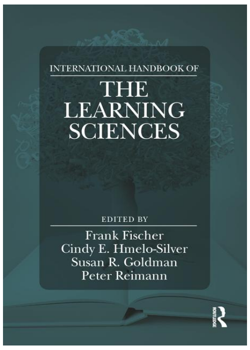

International Handbook of the Learning Sciences

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Publication details
https://www.routledgehandbooks.com/doi/10.4324/9781315617572-30
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Published online on: 20 Apr 2018

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Collective Inquiry in Communities of Learners

James D. Slotta, Rebecca M. Quintana, and Tom Moher

Introduction

Collective Inquiry is a pedagogical approach in which an entire classroom community (or potentially multiple classrooms) is engaged in a coherent curricular enterprise, with well-defined learning goals for both content and practice. Participants work individually or in small groups, holding a common understanding of their purpose as a learning community (Bielaczyc & Collins, 1999). As individual members add observations, ideas, or artifacts, the products of their efforts are integrated as a pooled community knowledge base. Students typically share a sense that the "whole is greater than the sum of its parts," as they build on their peers' contributions, organize content, synthesize ideas, identify gaps, and gain inspiration. This approach is related to the broader category of Inquiry Learning, as addressed by Linn, Gerard, McElhaney, and Mattuk (this volume).

There is an established international community of scholars investigating the learning community pedagogy, with contributions from Scandinavia (e.g., Lipponen & Hakkarainen, 2007), Europe (e.g., Cress & Kimmerle, 2007), Israel (Kali et al, 2015), Japan (Oshima, Oshima, & Matsuzawa, 2012), Hong Kong (e.g., van Aalst & Chan, 2007), the US (Chen & Zhang, 2016), and Canada (e.g., Scardamalia & Bereiter, 2006; Slotta, Tissenbaum, & Lui, 2013), amongst others. In the learning community approach, students are engaged as a scientific community, reminiscent of real-world science, and encouraged to develop their own inquiry progressions, building on one another's findings, collaborating with peers, and developing shared observational data.

This chapter will report on our own recent collaboration in which we developed a learning community curriculum to help elementary science students collectively investigate a simulated ecosystem embedded within their physical classroom space (e.g., in the walls or floor; Moher, 2006). No student working alone could understand these phenomena sufficiently, thereby establishing the pretext or need for cooperation and collaboration. Such an approach is well suited for collective inquiry, but does not in itself offer any solutions for *how* students can progress as a community, building on one another's ideas and gaining strength through their numbers. What should the community's objectives be when faced with such an object of inquiry, and how should inquiry progress? How should we represent community knowledge and scaffold inquiry practices and discourse? Our research investigates a model for the design of materials and activities that engaged students individually, in small groups, and as a whole class. We examine how knowledge was contributed and reused within the community, as well as what technology scaffolds could support these processes and reinforce collective inquiry. Our chapter begins with a review of learning communities, including a set of key challenges for collective inquiry, and describes how our own research has responded to those challenges, including an important role for scripting and orchestration.

Learning Communities for Collective Inquiry

The learning community approach positions learners as active constructors of knowledge within "a culture of learning in which everyone is involved in a collective effort of understanding" (Bielaczyc & Collins, 1999, p. 271). Learners are given high levels of agency and are responsible for developing their own questions and approaches to addressing those questions, for critiquing the ideas of peers, and for evaluating the progress within the community. Expertise does not reside solely with the teacher, but is rather distributed amongst all members (Brown & Campione, 1994). The teacher is a member of the community, and participates as a knowledgeable mentor. Artefacts, observations, and other products of student inquiry are often contributed to a community knowledge base—usually situated within a technology-mediated environment—where they become available for critique, improvement, and reuse. Slotta and Najafi (2013) articulated three common characteristics of learning communities: (1) an epistemic commitment to collective advancement, (2) a shared community knowledge base, and (3) common modes of discourse.

