPIC is to investigate "Embedded Phenomena" (EP—Moher 2006), which are room-sized digital and physical simulations embedded (i.e., via computer displays, audio amplifiers, etc.) in the walls, floor, or furniture of the classroom environment. Elementary students collectively investigate these EP in their classrooms over a time span of several weeks or months to advance their understanding of the underlying scientific concepts. EP have been developed for immersive classroom learning experiences focused on biodiversity, planetary orbits, and aquifer hydrodynamics. The EPIC project was funded to investigate a learning community approach to support student and teacher inquiry in EP environments. Throughout each year of EPIC research, CK has been iteratively developed as one component of the broader technology environment and curriculum design, playing a distinct role as a note-sharing and classroom discourse system.

Design-based research (DBR—Collins et al. 2004) is an empirical method for iteratively designing and investigating learning innovations in authentic classroom contexts, to understand how, when, and why they work in practice, with an eye toward the improvement of theory and practice (Wang and Hannafin 2005; Bell 2004; Collins et al. 2004). Iterative cycles of design, enactment, analysis, and redesign enable researchers to systematically refine the innovation and produce extensible design principles (Amiel and Reeves 2008). In EPIC, all curriculum activities, materials, and technology, including CK, were developed through the process of co-design (Roschelle and Penuel 2006), in which researchers, teachers, and technologists collaborated to conceptualize and develop research and material designs, as well as enactment and review of procedures (Sanders and Stappers 2008). Our partner teachers each had a combined grade 5/6 classroom. They alternated their science focus between life science and astronomy every other year, to avoid having students engage with the same topic and activities in grade 5 and again in grade 6). Such changes in curricular focus between CK iterations were a major variable, leading to radically different inquiry scripts and sequences, and different requirements for CK. Thus, we were not able to run a historically-controlled "design experiment", where we were able to examine the effect of specific changes from one iteration to the next. Nonetheless, we argue that this work is a valid form of DBR, as (1) the design itself serves as an important product of the research—to be inspected as a source of insight into the underlying questions, and (2) the outcome of one iteration served as the primary source of evidence that informed the subsequent iteration (Design-Based Research Collective 2003).

Recall our main research question: How do teachers orchestrate a KCI script, leveraging CK; to achieve the desired progression of activities, maintain a collective epistemology, as well as help students access and work with their learning community's ideas? To investigate this question, we deconstructed it into three operational research sub-questions that articulate components to be measured:

1. How do teachers pace teacher-guided and student-driven inquiry activity within a KCI script, leveraging CK?
2. What orchestration patterns do teachers use to coordinate teacher-guided and student-driven inquiry activity within a KCI script, leveraging CK?
3. What patterns of teacher discourse orientation occur, and how do these vary with activity structures and CK technology design?

We use the term "teacher discourse orientation" to collectively refer to the *social participation structure* (Erickson 1982) and the revoicing (O'Connor and Michaels 1993, 1996) stance adopted by teachers to foster that participation structure. For each iteration of the curriculum, we conducted three analyses. First, a *design analysis* was conducted in advance of any classroom enactment, to examine the technology features, inquiry script, and anticipated patterns of discourse in terms of their fit to the KCI principles (i.e., to determine if our designs achieved the KCI model). Second, an *enactment analysis* captured data about how students and teachers actually engaged with our designed materials during their inquiry (i.e., to determine whether the design was faithfully enacted). Data included students' note contributions, video-recordings of classroom activities, as well as student and teacher interviews. Finally, we conducted a *discourse analysis* to evaluate the teacher's orchestration using CK, including the role of technology, peer exchanges, and teacher-guided discussions. These analyses served to evaluate CK's technological and pedagogical features, using segmented video transcripts of selected class periods (i.e., several 90-min class sessions in which CK discourse figured prominently). The outcomes enabled us to progress in our design of CK by understanding it within its curricular context, and comparing our design ideas against what actually transpired.

Participants

All versions of EPIC curriculum and technology, including CK, were co-designed with two elementary teachers—given pseudonyms Brad and Jen—and the vice-principal of the school. The school has a focus on inquiry-based learning, and all three educators have a wealth of experience with Knowledge Building pedagogy (Scardamalia and Bereiter 2006), providing them with excellent grounding in the pedagogical and epistemic commitments of the learning community approach. Furthermore, the teachers were eager to work with KCI and our design team. Their expertise in classroom discourse as a means of encouraging student consideration of peer ideas and guiding inquiry, provided a foundation for our initial designs and guided all development of CK technology. Brad had been teaching for 6 years and Jen for 3 years when we first began collaborating with them in spring 2011. In the two iterations ("CK1" and "CK2"), both teachers enacted CK with their grade 5/6 classes, with 23 students in all classrooms.

CK1 design

We investigated a learning community curriculum centred around the *WallCology* EP, in which an ecosystem of digital insects is simulated, along with their food ("mold" and "scum") that is virtually embedded inside the classroom walls. Four computer monitors, each positioned on one of the classroom walls serve as "wallscopes" into the simulation. Over a 9-week period (two 90-min sessions per week), students were tasked with collectively determining the life cycles of the various insects within the ecology, their food web relationships, and environmental preferences of each species. A mobile app was developed to guide students through six successive inquiry phases: (1) Habitats—observing habitats; (2) Organisms—observing organisms; (3) Life Cycles—capturing and determining each organism's life cycle; (4) Relationships—determining energy relationships to create the ecosystem's food web; (5) Counts—estimating organism populations; and (6) Investigation—manipulating the environment in response to habitat pressures (Moher and Slotta 2012). Within each phase, students were scaffolded by a carefully designed technology environment, which was accessed through separate tabs in the WallCology inquiry app, and contributed to aggregate representations of the community's collective data visualized on the common wall.

In each phase, common knowledge was accessible from the inquiry app as another tab, including tags that were specific to the inquiry phase at hand. Thus, CK1 was integrated into this broader suite of WallCology inquiry tools, providing a digital environment for learners to share notes and develop ideas about their collective observational data. Students could continuously access their peers' CK notes from digital tablets, as well as compose new notes, incorporating pre-programmed keyword tags related to science content and process that were specific to the inquiry phase at hand. The curriculum design included planned CK discussions, but also anticipated spontaneous uses of the growing corpus of ideas and student observations.

All student-contributed CK notes appeared dynamically on their peers' tablets as well as on the common wall (displayed on the classroom's Interactive White Board—IWB), where note headlines appeared as movable white text boxes (see Fig. 1, right). Students could add content-oriented "tags" to their note (e.g., temperature, light, organism). Content-oriented keywords changed with each phase of the inquiry script. A second set of tags allowed students to indicate the *type of note* they were contributing: questions, observations, theories, or other ideas (see Fig. 1, left, tags at bottom of screen). These process-oriented tags were intended to help students reflect on the purpose or role of their note and develop metacognitive awareness of the specific forms of inquiry in which they were engaging. At the IWB, teachers could tap the topic headline to open the note for reading, and drag notes into spontaneously identified topic clusters. Tags appeared in a "Keyword" button panel along the right side of the IWB, enabling teachers to filter notes (i.e., display notes associated with the selected tags) as they facilitated topic-focused discussions.

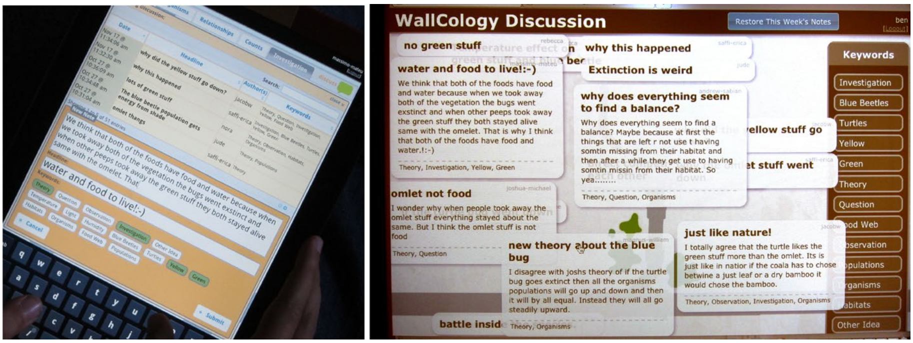


Fig. 1 Left: CK1 tablet interface. Right: CK1 Common Wall IWB interface, no tag filters currently selected

CK2 design

Whereas CK1 was developed as an embedded support for a progression of inquiry around the WallCology EP, CK2 was a standalone application (i.e. not embedded as a component of a larger inquiry app) that served to guide a learning community's inquiry progression through three distinct inquiry phases: *Brainstorm*, *Propose*, and *Investigate* (see Table 1). Early in our design sessions, the teachers articulated three "big ideas"—key principles underpinning the curriculum learning objectives: gravity, scale, and nested systems. Throughout 7 weeks of enactment (two 90-min sessions per week), teachers kept these big ideas in mind, as they used CK2 to scaffold their student learning communities through brainstorming topics of inquiry, proposing various ways to explore those topics, and then investigating their proposals.

