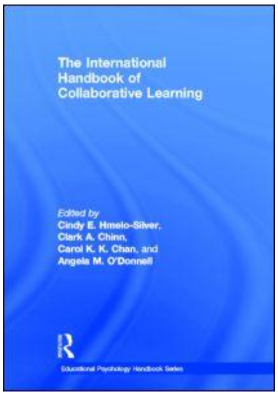

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COLLABORATIVE KNOWLEDGE BUILDING

Towards a Knowledge Creation Perspective

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INTRODUCTION

Helping students to engage in collaborative inquiry and work creatively with ideas is now a major educational goal. Despite widespread interest in inquiry learning and computer-supported learning, most schools continue to focus on surface forms of constructivist learning, with students busily engaged in gathering information from the Web and completing tasks (Scardamalia & Bereiter, 2003); for example, inquiry learning is often limited to predetermined goals, sequences of activities, and fixed standards that focus on skills rather than creating knowledge, which is the goal of real scientific inquiry (Chinn & Malhotra, 2002). Sustained and emergent inquiry that aims at *knowledge creation*, much valued in scientific and innovative communities, poses major challenges for theories and designs for collaborative learning.

A major research theme in computer-supported collaborative learning (CSCL) and the learning sciences examines how students, supported by technology, engage in inquiry, problem solving, and collaboration (Jacobson & Reimann, 2010; Koschmann, Hall, & Miyake, 2002; Stahl, 2006). Learning collaboratively has been theorized in terms of knowledge acquisition, acculturation, and knowledge creation (Paavola, Lipponen, & Hakkarainen, 2004). "Knowledge building" is an educational model of the productive knowledge work typical of scientific, research, and innovative communities. Children can collaboratively create and improve ideas that add value to the community in a way that is similar to scientists working to generate new knowledge (Bereiter, 2002; Scardamalia & Bereiter, 2003, 2006). Much of this work takes place in a computer-supported learning environment called Knowledge Forum®, which is designed to support the improvement of ideas, synthesis, and developing higher levels of conceptualization.

Scardamalia and Bereiter (2006) suggested that they were the first to use the term *knowledge building* in education, but found it in 125,000 Web documents in this domain in 2005. The term is now used frequently in the research literature on CSCL, where it generally refers to computer-supported and collaborative meaning-making processes by which groups construct understanding (Stahl, 2006). In recent years, these authors have begun to use the term *knowledge building* synonymously with *knowledge creation* to focus attention on the model (Bereiter & Scardamalia, 2008, p. 87). Knowledge building, conceived as knowledge creation, focuses on how people work together to advance the state of knowledge of the community (Scardamalia & Bereiter, 2003). These authors advocate an education agenda that students need if they are to develop a knowledge-creating culture to extend the frontiers of knowledge of the community. The need for knowledge creation is recognized in many fields, and collaborative learning designs for the knowledge era need to support students to work with knowledge productively and creatively.

This chapter focuses on the model of knowledge building, developed by Scardamalia and Bereiter since the 1980s, which can be defined as "the production of knowledge that adds value to the community" (Scardamalia & Bereiter, 2003, p. 1370). Knowledge building and Knowledge Forum were a forerunner of CSCL and have continued to develop since the 1980s; knowledge building is considered one of the major models of the learning sciences (Sawyer, 2006). There has been seminal publication of the framework (see Bereiter, 2002; Scardamalia & Bereiter, 1994, 2006) together with substantial evidence from empirical studies conducted in different countries (see Knowledge Building Exchange http://kbc2.edu.hku.hk). Despite much interest, thus far, there has been no integrative review of this model encompassing theory, analysis, design, and impact. This chapter aims to provide a comprehensive review, with a focus on knowledge creation, and to examine research issues relevant to CSCL. Following a historical introduction and overview of Knowledge Forum, the following questions will be addressed: (a) What is knowledge building from the lens of knowledge creation? (b) How can knowledge building be analyzed with a focus on knowledge-creation processes? (c) Can a model focusing on collective knowledge bring about educational benefits for individuals? (d) How is knowledge creation designed and supported in classrooms? (e) What are the roles of technology and communities in knowledge creation? The chapter closes with research directions and implications. In this chapter, the term *knowledge creation* will be used synonymously with *knowledge building* when referring to this research model.