The learning community approach is well suited for designs in which students engage in in practices that mirror those of scientific communities, such as investigation and argumentation. Within such a community, students bring their diverse interests and expertise, with a shared understanding that their learning activities will align to advance the community's cause while at the same time helping individuals learn, and allowing everyone to benefit from the community's resources. With appropriate scaffolding, students can design their own experiments, interpret evidence to inform arguments, and synthesize knowledge from their peers. They are challenged to make the products of their work accessible and relevant within a community of peer investigators (Brown & Campione, 1994). Hence, this approach is well suited for 21st-century science education—engaging students directly in relevant STEM practices (e.g., working with data, collaborating with peers, interpreting evidence). Students' efforts ultimately feed back into the community, advancing the understandings of all members, leading to a sense of "collective cognitive responsibility" (Scardamalia, 2002).

Perhaps the most prominent example of collective inquiry is that of knowledge building communities (Scardamalia & Bereiter, 2006) which focuses on intentional learning and idea improvement. Knowledge Building (KB) is distinguished amongst learning community approaches by its "idea-centered" pedagogy, and reliance on students to determine the specific learning activities. This emphasis runs counter to the notion of scripting (Dillenbourg & Jermann, 2007), and instead includes parallel strands of student-driven inquiry. The teacher plays an extremely important role in KB, and student "knowledge work" is scaffolded by a technology environment called the Knowledge Forum® that is specifically designed to support such "knowledge work" (Scardamalia & Bereiter, 2006; Cress and Kimmerle, this volume, also discuss this research tradition).

Another well-recognized project is Fostering a Community of Learners (FCL), in which students are engaged as a scientific community of practice, with specific content and epistemic learning goals (Brown & Campione, 1994). FCL curricula are scripted around an iterative research cycle that consists of three interdependent stages: *research, share, and perform*. The cycle is launched by an anchoring event, in which the class shares in a common experience (e.g., watching a video or play, reading a work of fiction, or learning about an experiment) that is tied to the "big idea" of the unit (e.g., animal/habitat interdependence). Students conduct research and share knowledge through a variety of research activities, including reciprocal teaching, guided writing and composition, cross-age tutoring, and consultation with subject matter experts outside of the classroom (Bielaczyc & Collins, 1999). The "perform" stage of the cycle is motivated by a consequential task (e.g., designing a biopark), which requires that all students have learned the entire targeted conceptual domain, not just portions.

Several scholars have observed that it is challenging for teachers or researchers to enact a learning community approach (Slotta & Najafi, 2013; van Aalst & Chan, 2007). As observed by Kling and Courtright (2003, p. 221) "developing a group into a community is a major accomplishment that requires special processes and practices, and the experience is often both frustrating and satisfying for the participants." Slotta and Najafi (2013) argue that the pragmatic and epistemic challenges of shifting from a traditional mode of "knowledge transmission" into a mode of collective inquiry have contributed to a relatively low uptake of this approach amongst researchers and practitioners, and that there is a need for structural models that guide the design of individual, small group, and whole class activities through which students work as a community in collective inquiry.

Knowledge Communities and Inquiry (KCI)

We articulate four key challenges to a learning community pedagogy: (1) to establish an epistemological context where all members share an understanding of the collective nature of their learning, an awareness of how their individual efforts contribute, and how they can benefit personally; (2) to ensure that community knowledge is accessible as a resource for student inquiry (i.e., with effective, accessible, and timely representations); (3) to ensure that scaffolded inquiry activities advance the community's progress as well as all individual learners; (4) to foster productive teacher- and student-led discourse that helps individual students and the community as a whole make progress. We have developed the KCI model in response to these challenges, to guide the design of "collective inquiry" curricula that integrate whole class, small group and individual activities (Slotta & Najafi, 2013; Slotta & Peters, 2008). KCI curricula entail: (1) a knowledge base that is indexed to the targeted science domain, (2) an activity "script" that includes collective, collaborative, and individual inquiry activities in which students construct the knowledge base and then use it as a resource for inquiry, and (3) student-generated products that allow assessment of progress on targeted learning goals.