The CK2 common wall—displayed on the classroom IWB—was designed to provide teachers and students with new levels of orchestration support. To capture the community's progress in each inquiry phase, the common wall represented the community's notes, tags, and votes. The common wall also included buttons that teachers used to advance from one phase of inquiry to a new phase in the inquiry script—universally changing the technology state on all CK devices. Also, a "Pause" button was added, allowing teachers to instantaneously capture student attention by freezing all CK tablets, for purposes of short whole-class discussions. Another new feature was the addition of four "Topic Boards" during the *Investigate* phase—mini common walls, which supported smaller special interest groups. Table 1 summarizes inquiry and technology script for the first 7 weeks. The final 2 weeks of the 9-week curriculum unit were allocated for student creation and presentation of culminating multimedia artefacts to share their learning.

Table 1 CK2 inquiry and technology script: phases of inquiry, collaboration groupings, and digital display formats

	Phase 1: Brainstorm Weeks 1-3	Phase 2: Propose Week 4	Phase 3: Investigate Weeks 5-7
Inquiry Activity	Explore "hook" activities Cluster Brainstorm notes Negotiate tags, then bucket tag Read peer Brainstorm notes Compose, refine, self-tag, contribute Brainstorm notes	Tags become topics; choose a topic of interest and read all associated Brainstorm notes Gather with peers of a similar topic interest; collaboratively develop Proposal notes based on Brainstorm notes Vote on Proposals	Gather with peers of a similar topic interest; choose a Proposal to investigate Test ideas, theories, hypotheses Report findings Knowledge Walk Vote on Reports
Collaboration Groupings (Social Planes)	Work individually, in dyads, or in small groups (Personal choice) Whole-group community discourse	Work individually, in dyads, or in small groups (Personal choice) Whole-group community discourse	Work in any of 4 topic interest groups (Personal choice, fluid movement between groups) Whole-group community discourse
Digital Display Formats (To support social planes)	Personal tablet Common Wall on classroom IWB	Personal tablet Common Wall on classroom IWB	Personal tablet 1 Topic Board per interest group Common Wall on classroom IWB

CK2 pase 1: brainstorm

The *Brainstorm* phase began by engaging students in the exploration of digital simulations, the creation of models using tangible materials, and the exploration of reference materials in print and digital media. These introductory "hook" activities triggered ideas and questions, which students shared via their tablets, as brainstorm notes. The notes appeared on the Common Wall (displayed on the classroom's IWB) as moveable white note icons that could be clustered and could also be read and built upon (i.e. adding a comment or extension to a peer's note) from students' tablets. Red dots visible in the top-left corner of note icons indicated the number of "build-ons" in that note's thread. A red vertical line on the left side of a note identified it as a build-on to the parent note above it. A word cloud representation was accessible from the Common Wall, providing formative assessment data as a visualization of trending content emerging from the community's brainstorm.

Partway through the Brainstorm phase, at a time chosen by the teacher, the brainstorm was paused, allowing the learning community time to read all the notes in their collective knowledge base. The teacher then facilitated a whole-class discussion, where students clustered the notes according to common themes that were recognized. Figure 2 shows the different clusters from each class, written on the IWB with digital ink. Based on these initial cluster themes, the teachers helped students decide on four distinct categories, merging related themes as appropriate.

Once the tags were agreed upon, they were input into CK2 by the teacher via the "Add Tag" button at the lower-left corner of the Common Wall. This precipitated a round of Bucket Tagging—a note distribution process where each note in the knowledge base is randomly distributed to students' tablets to be tagged (i.e., as if pulled from a bucket). This approach allowed all learning community members to work in parallel and at their own pace, resulting in all notes getting tagged with high efficiency (i.e. minutes). As the community tagged notes, they were visualized on the common wall with connection lines to their corresponding tag nodes (Fig. 3, top). Tag nodes also functioned as note filters to reduce visual clutter and focus on notes about one particular topic.

After all notes had been distributed and tagged (i.e. the "bucket" was emptied), students were able to contribute new Brainstorm notes, with the added feature of being able to tag their notes (Fig. 3, bottom). The left panel provided an index of the community's CK notes. Yellow items indicated the note was one the student user had authored. Pink items indicated the note currently being displayed in the centre reading panel. Students could also

Fig. 2 Social negotiation of tags. Left: Brad's class common wall. Right: Jen's class common wall

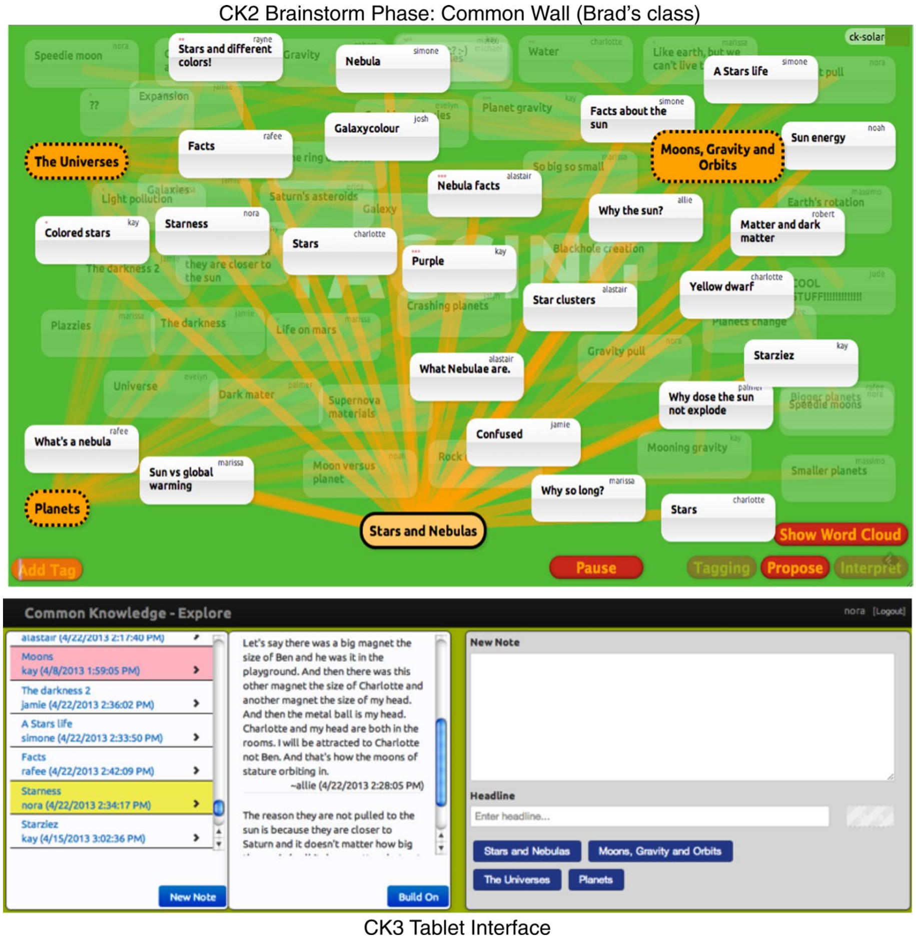


Fig. 3 *Top:* After bucket-tagging, all Brainstorm notes are visually organized by their associated tags. Brad's class Common Wall is currently filtering for the "Stars and Nebulas" tag. *Bottom:* CK2 Tablet interface in Phase 1 "Brainstorm" state

build-on any note from the centre reading panel, and they could compose a new note in the right panel with a required headline and at least one tag.

CK2 phase 2: propose

In this phase, CK2 supported the learning community in proposal development to address initial brainstorm ideas and collectively identify the most "promising" (Chen et al. 2012) proposals. Teachers initiated the *Propose* phase by tapping the "Propose" button on the Common Wall (see Fig. 3, top). This sent the CK2 environment into the *Propose* state, where brainstorm notes were no longer visible on the common wall, and the tag nodes—now elevated to "topic" status, appeared in distinct colors. Teachers decided when to initiate this phase transition, based on their judgment about whether the brainstorming had run