HISTORICAL BACKGROUND AND KNOWLEDGE FORUM

The theoretical ideas of knowledge creation originated from cognitive studies on writing in the early 1980s that contrasted "knowledge telling," a linear process regurgitating what one already knows, versus "knowledge transformation," a recursive process with dialectics between the content and rhetorical spaces that transform one's knowledge (Bereiter & Scardamalia, 1987). In the 1980s, research on intentional learning examined student agency and constructive learning efforts over and above what is needed for task completion (Bereiter & Scardamalia, 1993). Cognitive research examines the nature of expertise and knowledge structure (Chi, Glaser, & Farr, 1988), but Bereiter and Scardamalia (1993) investigated the process of expertise and how people advance their expertise via progressive problem solving; building new knowledge involves students viewing their knowledge as something problematic that needs to be explained (Chan, Burtis, & Bereiter, 1997). For intentional and expert learning to take place, students need to execute high-level cognitive processes on their own and the community must become a sustaining force for knowledge advances. A new kind of learning environment was needed, with students exerting high-level agency supported by community processes, to counteract the familiar teacher-directed process.

In 1983, against this background, a prototype environment, Computer-Supported Intentional Learning Environments (CSILE) was developed for a university course. By 1986, a networked version was being used in an elementary school. CSILE continued to evolve; in 1997, it was replaced by Knowledge Forum, which was designed to make knowledge-creation processes accessible to children and to foster the creation and continual improvement of public knowledge (see http://www.knowledgeforum.com).

CSILE/Knowledge Forum is a networked environment that provides a communal knowledge space where students share their ideas and theories and work on improving them for theory building, not just information sharing. Primarily, students write (author and coauthor) computer notes consisting of questions, explanations, evidence, experiments, or reference materials that can be "contributed" (posted) as text or graphics. A major feature is the "view," which is the shared workspace where students contribute and build on others' notes (Figure 25.1). A Knowledge Forum database spanning over weeks or months typically consists of a number of views for different inquiry problems (or curriculum topics) created during the course of study. Students post notes consisting of their ideas and questions; these may develop into different theories and conceptual themes, and they can be represented graphically in the view. As an example, Figure 25.1 shows a "plate tectonics" view in which students started with a problem on how continents move apart; the squares are note icons, and the lines between the notes show the links among students' responses to each another. Many different notes are posted and students, working with their teacher, have organized disparate notes into several conceptual and inquiry themes—continental drift, sea-floor spreading, earth structure, and fossil evidence—that can be taken up in new views for deeper inquiry into the key problem. Computer notes can be moved from one view to another so that the same idea (e.g., information, evidence) can be examined from different contexts and perspectives.

As an example, with more notes on these different inquiry themes, the teacher may have discussions with students about what new areas of inquiry are needed and, with that, new views on "fossils" or "earth structure" may be created and students can further their inquiry in these areas. It is also possible that different groupings of students may specialize in different inquiry themes, taking responsibility for different views. Such an arrangement is akin to scientific inquiry in which researchers identify different themes and different research labs then delve deeper into these different issues. Views are connected and "rise-above" views can be formed to support the superordination of higher-level ideas. An example of a "rise-above" view can be "Landforms and Processes," in which students may consider the research evidence from other views to address the more central problem.

When writing computer notes or building on (responding to) others' notes, students can add scaffolds (metacognitive prompts) to support idea generation and theory improvement. Figure 25.2 shows a computer note posted by a student as she wonders about the relations between plate tectonics and continental drift. Students can start a note through the flexible use of Knowledge Forum scaffolds. The scaffolds, which include stems such as "I need to understand," "my theory," "new information," "a better theory," and "putting our knowledge together," reflect the centrality of theory development in knowledge building.