The notions of *scripting and orchestration* (Kollar, Fischer, & Slotta, 2007) help respond to the challenges of learning communities. In general, a pedagogical script serves to specify the media (e.g., worksheets, student-contributed content, or social media), activities (e.g., inquiry projects, class brainstorms, problem solving, modeling, argumentation, or reflection), grouping conditions (e.g., jigsaw) and activity sequences (e.g., brainstorm, followed by reflection, followed by a jigsaw group design, followed by a culminating project). The script is *"orchestrated"* by the instructor, and scaffolded by a technology environment, which helps track student progress, distribute instructions, materials and prompts, pause students for planned or spontaneous discussions, and collect and organize student work (Dillenbourg & Jermann, 2010). The orchestration of the script further depends upon in-the-moment decisions by the instructor, whose role is one of collaborator and mentor, responding to student ideas as they emerge, and orchestrating the flow of activities. Teachers are not just a "guide on the side" but rather have an explicitly scripted role at all times, in addition to responsibility for overall coordination of the curriculum. Large projected displays help teachers identify pedagogically meaningful signals from amidst the noise of student contributions, and help the community stay on target for learning goals (Slotta, Tissenbaum, & Lui, 2013).

KCI curricula typically span multiple weeks or months, and are developed through a sustained process of co- design (Roschelle, Penuel, & Shechtman, 2006) that includes researchers, teachers, and designers. Technology environments, such as wikis, are employed to give structure to the community's knowledge base and to scaffold collective knowledge building. Slotta and Peters (2008) engaged five sections of a 10th-grade biology course (n=108) in co-authoring wiki pages about human disease systems, ultimately producing a substantive "disease wiki" that served as a resource for their subsequent development and solution of peer-created medical cases. In this way, individual students are able to perceive their contributions within a broader collective effort, recognizing that they will benefit from the collective product and understanding the value of their individual contributions. The KCI script typically includes a major inquiry project, sometimes happening in the final phase of the curriculum, other times revisited throughout the curriculum that is carefully designed such that student products reflect their understanding and application of the targeted content and process learning goals.

Embedded Phenomena for Inquiry Communities

We recently began a collaboration where we applied KCI to support students in collectively investigate scientific phenomena, in the form of digital simulations, that are embedded within the physical space of their own classrooms (Moher, 2006). These simulations provide a location-based experience for scientific discovery learning and seek to "provide the opportunity for students to engage in spontaneous, harmless, and sustained investigation" (Malcolm, Moher, Bhatt, Uphoff, & López-Silva, 2008, p. 238). Students work collectively to monitor and manipulate the simulation in an effort to address their own inquiry questions. Known as Embedded Phenomena (EP), these unique objects of collective inquiry have been developed to situate investigations within the domains of seismology (*RoomQuake*), life sciences (*WallCology*, *Hunger Games*), astronomy (*HelioRoom*), and hydrology (*AquaRoom*).

Typically, EP persist over several weeks, with simulations running constantly, 24 hours a day, which provides students with opportunities for extended observation and systematic data collection. The design rationale behind such a temporal distribution is that it reinforces the concept that in nature, "things happen when they happen," and do not conform to the schedules of scientists, or even school cycles (Moher, 2006). Students could return from recess to find that the EP they are studying has undergone a major shift (e.g., catastrophic habitat destruction). As the simulation exhibits several changes (e.g., a series of earthquakes occur), a narrative unfolds, giving students opportunities to draw conclusions from their investigations, make comparisons with previously collected data, and engage in collaborative decision-making processes concerning how they might respond to the changes in the phenomena.