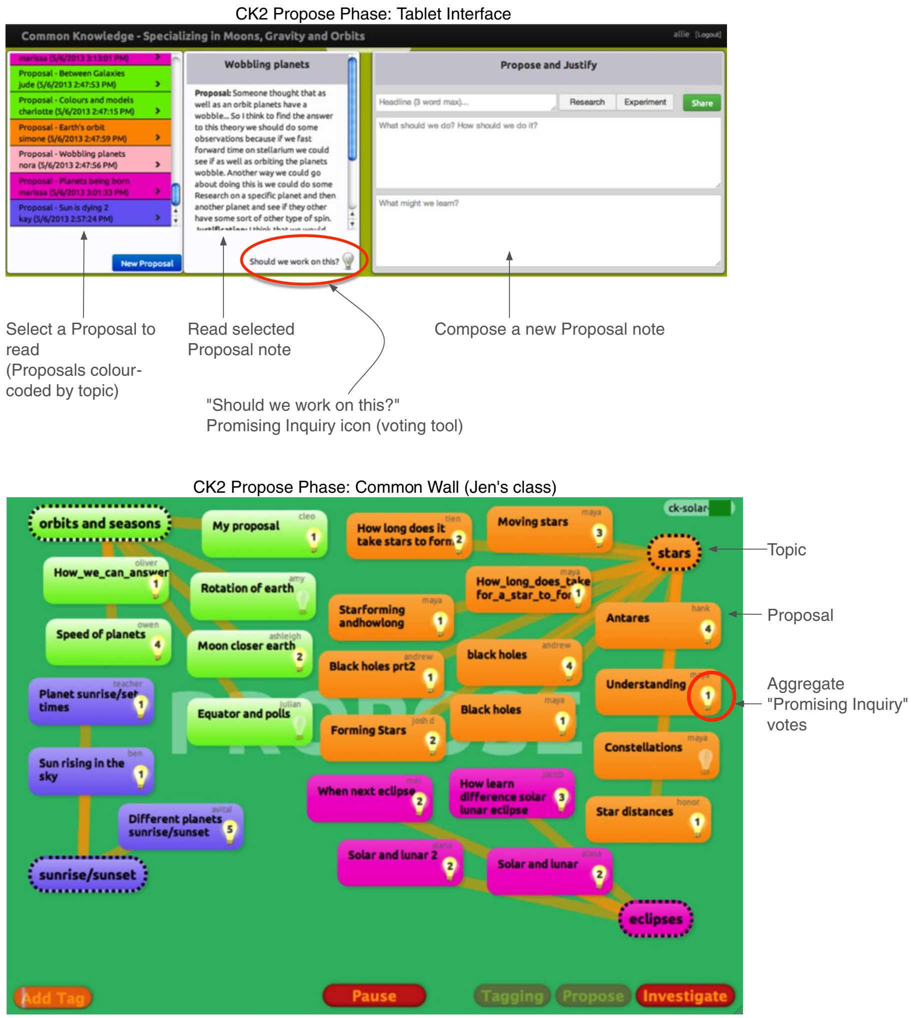


Fig. 4 *Top:* CK2 tablet interface in Phase 2 "Propose" state. *Bottom:* CK2 Common Wall IWB interface in Phase 2 "Propose" state

its course, with sufficient ideas for the learning community to proceed with proposal development. Students chose to sit at one of four topic interest tables, where they could use their tablets to read Brainstorm notes corresponding to that topic, and discuss these with group mates to develop research proposals stemming from their syntheses of multiple Brainstorm notes. Proposal notes consisted of a basic idea for further inquiry, and a justification for the proposed inquiry (Fig. 4, top).

When submitted, a new Proposal note would appear on all tablets and on the Common Wall IWB, color-coded by its corresponding topic color, and connected by a line to the relevant tag node (Fig. 4, bottom). When reading a Proposal, if a student thought it would help advance the community's knowledge, s/he could indicate this by tapping the "Promising Inquiry" icon (a light bulb—see Fig. 4, top) to cast their vote. On the Common Wall, each Proposal appeared as a thumbnail, including a light bulb icon with a number inside showing the total of all votes for that Proposal (Fig. 4, bottom). Thus CK2 offered the learning community a dynamic visualization of its collective inquiry trajectories and their aggregate “promisingness judgments” (Chen 2016).

CK2 phase 3: investigate

Once they had concluded the learning community had developed a sufficient number of Proposal notes to motivate student inquiry, teachers initiated a transition into the *Investigate* phase by tapping the “Investigate” button on the Common Wall. Throughout the *Investigate* phase, students drove their own investigations of Proposal notes in the collective knowledge base, and could also add new Proposal notes (Fig. 4, top), if new trajectories emerged. CK2 offered two note types with which students could document their investigations: Inquiry notes and Experiment notes. Two questions scaffolded an Inquiry note: *“What new information have you observed, measured, or read about?”* and *“What resource(s) did you use to learn this?”* Five questions scaffolded an Experiment note: (1) *“Question—What question are you investigating?”*, (2) *“Hypothesis—Make an educated guess about how this works!”*, (3) *“Method—How will you test your hypothesis?”*, (4) *“Results—Share all your observations and/or measurements from your experiment!”*, and (5) *“Conclusions—Analyze your observations and/or measurements to see if your hypothesis is true or false!”*. Students grouped themselves according to their topic of interest, and could spontaneously form new groups as their research interests evolved. Brainstorm notes were no longer accessible from the tablets nor the IWB during the *Investigate* phase. This was another intentional productive constraint, to focus the learning community’s attention on their proposed investigations.

At this point, each interest group received its own large computer monitor displaying a Topic Board (Fig. 5). The display had a similar interface to the main common wall IWB, without the teacher’s orchestrational tools (e.g., phase transition buttons, Pause button). The topic of each Topic Board was displayed prominently, with a distinct background color.

The CK2 Topic Boards spatially distributed the different topics around the classroom, displaying each interest group’s ideas and activities as their investigation notes grew around the Proposals. Such interest-based co-location enabled students with common inquiry interests to dialogue about their work and offered opportunities for collaboration on investigations—thus leveraging the physical classroom space as an additional dimension of scripting and orchestration (Hod 2017; Fong et al. 2015b). At the front of the classroom, the common wall synthesized content from all four Topic Boards, color-coded by topic (Fig. 6). Topic nodes, outlined in black, also served as note filters, allowing selective display of notes associated with any selected topic node(s).

Data collection and analyses

To address our first and second operational research sub-questions about the orchestrational supports provided by CK, we examined the pacing and coordination patterns of activity in the classroom, connected with the use of CK. To address our third operational research sub-question, concerned with the discourse orientation patterns that occurred when CK was in use, we examined the revoicing (O’Connor and Michaels 1993, 1996) stances teachers adopted to foster various social participation structures (Erickson 1982)

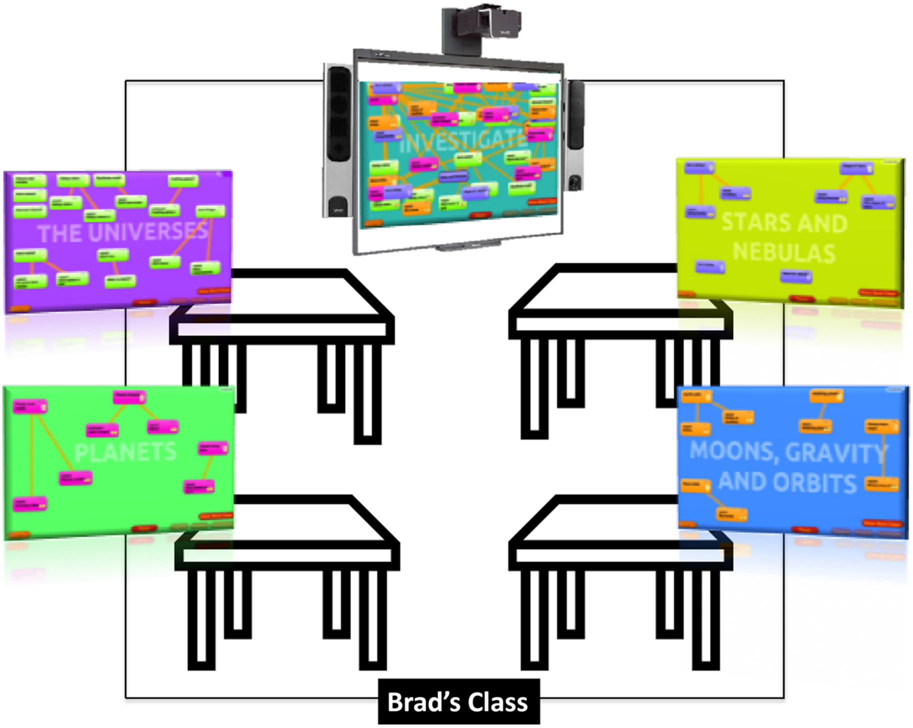


Fig. 5 Spatial distribution of topic boards and the common wall IWB during the investigate phase of inquiry

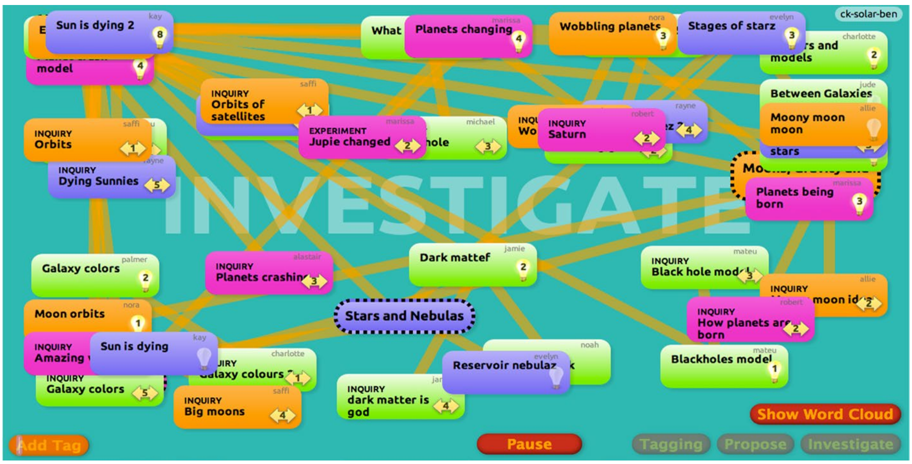


Fig. 6 Common Wall IWB during the Investigate phase (Brad's class); all topic nodes currently selected

as they facilitated inquiry discourse. Since the outcomes enabled by the various CK design features can be better understood by comparing the two versions, we will present them side-by-side.