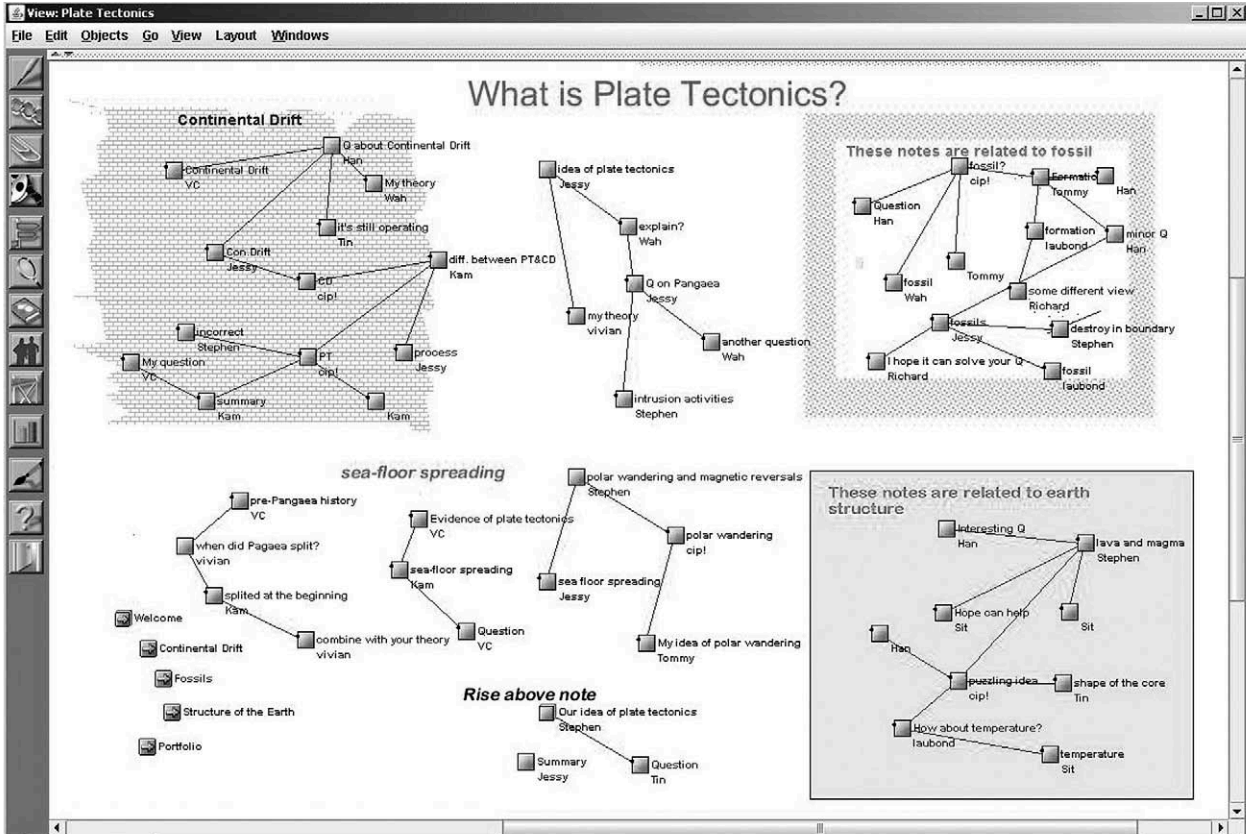

Figure 25.1 A view on Knowledge Forum for Collective Inquiry.