Our research collaboration, titled Embedded Phenomena for Inquiry Communities (EPIC) and began in 2010, includes learning scientists from several different research labs. Using EP as a source of inquiry, we have investigated collective inquiry scripts as well as technology-based orchestration supports for learners and teachers. We were particularly interested in the role of emergent visualizations of the community's aggregated knowledge (Cober, McCann, Moher, & Slotta, 2013), and the nature of teacher-led discourse that referred to those visualizations and served to advance community inquiry (Fong, Pascual-Leone, & Slotta, 2012). KCI served as a theoretical foundation, guiding our design of student inquiry, knowledge representations, and orchestration supports (Slotta & Najafi, 2013).

The next section describes our KCI script for the *WallCology* EP—a simulated ecosystem in which computer monitors are placed on each wall in the classroom, providing a form of X-ray "wallscope" that reveals hot and cold water pipes, as well as several different species of insects crawling around on those various surfaces, and vegetation (e.g., "mold" and "scum") that some insects are eating. Other insects are predators, and these food-web interactions are directly observable. Insects vary in terms of their preferred habitat (i.e., brick or pipes) and temperature tolerance (low, medium, high). Statistical information about each Wallscope habitat is available onscreen, in the form of population and temperature graphs as a function of time (see Figure 30.1).

One of the key technical and conceptual features of *WallCology* is that the simulations can be perturbed or changed over time, allowing an emulation of climate change, where the temperatures gradually or suddenly increases, or an "invasive species" that causes interesting or alarming readjustments in species population levels. An underlying biological model drives the simulation, developed in close collaboration with an expert biologist using the mathematics of a complex biological system of predators, prey, habitat conditions, and other factors. These dependencies make the inquiry environment sufficiently challenging to support a wide range of student investigations. Students can

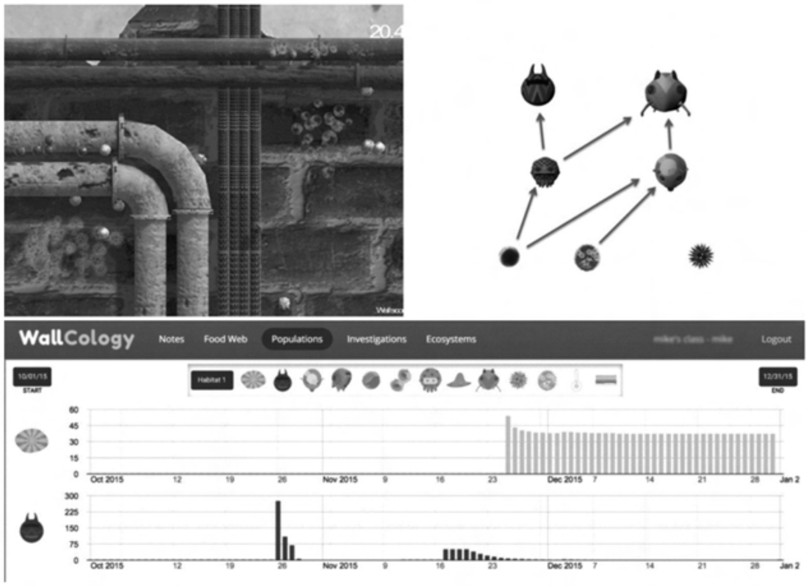

Figure 30.1 W*all*C*ology* habitat viewed through a wallscope (top left); subset of W*all*C*ology* species (top right); W*all*C*ology* population graph (bottom)

identify and classify species, observe their habitat preferences, uncover food webs, and predict and evaluate species' responses to environmental changes. Finally, *WallCology* allows students to alter the state of the ecosystem, by adding or removing species, in order to respond to perturbations.

Working in pairs, students were scaffolded by a software environment called *Common Knowledge* (Fong et al., 2013), implemented on a tablet computer, which guided their food-web and predation observations, brainstorm discussions, access of the community knowledge base, and development of plans for responding to perturbations. An interactive whiteboard was located at the front of the room, providing summative views and interactive tools for sorting and presenting electronic contributions (Slotta et al., 2013).