Activity orchestration: pacing and coordination

In CK pilot tests, teachers were observed demonstrating an orchestration pattern described as "Reflect-and-Release"—in which the teacher intermittently intervenes in students' autonomous note-writing to engage them in whole-class discussion and re-direct their subsequent inquiry activities (Fong et al. 2012). From this pattern, we identify two distinct modes of interaction: teacher-guided community discourse (TG) and student-driven inquiry activity involving CK use (SD). TG events were coded for any teacher-guided whole-class discussion about the inquiry activity, involving the teacher and at least one student speaker and lasting for at least 1 min. To examine the pacing and coordination of the community's inquiry activity, analyses were conducted to determine the temporal relationship between activity (TG and SD) and note contribution within the learning community.

Discourse orientations

Further coding of classroom video of TG events revealed teachers' discourse orientations—the different revoicing stances by which they fostered various student participation structures during inquiry discourse. Two consecutive class sessions were selected as "focus sessions" for CK1 analysis; from the sixth and seventh weeks for Brad, and the seventh and eigth weeks for Jen. For CK2 enactments, three focus sessions—one for each inquiry phase—were chosen for coding of CK discourse opportunities and note contributions within a session. For the CK2 coding, we also tried to select class sessions that included the inquiry phase transition (i.e., the session in which teachers pressed the "Propose" or "Investigate" buttons). To this end, some sessions were concatenations of the end of one class period with the start of the next day's class period, which combined to provide rich windows for coding, ranging in length from 60 to 130 min. Grounded coding of teachers' discourse orientations during TG events enabled us to gain understanding of the orchestration cycle by which they guided a learning community's collective inquiry toward curriculum learning objectives. This also allowed us to characterize how teachers socially positioned their utterances in relation to the community—such as by asking a direct question to a particular student, or an open question for the whole class, or in making a declarative statement not intended for any response.

Findings

Activity orchestration: pacing

To gain an understanding of the orchestration patterns involved in the pacing of TG and SD activity, video footage of every classroom session in which Brad and Jen used CK1 and CK2 were reviewed and coded for instances of TG and SD (see Table 2).

In both teachers' orchestration with CK1, students spent less time in student-driven (SD) than in teacher-guided (TG) activities—a pattern that is notably reversed in their CK2 enactments, where student-driven activity was favored (see Fig. 7). While there were

Table 2 Teachers' cumulative orchestration time spent on CK activity, across CK1 and CK2 enactments

	Total Classroom Enactment Time (Min)	Total CK Activity (Min)	Teacher-Guided (TG) Inquiry Discourse (Min)	Student-Driven (SD) Inquiry Activity (Min)
Brad's CK1 Orchestration	1620.0	457.1	290.6	166.6
Jen's CK1 Orchestration	1620.0	559.9	467.2	92.7
Brad's CK2 Orchestration	1110.0	558.7	263.3	295.4
Jen's CK2 Orchestration	1080.0	597.8	205.7	392.1

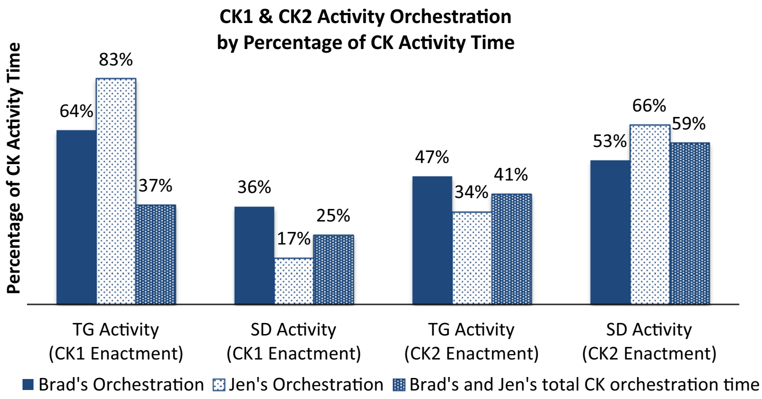


Fig. 7 A comparison of teachers' orchestrated time on teacher guided community discourse (TG) and student-driven inquiry in the CK environment (SD) throughout CK1 and CK2 enactments. SD is notably higher in CK2 enactments; particularly for Jen. Percentages were calculated from total CK activity times (Table 2)

some differences between the two teachers, in terms of their allocation of time for teacher-guided versus student-driven CK activity, these were not statistically significant. Two-factor repeated ANOVA measures compared teachers' orchestration time allocation (TG vs. SD) across the two iterations, yielding $F(1,3)=2.354$, $p=0.137$, partial eta squared = 8.3%. Although the *p*-value did not meet statistical significance, we have a partial eta squared of 8.3%, demonstrating a small effect between CK iteration and CK activity. In other words, distinct levels of TG and SD activity involving CK use, are associated with the two different iterations. It is not surprising that such characteristic patterns would emerge, reflecting differences in the underlying curriculum designs; in that CK1 was used as a supportive environment whereas CK2 was used to guide the inquiry progression.

This notable change in allocation of time given to student-driven activity reflects a behavioral shift in classroom discourse, associated with the activity script and features of the CK technology. In other words, it appears the differences in curriculum and technology between CK1 and CK2 made the teachers feel less of a need to intervene in community discussions, in favor of autonomous student work.

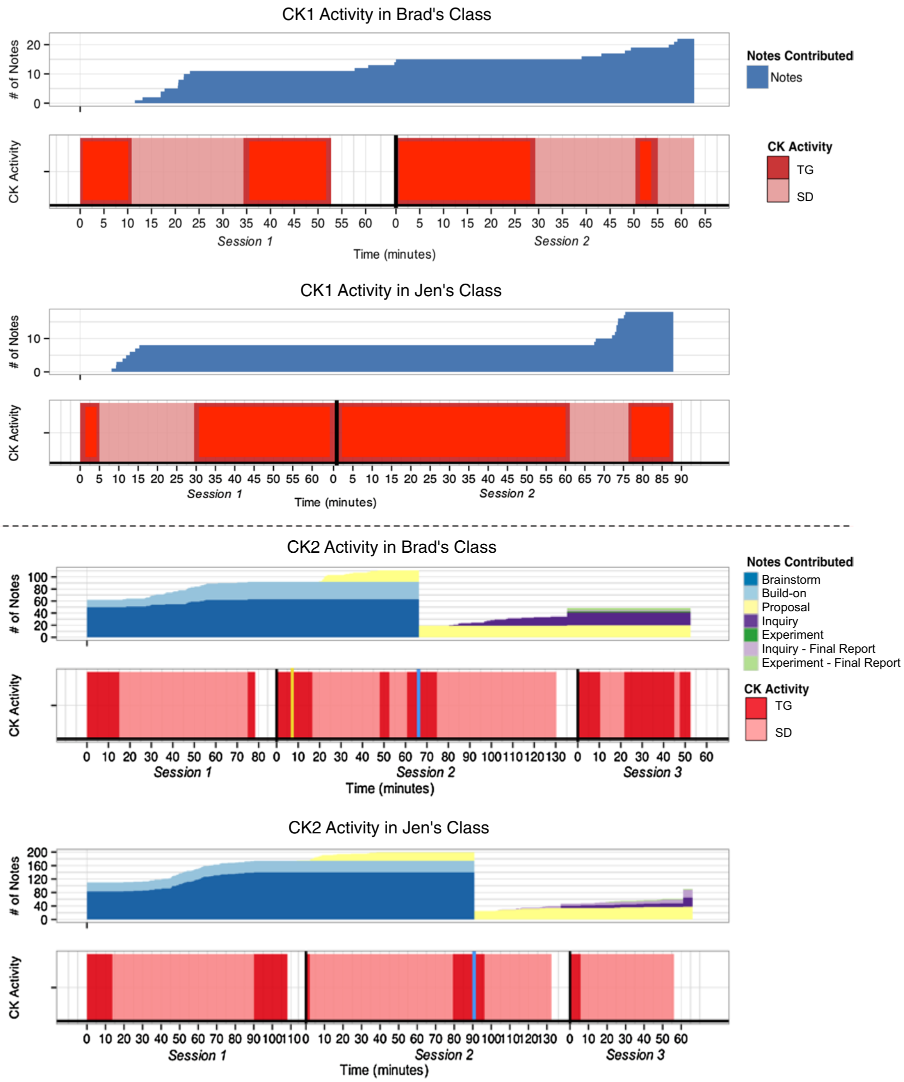


Fig. 8 Enactment timeline for Brad's and Jen's orchestration of CK1 (top) and CK2 (bottom) activity

Activity orchestration: coordination

We further examined teachers' CK1 and CK2 focus sessions to gain an understanding of the orchestration patterns involved in coordinating TG and SD activity. In Fig. 8, the red and pink CK activity timelines illustrate the sequencing and pacing of teacher-guided *Reflection* discussions that referenced CK notes (i.e. the red TGs), and the *Release* time given to students to independently pursue their inquiry within the CK environment (i.e. the pink SDs). The black vertical lines delineate the end of one focus session and the beginning of the next focus session. Above each CK1 activity timeline, we provide another graph (in blue) of the learning community's cumulative CK note contribution activity. Comparing between the graphs shows that notes were contributed during the SD (pink) events—which makes sense, given that is when student-driven CK activity occurred.

The lower half of Fig. 8 exhibits the sequencing and pacing of the teachers' orchestration of CK2 activity during the three focus sessions. CK2 included three distinct inquiry phases, each with a different type of note that students could contribute. Hence, graphs of CK2 note contribution activity (located above each community's CK2 activity timeline) show multiple note types: blue for Brainstorms and Build-ons, yellow for Proposals, and purple and green for Investigation notes. The yellow vertical line marks when Brad initiated the Propose phase. Jen initiated the Propose phase in a session that was not included as part of our focus sessions for analysis. The blue vertical lines mark when each teacher initiated the Investigate phase. Predictably, student contribution of notes is seen again during SD periods, when teachers circulated among student groups to monitor their progress, probe their thinking, challenge any misconceptions, and respond to questions. Teachers were also observed to periodically approach the Common Wall and monitor the community's emergent ideas, occasionally dragging notes into topically meaningful clusters.

In order to analyze *how*—not just how much and when—teachers guide student inquiry toward curriculum learning objectives, we looked more closely at the *Reflect* phase of the Reflect-Release orchestration sequence. Specifically, we coded the discourse orientations adopted by teachers during their facilitation of community discourse events.

Teacher discourse orientations

Teacher-guided (TG) community discourse events were examined in terms of evident social participation structures, revealing four discourse orientations (see Table 3). These orientations often occurred within the same TD event, with teachers moving fluidly between them for rhetorical purposes. 20% of teachers' video-recorded discourse moves were independently coded for these discourse orientations by a second rater and the primary researcher. Inter-rater agreement for CK1 data was 80.0% and Cohen's Kappa = 0.72. Inter-rater agreement for CK2 data was 94%, and Cohen's Kappa = 0.91.

Since Brad and Jen had similar discourse orientation patterns to each other in all CK enactments, we collapsed the discourse orientation measures across both teachers, and

Table 3 Teachers' discourse orientations

Orientation	Definition
Teacher Reflection (TR)	Teacher thinks aloud as s/he reflects upon the community's ideas, or comments about the community's inquiry strategies. Includes teacher validation of student input.
Individual Student Reflection (IR)	Teacher invites a specific student or working group to reflect on an inquiry question.
Community Reflection (CR)	Teacher invites the classroom learning community to reflect on an inquiry question.
Community Instruction (CI)	Teacher gives direct instruction to the classroom community, about what to do next, or what materials are needed. Includes delivery of a benchmark lesson, technology instruction, and recall of prior class experiences.

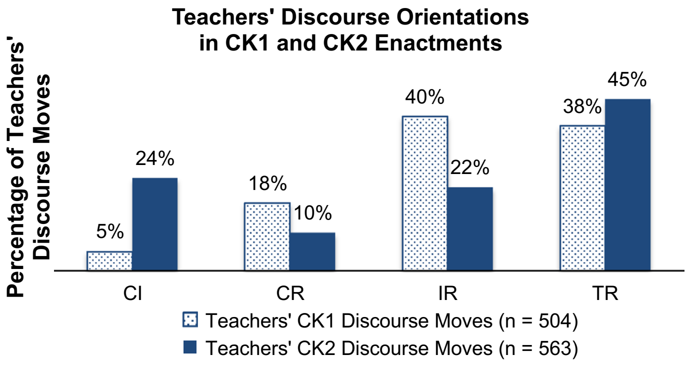


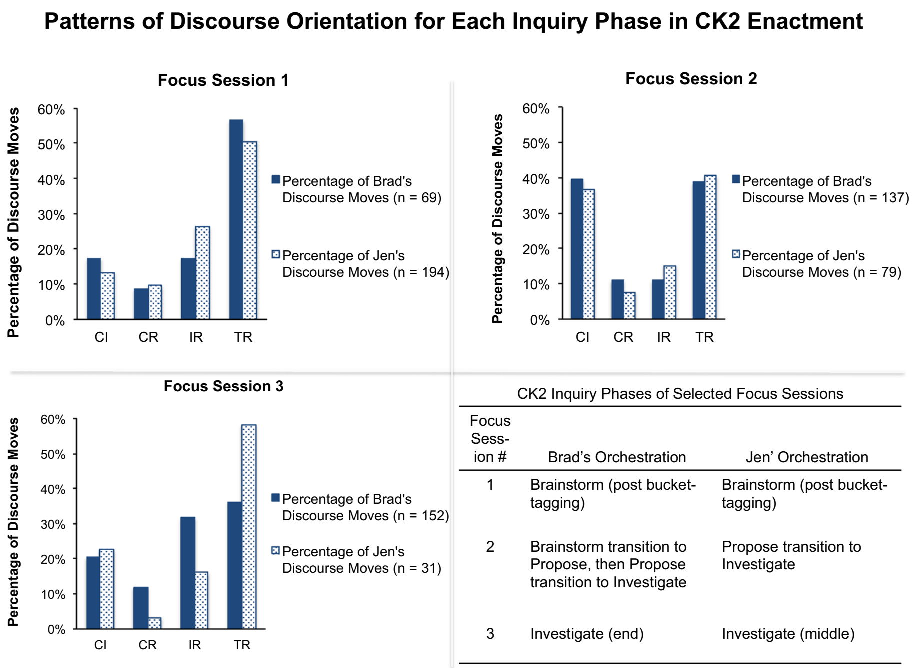
Fig. 9 A comparison of teachers' discourse orientations during Teacher Directed (TG) discourse episodes, as a percentage of teachers' total discourse moves, in both CK1 and CK2 enactment focus sessions. See Table 3 for discourse orientation definitions

compared the overall percentages occurring in CK1 and CK2 enactments (Fig. 9). There were interesting differences between the two enactments, corresponding to the noted differences in student-directed activity (Fig. 7). Thus, this finding reveals that teachers placed less emphasis on community reflection (CR) and individual student reflection (IR) in CK2 enactments than they had with CK1, and increased their emphasis on community instruction (CI) and teacher reflection (TR). We interpret this as reflecting the changing task demands between the CK1 and CK2 the activity system, resulting in distinct orchestration and discourse profiles for the two enactments' iterations.

In the CK2 enactment, teachers' discourse orientations also shifted in distinct patterns across the three inquiry phases, reflecting the distinct aspects and orchestrational demands of the inquiry activities in each phase (see Fig. 10). The teachers both exhibited the same pattern, in support of this interpretation, and were remarkably similar in their patterns except for phase 3 (Investigate), where Brad made five times the number of discourse moves as Jen, and we nevertheless see that Jen placed much greater emphasis on TR than Brad. Given Brad's 5-fold occurrence of discourse moves in phase 3, the frequency differences in his usage of the four discourse orientations would have felt more pronounced than Jen's differences in the same phase.

The characteristic patterns of discourse orientation between CK1 and CK2, and across the three phases of CK2 are reminiscent of Polman's (2004) notion of "dialogic activity structures", albeit on a coarser level of granularity. A closer examination of teachers' discourse orientations in CK1 and CK2 enactments during the Reflect phases of the orchestration sequence, also revealed that the *reflective* community discussions culminated in teacher-issued instructions or guidance to *refocus* the learning community's subsequent inquiry tasks or goals, just prior to their *release* into autonomous inquiry pursuits. Hence the reflect–release orchestration sequence may be expanded to a *reflect–refocus–release* (3R) orchestration cycle (Fig. 11).

Thus, TG events immediately preceding a period of student-driven autonomous work (i.e. SD) often began with the teacher bringing the community's attention to a student-contributed note(s), and culminated with *refocusing instructions* that synthesized or responded to ideas that emerged in the discussion. When asked how they chose the initial note(s) to spur community discussion, teachers indicated they sought out notes containing ideas that most closely connected with conceptual understandings,



Focus Session #	Brad's Orchestration	Jen' Orchestration
1	Brainstorm (post bucket-tagging)	Brainstorm (post bucket-tagging)
2	Brainstorm transition to Propose, then Propose transition to Investigate	Propose transition to Investigate
3	Investigate (end)	Investigate (middle)

Fig. 10 A comparison of each teacher's discourse orientations during teacher-guided discourse events (TG) for each CK2 focus session, and a description of each teacher's activity orchestration for each focus session

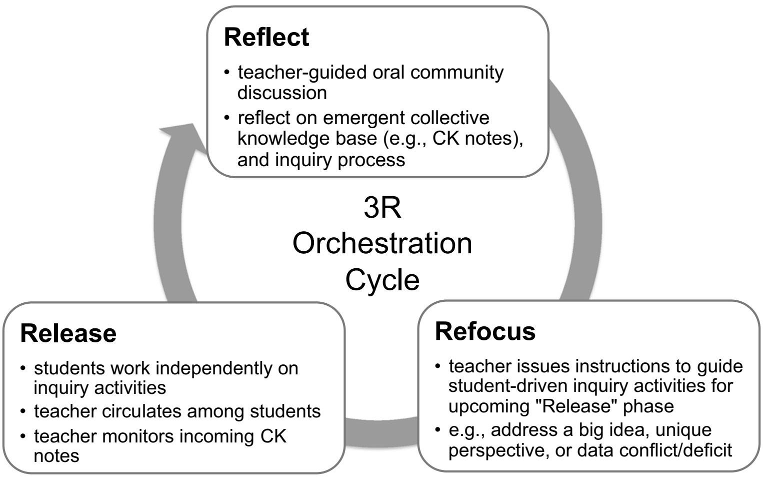


Fig. 11 The 3R orchestration cycle: Reflect–Refocus–Release

or approximating curriculum learning objectives they wished to reinforce (i.e. gravity, scale, nested systems). Table 4 provides examples of teachers' paraphrased refocusing instructions from the CK1 and CK2 focus sessions, including the number of student-contributed CK notes referenced by teachers during that discussion.