We were interested in how these *WallCology* features could engage upper elementary students and teachers as a learning community, allowing students to investigate and report their findings, build knowledge with their peers, and develop a deep understanding of the relevant science content and practices. Our goal was to engage students in scientific investigations, evidence-based argumentation, collective knowledge building, and applications of their community knowledge within their own inquiries. One important feature of KCI is the use of dynamically assembled "aggregate representations" of student observations to provide an emergent, summative representation that allows a sense of progress and supports teacher-led discourse (Cober et al., 2013).

A KCI Script for WallCology: An Example of Collective Inquiry

Our team developed a KCI script, and corresponding orchestration supports, which included complex grouping conditions and activity sequences, and emphasized community progress and individual learning. We wanted to situate students' learning within the context of a scientific community, in which they work amongst peers to actively investigate the *WallCology* phenomena. The primary science learning goals included understanding habitats, species, and populations, as well as food webs, biodiversity, and ecosystems. Another important set of goals was concerned with engaging students in investigation and argumentation practices, including: interpreting graphs, reasoning from evidence, planning experiments, communicating findings, and collaborating with peers. Our overall design included three phases, each of which took between two and four weeks: (1) taking inventory of phenomena and constructing models of the food webs, including distinct trophic levels; (2) understanding implications of perturbation, such as temperature rise or habitat loss, in each of the ecosystems; and (3) investigating impact of changes to the ecosystems, such as adding new species or trapping and removing some existing species.

The first phase was conducted as a whole-class activity, with students familiarizing themselves with all four habitats to inform a community-wide knowledge base of the habitats, the species, and their interdependencies. The four ecosystems varied in terms of habitat conditions (how much pipe and brick, and what temperature) and also varied in terms of the population levels of different species (flora and fauna). Students were divided into four teams, with each taking stewardship of one wall (i.e., its habitat and denizen species), and tasked with understanding their habitat and species, then reasoning and problem-solving around any observed perturbations, making use of community-level knowledge, and sharing their own findings with the wider community. In the first phase, the student pooled their various observations into a collective knowledge base about all the various species and habitats—knowledge that would be crucial to their success in the latter two phases, where each team had to first understand a crisis that struck their habitat, and then intervene, creating a more balanced and healthy ecosystem.

Phase 1: Students walked into their classroom and discover the *WallCology* EP that was installed in their classrooms. The EP simulation ran continuously (i.e., all day) on the four monitors that were positioned on four different walls around the room, each displaying a distinct ecosystem. Students used the *Common Knowledge* tools to record observations, including details about the species' behavior, physical traits, habitat preferences, and food preferences. Wherever they witnessed a predation event, they recorded pairwise consumer–producer relationships, which were added to an aggregate food-web grid that appeared at the front of the room (i.e., tallying all observations in real time). Using that grid, each team then constructed their own food-web diagrams, consisting of the subset of species that were spotted within their ecosystem. Teachers then facilitated the construction of a whole-class food web, consisting of all species, using printed species and large paper that was affixed to the classroom wall for the remainder of the unit.

Phase 2: Students entered their classrooms and discovered that a major perturbation had taken place within their group's ecosystem. This was immediately apparent in terms of drastic changes in populations of some of the species in the ecosystems. Students interpreted the species and temperature graphs to deliberate what had happened to their ecosystem, which was drawn from one of four scenarios: habitat destruction, invasive vegetation, invasive predator, and climate change (i.e., temperature increase or decrease). After the students had come to some determination about their specific perturbation, the teacher led a discussion about real-world examples of ecosystem disruption (i.e., do to invasive species, climate change, etc.)—including some examples where ecologists had taken remediating measures. Using the *Common Knowledge* tool, the class brainstormed what constitutes a "healthy ecosystem" and the teacher helped students develop a community consensus, which was to be applied as a rubric to their own habitats (i.e., to measure their remediation).

Phase 3: In the final phase, teams could make changes to their ecosystems by either introducing a new species, or increasing or decreasing a species that was already present. The goal was to improve the overall health of the ecosystem, either by trying to return the ecosystem to its original state or by creating a more diverse ecosystem (i.e., with a robust combination of predators, herbivores, and resources). Findings from any team were shared within the community using *Common Knowledge*, which scaffolded each team in making one cycle of remediations, where each effort was then added to the community knowledge base, indexed to species and habitats. Each cycle began by designing a plan, included proposed steps and predictions about the outcome of their intervention (i.e., which species populations would increase or decrease, and why). At the end of that day's class, the teacher would implement the plans in each ecosystem, so that in the next class period—often with great excitement—students would discover the accuracy of their predictions and record their outcomes. Again, the reports were scaffolded by a new section of the *Common Knowledge* environment, which ensured that they would reflect on the failures and successes, compare against their predictions, and motivate the next intervention. In recording their results, students were asked to include relevant populations graphs and *WallCology* screen captures as evidence. Each team then shared their plan, predictions, and outcomes with their peers in a class presentation, using the *Common Knowledge* tool projected on the classroom's interactive whiteboard. This cycle was repeated several times, until each team was satisfied that they had improved the health of their ecosystem and achieved a desirable balance of populations.

Finding: A Role for Aggregate Representations of Community Knowledge

The *Common Knowledge* scaffolds were designed in close concert with our script, to provide orchestrational supports for students and teachers. This also allowed us to process the contents of the community knowledge base in order to create emergent, community-level views or representations that provided a sense of progress, allowing students and teachers to identify patterns, gaps, or conflicts in their collective products. For example, students worked in pairs to collect food-web observations, each of which took the form of a pairwise relationship (e.g., species X is eaten by species Y). As more and more of those observations were added (i.e., students wandering the room, observing predation events, and entering them using the *Common Knowledge* observation forms), we synthesized them into a table-like grid of all their aggregated contributions, which was displayed on the interactive whiteboard. As a result of students' distributed, independent observations, a collective product thus emerged, which became "greater than the sum of its parts"—revealing statistical patterns that could help resolve conflicts (e.g., if two student thought that an insect was a vegetarian, but there were eight observations of that species eating another insect), or suggest places where more effort was needed (e.g., if there were insufficient observations for certain species, the teacher could refer to the table to encourage students to fill in the gaps).

These aggregate representations made patterns within the data readily apparent to teachers and students, providing an important resource for whole class discussions. Teachers used them as a shared reference, highlighting areas of convergence and divergence, or gaps that required some attention. When the aggregate representations showed agreement in the data, teachers used them to facilitate discussions that allowed the class to reach consensus. Conversely, when the aggregate representations displayed disagreement, they provided direction for students on how to adjust their ongoing investigation. Divergence in the aggregate representation also provided a basis for discussion regarding best practices for inquiry, such negotiating acceptable levels of disagreement or planning how to resolve disagreements. In addition to providing a useful shared referent to guide discussions, the aggregate representations were used by students as an evidentiary database. For example, students referred to the aggregate representations of the producer–consumer relationships to construct their table group's food web.

Finding: Supporting Evidence-Based Arguments in a Scientific Community

An important goal of our research was to engage students in scientific arguments and explanations, using evidence from their *WallCology* investigations (e.g., the species population graphs showing changes in populations that resulted from their interventions). This occurred most prominently within phase 3, where students were scaffolded by the *Common Knowledge* environment, which included three distinct sections for (1) making a plan, (2) making and explaining predictions about species population changes, and (3) providing a report on the results of the investigation (i.e., how did the populations really change, and why did the changes vary from those predicted?). These reports were published in the community knowledge base and provided the basis for group presentations.