Table 4 Teachers' Refocusing instructions (paraphrased) during teacher-guided community discourse events

Teacher	# of Notes ref.	Paraphrased Refocusing Instructions
CK1 Enactment		
Brad	8	Choose one of the four big topics to work in, and you have a choice about how you want to work. For example—write a CK note, run an investigation, do a population count, use any WallCology tool….
Jen	4	We'll need to decide what to do next, now that there's a new species in the habitats. We know that there's competition, and that there are certain environmental conditions that will cause us to lose one of our species. We'll have to do more thinking about this to decide what we're going to do about it.
CK2 Enactment		
Brad	5	CK2 Propose Phase Choose whether you want to work on "Universes", "Planets", "Stars & Nebulas", or "Moons Gravity and Orbits". Choose a couple of notes that from that topic. Try to organize the ideas from them into one project Proposal that someone could do.
Jen	3	CK2 Investigate Phase Choose an interest group. Choose a Proposal to work on. Do some research. Read any of the following photocopied research articles (corresponding to the 4 tags). Keep the following in mind when note-taking from these articles: (1) read through twice—first for understanding, and a second time to highlight the big ideas; (2) jot notes about big ideas in your lab book; (3) then use the tablet to jot your thinking as a CK Inquiry note.

Discussion

This paper examines the relationships between technology and activity design features, and the discourse required of teachers to help ensure the effective orchestration of a KCI curriculum in a blended learning environment. Recall our main research question: *How do teachers orchestrate a KCI script, leveraging CK; to achieve the desired progression of activities, maintain a collective epistemology, as well as help students access and work with their learning community's ideas?* We discuss how we have addressed this question through our three operational research sub-questions; then comment on the implications of our work, future directions, and limitations.

How do teachers pace teacher-guided and student-driven inquiry activity within a KCI script, leveraging CK?

We found that distinct levels of teacher-guided (TG) and student driven (SD) activity involving CK use are associated with the two different CK iterations—with more time allocated to student driven inquiry activity in CK2 enactments. Bearing in mind that CK1 was used as a support for a content-oriented environment whereas CK2 was used to guide the inquiry progression, it is not surprising that such pacing differences emerged between the two iterations—reflecting underlying design differences in curriculum, activity script, and CK technology features. These differences appear to have made the teachers feel less need to intervene in community discussions, in favor of autonomous student inquiry activity in CK2 enactments. While it is not possible to determine the "best" blend of student-driven versus teacher-guided activities, it is interesting that changes in the script and technology would induce such a behavioral shift in classroom discourse.

What orchestration patterns do teachers use to coordinate teacher-guided and student-driven inquiry activity within a KCI script, leveraging CK?

Teachers utilized an orchestration cycle of *Reflect–Refocus–Release* (*3R*) as a means of managing the learning community's complex knowledge flow between the online CK environment and the face-to-face classroom environment (2015a). Closer examination of teachers' discourse orientations during whole-class reflections, revealed these discussions culminated in teachers' *refocusing* instructions that guided students' subsequent inquiry work. Furthermore, the ideas articulated in student notes were vital to informing subsequent teacher-guided community *reflections*, as teachers were seen to use these notes for spurring the reflections. When asked how teachers chose notes to spur community discussion, teachers indicated they sought notes that contained ideas (perhaps loosely) connecting with conceptual understandings, or approximating curriculum learning objectives they wished to reinforce (i.e. gravity, scale, nested systems).

An interesting shift in the allocation of instructional time (i.e. pacing) occurred between the CK1 and CK2 enactments, with more time allocated for *Release* of students to pursue autonomous inquiry in the process-focused CK2 enactments than for the more content-focused CK1 enactments. Evidently, this is a result of the differing forms of inquiry and the corresponding difference in requirements for teacher-guided discourse. Since CK2 content was more student-driven than CK1, teachers spent more time in small group interactions with student collaborators working on common inquiry goals. This resulted in more orchestration time given to student-driven inquiry activity (i.e., *Release*) in the CK2 environment, and less time given to community reflection discussion (i.e. *Reflect*).

Our studies of CK have provided insight into how a learning community curriculum can be designed using KCI, and how teachers can be supported in orchestrating those designs. The sequencing of inquiry activities within such a curriculum, carefully integrated with a supportive technology environment, serves as an inquiry script—or what Script Theory of Guidance (Fischer et al. 2013) may consider as an "external script"—that guides community progress. By making student ideas visible to all members of the learning community (i.e. students and the teacher), these ideas become central to their inquiry discussions about progress. CK supported teachers to manage the learning community's inquiry progression, promote awareness of the community's inquiry process and knowledge products, and make knowledge more accessible as a resource for the community's inquiry. In CK2, we emphasized this orchestrational role in scaffolding transitions between inquiry phases, and the use of community knowledge artefacts from one phase (e.g., Brainstorms) in the next (e.g., Proposals). With the KCI model informing the curricular script, CK was designed to scaffold students and teachers in creating a knowledge base that served as a resource for subsequent inquiry activities and discussions.

What patterns of teacher discourse orientation occur, and how do these vary with activity structures and technology design?

KCI recognizes the critical role of the teacher in guiding the learning community's inquiry. Teacher revoicing of student comments (O'Connor and Michaels 1996) can advance inquiry and focus students' attention. We examined teacher-facilitated whole-class discussions in terms of the *social participation structures* (Erickson 1982), to determine how teachers positioned their utterances in relation to the learning community. Teachers' discourse in both iterations revealed the presence of four orientations*: Community Instruction* (*CI*), *Community Reflection* (*CR*), *Teacher Reflection* (*TR*), and *Individual Reflection* (*IR*). We observed teachers using TR discourse orientations to model inquiry processes as they interacted with students' CK note contributions. They also used TR discourse orientations to empower students by amplifying and revoicing students' ideas in the public sphere. Through the TR orientation, teachers were observed to legitimize students' contributions by asking them for further elaboration, sometimes following-up by paraphrasing the student's elaboration and fusing it with their own phrasing towards a purposeful conceptual direction, then ending with a question back to the student, asking for validation. This encouraged students evaluate the statement, and thereby authenticate the teacher's revoicing. This can be seen as disrupting the traditional teacher–student power dynamic, since the student is now positioned to evaluate what the teacher said. Thus, the teachers positioned themselves as co-learners within the community. Furthermore, it would seem the TR discourse orientation is the mechanism by which teachers in this study sought to explicitly nurture the learning community's thinking processes, metacognition, and inquiry mindset. This indicates that the critical role of the teacher extends beyond an orchestrational role and facilitator of community inquiry (i.e. KCI principle #4), but also a nurturer of the learning community's metacognition. We found that CR and IR orientations were often employed to empower students through role-casting individual students (IR) or the community-at-large (CR) as legitimate participants of inquiry (e.g., questioner, observer, theorizer, inquirer), while simultaneously seeking students' explanations of what they had shared in their CK notes. CR and IR orientations were also used, although less frequently, as teachers were observed encouraging students to verbally build-on an idea, synthesize multiple ideas or multiple CK notes, comment about the current epistemic approach, or suggest a new epistemic approach. Such common forms of discourse exchange between teachers and students are similar to Polman's (2004) notion of dialogic activity structures—verbal exchange sequences suited to project-based learning environments.

The observed differences in discourse patterns between the two CK iterations, in terms of the degree to which the teachers used each of the four orientations, reflected the distinctions in corresponding activity systems. A substantial reduction in the use of IR and CR orientations was seen in CK2 enactments, accompanied by an increase in community instruction (CI) and teacher reflection (TR), which presumably reflects the different orchestrational demands of their respective activity structures. One possible explanation may be that the inquiry script design of CK1 was more content-oriented (i.e. the WallCology investigations), while CK2 was more process-oriented (i.e. student-driven astronomy inquiry). As such, community discussions during CK1 enactment were more content–oriented, and less process-oriented; while discussions during CK2 enactment were more process-focused, looking for patterns and connections within the knowledge base. Teachers' use of TR discourse orientations to model inquiry and thinking processes as they interacted with students' CK notes was critical to helping students identify connections within their community's knowledge base. Another possible explanation may be that CK2 was more structured overall, scaffolding the inquiry progression in distinct phases, and thus placing a more targeted set of needs or requirements on the teacher—to support students in what they were supposed to be working on within the various inquiry phases). Thus, different allocations of time and different emphases may have emerged within the activity system.

Implications and future work

This research explored how a pedagogical model such as KCI can inform the development of a learning community's external script—embedding inquiry process and curricular content into the technological features of a scaffolded learning environment. By tightly coupling the technology and inquiry designs, in accordance with such a structural model, students were scaffolded to work as a learning community, creating a shared knowledge base that served as a resource for subsequent inquiry activities. Thus, CK served to reinforce the KCI design principles, and help the teacher succeed in orchestrating a complex form of whole-class inquiry. Further examination of the content of CK notes and students' culminating products will be needed to determine if students ultimately achieved the targeted understandings (i.e., in the astronomy topics of gravity, scale, and nested systems)—which is an important requirement of the KCI model. Moreover, further analysis of students' epistemic commitments before, during, and after the curriculum can reveal whether they were focused on the progress of the community or just on their own specific inquiry topics. The teacher's role within KCI and the orchestrational role for the CK environment will remain an important topic for further research.