During these presentations, student groups reviewed their experiments in front of the community, with two primary goals: (1) to inform the other teams' planning (e.g., if other groups were planning manipulations involving the same species, and could learn from outcomes); and (2) to receive feedback and ideas about what they might try next (e.g., if students from other groups had done something similar or relevant, or had insights to offer about why a manipulation hadn't produced desired results). In analyzing students' presentations, we looked for three components: a claim (i.e., some conclusion or answer to their original question of how to make their ecosystem healthier), evidence (scientific data that are appropriate and sufficient to support the claim), and reasoning (a justification that connects evidence to claim). We used a customized rubric to evaluate students' scientific explanations, following the Claim, Evidence, Reasoning model outlined by McNeill and Krajcik (2011). In each of the two classrooms that we studied, teams showed consistent progress over four intervention cycles, learning from their own investigations and from the reports of their peers, and repeated this cycle four times. With each iteration, student groups were more strategic in their investigations as they became more knowledgeable about the species within their ecosystem, and about how to plan an effective manipulation. We found that students used an average of two claims in each of their presentations, with reasoning supported by evidence, including the results from other teams' investigations (Slotta, Quintana, Acosta, & Moher, 2016).

Conclusions: Classrooms as Learning Communities

KCI has been described here as a formal model for scripting and orchestration of collective inquiry, with the aim of transforming classrooms into learning communities. This model is under development through research such as the *WallCology* study reviewed above, and fits within a broader literature within the learning sciences including the FCL and KB models, which continue to receive attention from a widening circle of scholars (e.g., Kali et al, 2015). The challenges of establishing an epistemological "climate" of collective inquiry remain a major obstacle to both research and practice, reflected in Bereiter and Scardamalia's (2010) observation that it can take up to two years for a teacher to shift toward a collective epistemology. There are also real pedagogical challenges, which bring opportunities for research. How can teachers encourage autonomous inquiry while also ensuring progress on the well-defined learning goals? How can they make time for substantive inquiry given the content coverage demands? How can these learning community methods offer a means of reaching all students in the classroom, and enabling everyone to contribute and learn deeply? KCI research has investigated how community knowledge can be made visible and accessible to inform teacher-led discourse and guide inquiry progressions. We also explore the role of scripting and orchestration, to scaffold specific inquiry processes within the community, and ensure progress on the targeted learning goals. In a learning community approach, technology environments become more than just tools or scaffolds for specific learning processes, but rather serve as holistic frameworks for scaffolding student inquiry, capturing and processing the products of that inquiry, and making them available as consequential resources in subsequent activities.

Further Readings

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This seminal paper provides an early review of the key aspects of learning communities, introducing the notion, reviewing FCL, and identifying some core characteristics of the broad approach.

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). Cambridge, MA: MIT Press/Bradford Books.

This book introduces the FCL model, connects it to the psychological literature, and reviews early classroom research.

Cober, R., McCann, C., Moher, T., & Slotta, J. D. (2013). Aggregating students' observations in support of community knowledge and discourse. *Proceedings of the 10th International Conference on Computer-supported Collaborative Learning* (*CSCL*) (pp. 121–128). Madison, WI: ISLS.
This published proceedings paper reviews the authors' prior research in related topics.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal Education in a Knowledge Society* (pp. 67–98). Chicago: Open Court.
This book chapter reviews the central tenets of knowledge building, clarifies the notion of collective cognitive responsibility, and articulates the teacher's role in a knowledge-building classroom.

Slotta, J. D., & Najafi, H. (2013). Supporting collaborative knowledge construction with Web 2.0 technologies. In C. Mouza & N. Lavigne (Eds.), *Emerging Technologies for the Classroom* (pp. 93–112). New York: Springer.
This book chapter reviews the KCI model and details two classroom implementations: (1) a semester-length climate change curriculum where 5 sections of a ninth-grade class worked in collective inquiry, and (2) a graduate level seminar in media design, where students build on an existing knowledge base, handed down from prior enactments of the course, and develop inquiry-oriented pedagogy for their own investigations of emerging media.

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