Student-driven collaborative inquiry, scaffolded by a digital tool such as CK, requires talented teachers with deep understanding of inquiry pedagogy to guide the collaborative inquiry along productive trajectories, towards targeted learning goals. This entails sequencing and pacing of activities—including management of the community's knowledge, and its movement between the face-to-face and digital environments—through nuanced use of discourse that empower students as a learning community. Future research could explore the discourse orientations more deeply, and could investigate possible discourse scaffolds for CK. There have been studies of pedagogical tools that incorporate scaffolds for teacher discourse, such as the Contingent Pedagogies for Conceptual Teaching and Learning project (Penuel and DeBerger 2011), which focuses on teacher use of formative assessment to inform their instructional moves. The development of pedagogical tools that includes a set of discourse orientations and corresponding inquiry scaffolds, referenced to varying activity structures, could be helpful to teachers in their early stages of implementing a learning community pedagogy.

Limitations

One necessary component of design research is an authentic classroom context, for which a learning innovation is iteratively designed, and in which the innovation is investigated (Cobb et al. 2003; Design-Based Research Collective 2003). Yet, such contexts are unique to each classroom, hence the findings of such research have limited generalizability. This is particularly true of interventions such as the present case, where a new digital learning environment is layered atop the existing classroom context, producing a truly unique hybrid environment. To study the impact of the 3R orchestration cycle or the four discourse orientations on student learning outcomes, would require either a second trial where the same teachers and students performed a different script with a different technology layer (i.e., the determine the potential benefits of those identified here), or a comparison across teachers who shared nearly identical contexts but deliberately varied in their approach. As such controls were not realistic for this research, no such comparisons could be made in terms of the relative advantage of using CK or certain discourse patterns to impact student learning.

Conclusion

This study presents a portion of a broader program of research on the application of KCI for the design of elementary science learning communities. We focused on the CK technology environment, which we co-designed to support learning communities in K-12 classrooms. Examination of teachers' time allocations for teacher-guided and student-driven inquiry activity between enactments of content-oriented CK1 and process-oriented CK2, revealed teachers allocated more time for student-driven inquiry activity in CK2 enactments. Analysis of teachers' orchestration patterns revealed a *Reflect–Refocus–Release* ("*3R*") orchestration cycle. Teachers' discourse moves revealed the presence of four discourse orientations*:* *Community Instruction* (*CI*), *Community Reflection* (*CR*), *Teacher Reflection* (*TR*), *and Individual Reflection* (*IR*). In CK2 enactments, teachers allocated more time to the Release phase of the 3R orchestration cycle, allowing more time for students to pursue their collaborative inquiry autonomously. In terms of discourse orientations in CK2 enactments, teachers placed more emphasis on teacher reflection (TR) and community instruction (CI). These shifts in orchestration pacing and discourse orientations may be attributed to the more processed-oriented inquiry activity structures, as well as the scaffolds that the CK2 environment offered.

Acknowledgements This research was made possible through the generous support of educators, administrators, students, and parents at the Dr. Eric Jackman Institute of Child Study Laboratory School; OISE/University of Toronto; cross-lab collaborations between the ENCORE Lab at OISE/University of Toronto and the Learning Technologies Group at the University of Illinois at Chicago; and funding from the Social Sciences and Humanities Research Council of Canada (Grant No. 410-2011-0474), as well as from the US National Science Foundation (Grant No. 1324977). We are grateful to Instructional Science reviewers and guest editors Dani Ben-Zvi, Katerine Bielaczyc, and Yotam Hod for careful review.

References

Acosta, A., & Slotta, J. D. (2013). Evaluating knowledge community curricula in secondary science using model-based design research. In *Proceedings of the 17th Annual Knowledge Building Summer Institute*. Puebla, Mexico: Institute for Knowledge, Innovation and Technology.

Amiel, T., & Reeves, T. C. (2008). Design-based research and educational technology: Rethinking technology and the research agenda. *Educational Technology & Society, 11*(4), 29–40.

Anderson, R. C., Chinn, C., Chang, J., Waggoner, M., & Yi, H. (1997). On the logical integrity of children's arguments. *Cognition and Instruction, 15*(2), 135–167.

Aronson, E. (1978). *The jigsaw classroom*. Beverly Hills, CA: Sage.

Asia Society Center for Global Education, & OECD. (2018). *Teaching for global competence in a rapidly changing world*. Paris: OECD/Asia Society. https://doi.org/10.1787/9789264289024-en.

Bell, P. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist, 39*(4), 243–253.

Bereiter, C., & Scardamalia, M. (2008). Toward research-based innovation. In Centre for Educational Research & Innovation (Ed.), *Innovating to learn, learning to innovate* (pp. 67–87). Paris: Organization for Economic Co-operation and Development (OECD).

Bereiter, C., & Scardamalia, M. (2012). Theory building and the pursuit of understanding in history, social studies, and literature. In M. J. Lawson & J. R. Kirby (Eds.), *The quality of learning*. New York, NY: Cambridge University Press.

Bielaczyc, K., & Collins, A. (1999). Learning communities in classrooms: A reconceptualization of educational practice. *Instructional-Design Theories and Models, 2,* 269–292.

Bielaczyc, Katerine, & Collins, A. (2006). Fostering knowledge-creating communities. In A. M. O'Donnell, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative learning, reasoning, and technology* (pp. 37–60). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Brown, A. L. (1994). The advancement of learning. *Educational Researcher, 23*(8), 4–12.

Brown, A. L. (1997). Transforming schools into communities of thinking and learning about serious matters. *American Psychologist, 52*(4), 399.

Brown, A. L., & Campione, J. C. (1996). Communities of learning and thinking, or a context by any other name. In P. Woods (Ed.), *Contemporary issues in teaching and learning* (pp. 120–126). New York, NY: Routledge.

Chen, B. (2016). Fostering scientific understanding and epistemic beliefs through judgments of promisingness. *Educational Technology Research and Development*. Retrieved from https://link.springer.com/article/10.1007/s11423-016-9467-0?utm_content=bufferee759&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer.

Chen, B., Scardamalia, M., Resendes, M., Chuy, M., & Bereiter, C. (2012). Students' intuitive understanding of promisingness and promisingness judgments to facilitate knowledge advancement. In *The future of learning: Proceedings of the 10th International Conference of the Learning Sciences* (*ICLS 2012*) (Vol. 1, pp. 111–118).

Chinn, C. A., O'Donnell, A. M., & Jinks, T. S. (2000). The structure of discourse in collaborative learning. *The Journal of Experimental Education, 69*(1), 77–97.

Cobb, P., Confrey, J., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9–13.

Cober, R., McCann, C., Moher, T., & Slotta, J. D. (2013). Aggregating students' observation in support of community knowledge and discourse. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.), *Proceedings of the 10th International Conference on Computer-supported Collaborative Learning* (*CSCL*) (Vol. 1, pp. 121–128). Madison, WI: International Society of the Learning Sciences (ISLS).

Coburn, C. E., & Penuel, W. R. (2016). Research-practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher, 45*(1), 48–54.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *Journal of the Learning Sciences, 13*(1), 15–42.
Cress, U., & Kimmerle, J. (2013). Successful knowledge building needs group awareness: Interaction analysis of a 9th grade CSCL biology lesson. In *Productive multivocality in the analysis of group interactions* (pp. 495–509). New York: Springer.
De Jong, T. (2006). Technological advances in inquiry learning. *Science, 312*(5773), 532–533.
Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5–8.
Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed.), *Three worlds of CSCL: Can we support CSCL?* (pp. 61–91). Heerlen: Open Universiteit Nederland.
Dillenbourg, P. (2013). Design for classroom orchestration. *Computers & Education, 69*, 485–492.
Dillenbourg, P., & Jermann, P. (2007). Designing integrative scripts. *Scripting computer-supported collaborative learning* (pp. 275–301). New York: Springer.
Erickson, F. (1982). Classroom discourse as improvisation: Relationships between academic task structure and social participation structure in lessons. In L. C. Wilkinson (Ed.), *Communicating in the classroom* (pp. 153–181). New York, NY: Academic Press.
Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013a). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist, 48*(1), 56–66.
Fischer, F., Slotta, J. D., Dillenbourg, P., Kollar, I., Stegmann, K., Wecker, C., et al. (2013). Scripting and orchestration: Recent theoretical advances. In N. Rummel, M. Kapur, M. Nathan, & S. Puntambekar (Eds.), *Conference Proceedings of the 10th Computer-Supported Collaborative Learning* (*CSCL*) (Vol. 1, pp. 564–571). Madison, WI: International Society of the Learning Sciences (ISLS).
Fong, C., Cober, R. M., Messina, R., Moher, T., Murray, J., Peebles, B., et al. (2015a). The 3R orchestration cycle: Fostering multi-modal inquiry discourse in a scaffolded inquiry environment. In O. Lindwall, P. Häkkinen, T. Koschmann, P. Tchounikine, & S. R. Ludvigsen (Eds.), *Exploring the material conditions of learning: The computer supported collaborative learning (CSCL) conference 2015* (Vol. 1, pp. 39–46). Gothenburg: The International Society of the Learning Sciences.
Fong, C., Cober, R. M., Moher, T., & Slotta, J. D. (2015b). Spatial mapping of inquiry discourse in the classroom through knowledge visualization. In T. Moher, & J. D. Slotta (Chairs), Knowledge Construction in the Instrumented Classroom: Supporting Student Investigations of Their Physical Learning Environment. In O. Lindwall, P. Häkkinen, T. Koschmann, P. Tchounikine, & S. R. Ludvigsen (Eds.), *Exploring the material conditions of learning: The computer supported collaborative learning* (*CSCL*) *conference 2015* (Vol. 2, pp. 634–635). Gothenburg: International Society of the Learning Sciences (ISLS).
Fong, C., Pascual-Leone, R., & Slotta, J. D. (2012). The role of discussion in orchestrating inquiry. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), *The future of learning: Proceedings of the 10th International Conference of the Learning Sciences* (*ICLS 2012*)*—Short Papers, Symposia, and Abstracts* (Vol. 2, pp. 68–69). Sydney, NSW: International Society of the Learning Sciences (ISLS).
Forte, A. (2015). The new information literate: Open collaboration and information production in schools. *International Journal of Computer-Supported Collaborative Learning*, 1–17.
Hod, Y. (2017). Future learning spaces in schools: Concepts and designs from the learning sciences. *Journal of Formative Design in Learning, 1*(2), 99–109.
Hod, Y., Basil-Shachar, J., & Sagy, O. (2018). The role of productive social failure in fostering creative collaboration: A grounded study exploring a classroom learning community. *Thinking Skills and Creativity*. https://doi.org/10.1016/j.tsc.2018.03.006.
International Society for Technology in Education. (2016). *ISTE Standards for Students*. International Society for Technology in Education (ISTE). Retrieved from http://www.iste.org/standards/standards/for-students-2016.
Jenkins, H. (2009). *Confronting the challenges of participatory culture: Media education for the 21st century*. Cambridge. MA: The MIT Press.
Kollar, I., Fischer, F., & Slotta, J. D. (2007). Internal and external scripts in computer-supported collaborative inquiry learning. *Learning & Instruction, 17*(6), 708–721.
Kolodner, J. L. (2007). The roles of scripts in promoting collaborative discourse in learning by design. In F. Fischer, I. Kollar, H. Mandl, & J. M. Haake (Eds.), *Scripting computer-supported collaborative learning* (pp. 237–262). Berlin: Springer.
Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319–337.
Lee, M. J. W., McLoughlin, C., & Chan, A. (2008). Talk the talk: Learner-generated podcasts as catalysts for knowledge creation. *British Journal of Educational Technology, 39*(3), 501–521.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.
Linn, M. C., Bell, P., & Davis, E. A. (2004). *Internet environments for science education* (pp. 315–339). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
Mehan, H. (1979). *Learning lessons: Social organization in the classroom*. Cambridge, MA: Harvard University Press.
Moher, T. (2006). Embedded phenomena: Supporting science learning with classroom-sized distributed simulations. In *Proceedings of the SIGCHI Conference on Human Factors in computing Systems* (pp. 691–700). Montreal, Quebec: ACM.
Moher, T., & Slotta, J. D. (2012). Embedded Phenomena for Knowledge Communities: Supporting complex practices and interactions within a community of inquiry in the elementary science classroom. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), *The future of learning: Proceedings of the 10th International Conference of the Learning Sciences* (*ICLS 2012*)*—Short papers, symposia, and abstracts* (Vol. 2, pp. 64–71). Sydney, NSW: International Society of the Learning Sciences.
Nassaji, H., & Wells, G. (2000). What's the use of'triadic dialogue'? An investigation of teacher–student interaction. *Applied Linguistics, 21*(3), 376–406.
National Research Council. (2012). *Education for Life and Work: Guide for Practitioners*. Washington, DC: National Academies Press. Retrieved from https://www.nap.edu/resource/13398/dbasse_084153.pdf.
O'Connor, M. C., & Michaels, S. (1993). Aligning academic task and participation status through revoicing: Analysis of a classroom discourse strategy. *Anthropology and Education Quarterly, 24,* 318.
O'Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. In D. Hicks (Ed.), *Discourse, learning, and schooling* (pp. 63–103). New York, NY: Cambridge University Press.
OECD. (2015). *Schooling redesigned: Towards innovative learning systems, educational research and innovation*. Paris, France: OECD Publishing. https://doi.org/10.1787/9789264245914-en.
OECD. (2017). *The OECD handbook for innovative learning environments*. Paris: OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/education/the-oecd-handbook-for-innovative-learning-environments_9789264277274-en.
Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension-monitoring activities. *Cognition and Instruction, 1*(2), 117–175.
Partnership for 21st Century Skills. (2011). *Framework for 21st century learning*. Washington, DC: Partnership for 21st Century Skills. Retrieved from http://www.p21.org/storage/documents/1.__p21_framework_2-pager.pdf.
Penuel, W. R., & DeBerger, A. H. (2011). *Sample of contingent pedagogies project materials*. Menlo Park: SRI International. Retrieved from http://contingentpedagogies.org/research.html.
Peters, V. L., & Slotta, J. D. (2010). Scaffolding knowledge communities in the classroom: New opportunities in the Web 2.0 era. In M. J. Jacobson & P. Reimann (Eds.), *Designs for Learning Environments of the Future* (pp. 205–232). New York: Springer.
Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. *Cognition and Instruction, 22*(4), 431–466.
Raes, A., Schellens, T., De Wever, B., Kollar, I., Wecker, C., Langer, S., et al. (2012). Scripting science inquiry learning in CSCL classrooms. In J. van Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.), *The future of learning: Proceedings of the 10th International Conference of the Learning Sciences* (*ICLS 2012*) (Vol. 2, pp. 118–125). Sydney, NSW: International Society of the Learning Sciences (ISLS).
Roschelle, J., & Penuel, W. R. (2006). Co-design of innovations with teachers: Definition and dynamics. In *Proceedings of the 7th International Conference on Learning Sciences* (pp. 606–612). Bloomington, Indiana.
Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-Design, 4*(1), 5–18.
Sandoval, William A., & Reiser, B. J. (2004). Explanation driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345–372.
Scardamalia, Marlene. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal Education in a Knowledge Society, 97,* 67–98.
Scardamalia, Marlene, & Bereiter, C. (1996). Student communities for the advancement of knowledge. *Communications of the ACM, 39*(4), 36–37.
Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97–118). New York: Cambridge University Press.

Schwarz, B., Dreyfus, T., Hadas, N., & Hershkowitz, R. (2004). Teacher guidance of knowledge construction. In *Proceedings of the 28th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 4, pp. 169–176). Cape Town: International Group for the Psychology of Mathematics Education. Retrieved from http://emis.ams.org/proceedings/PME28/RR/RR175_Schwarz.pdf.

Sfard, A. (2007). When the rules of discourse change, but nobody tells you: Making sense of mathematics learning from a commognitive standpoint. *The Journal of the Learning Sciences, 16*(4), 565–613.

Slotta, J. D. (2010). Evolving the classrooms of the future: The interplay of pedagogy, technology and community. In K. Makital-Siegl, J. Zottmann, F. Kaplan, & F. Fischer (Eds.), *Classroom of the future: Orchestrating collaborative spaces* (pp. 215–242). Rotterdam: Sense Press.

Slotta, J. D. (2013). Knowledge Community and Inquiry. In Network of Associated Programs in the Learning Sciences (NAPLeS).

Slotta, J. D., & Najafi, H. (2010). Knowledge communities in the classroom. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International encyclopedia of education* (pp. 189–196). Oxford: Academic Press.

Slotta, J. D., & Najafi, H. (2012). Supporting collaborative knowledge construction with web 2.0 technologies. In N. Lavigne (Ed.), *Emerging technologies for the classroom: A learning sciences perspective*. New York: Springer.

Slotta, J. D., Tissenbaum, M., & Lui, M. (2013). Orchestrating of complex inquiry: Three roles for learning analytics in a smart classroom infrastructure. In D. Suthers, K. Verbert, E. Duval, & X. Ochoa (Eds.), *Proceedings of the Third International Conference on Learning Analytics and Knowledge* (pp. 270–274). Leuven: The Association for Computing Machinery (ACM).

Songer, N. B., & Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching, 28*(9), 761–784.

Stahl, G. (2012). Traversing planes of learning. *International Journal of Computer-Supported Collaborative Learning, 7*(4), 467–473.

Vygotsky, L. (1962). *Thought and language*. Cambridge, MA: The MIT Press.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development, 53*(4), 5–23.

Weinberger, A., Stegmann, K., & Fischer, F. (2010). Learning to argue online: Scripted groups surpass individuals (unscripted groups do not). *Computers in Human Behavior, 26*(4), 506–515.

Wertsch, J. V., & Smolka, A. L. B. (1994). Continuing the dialogue: Vygotsky, Bakhtin & Lotman. In H. Daniels (Ed.), *Charting the agenda: Educational activity after Vygotsky* (pp. 69–92). London: Routledge.