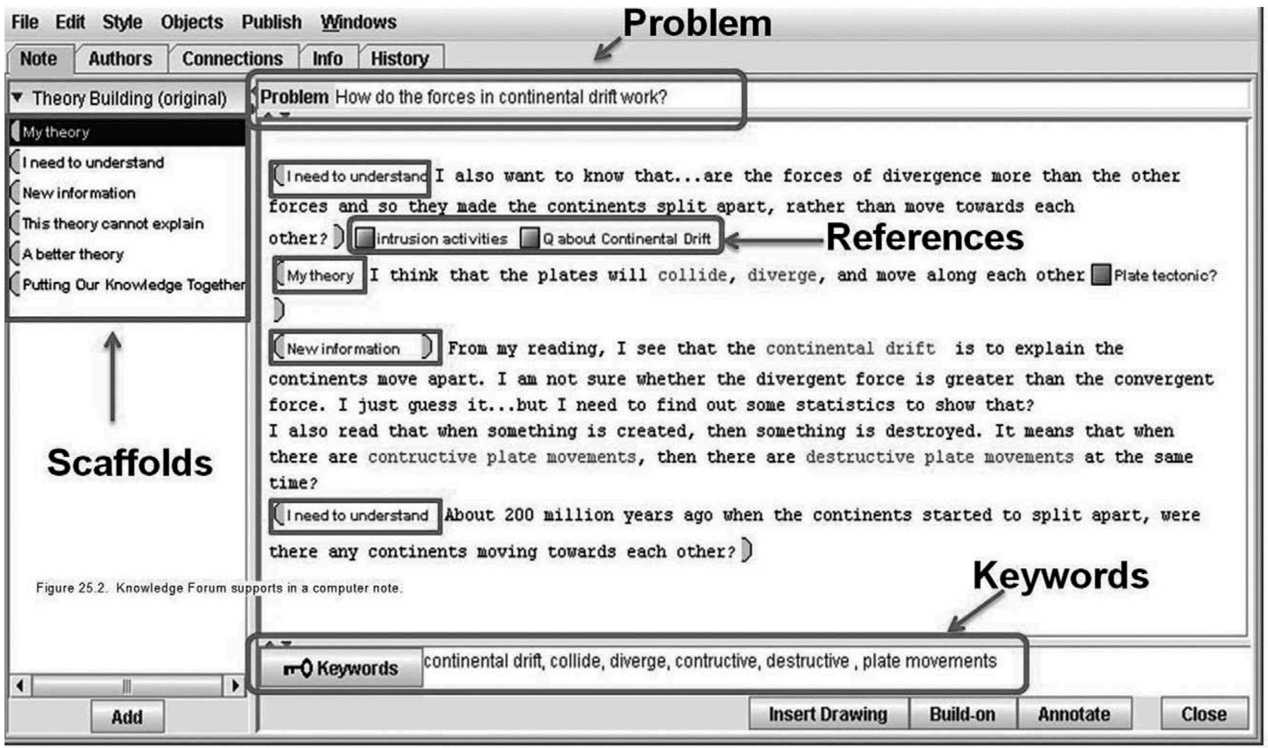

Figure 25.2 Knowledge Forum supports in a computer note.

Another feature is a *problem* prompt that helps to scaffold a problem-oriented rather than a topical approach to the discourse. A problem is usually more general than the questions for which students use the "I Need to Understand" scaffold; this functionality allows students to search to find out who in the community is working on similar problems. Other features include *keywords* to highlight domain vocabulary and for searches into similar ideas; *annotations* for individual students rather than the whole community; and *graphics* to illustrate the ideas, within a note. It is also possible to cite the contributions of others as happens in a scientific community; for example, when one student writes a note, she may add *reference links* to other notes that explain plate tectonics and continental drift, and then put forth her integrated idea (theory). Finally, the *rise-above note* can be used to synthesize contributions and introduce higher levels of conceptualization; the notes that are used in this process are subsumed by the rise-above note and are therefore no longer viewable in their original context in the view (e.g., Figure 25.1: "Our idea of plate tectontics"). The community space is designed not only for interaction, but also for enhanced community activity and improvement around shared knowledge objects.

Typically, students start their inquiry in the classroom with face-to-face discussion, then record and work on their ideas collaboratively on Knowledge Forum. Classroom inquiry frames the online work that, in turn, enriches classroom discourse. Using both the online and offline aspects of the discourse, students formulate problems (e.g., why do rainbows have colors?), advance theories, examine different ideas and models, and identify relevant information in the process of revising their theories. Students may also work in small groups on some occasions and in whole-class mode on others, conducting experiments to test theories, reading to understand difficult information, and using "knowledge-building talks" to tackle problems emerging from forum discourse. Knowledge Forum is accompanied by a set of *analytic tools* that index contributions, interactions, connectedness, and other measures (Figure 25.3). These indices provide not only research data for analysis, but also formative feedback, enabling students to assess their own contributions (see sections on analysis and technology).

KNOWLEDGE BUILDING AS KNOWLEDGE CREATION: THEORIES AND PRINCIPLES

In the CSCL and learning sciences literature, knowledge building often refers to collaborative learning and group processes to construct shared understanding supported by technology. Although this is educationally valuable, it may not include notions *of knowledge creation*. Knowledge building, with a focus on knowledge creation, places emphasis on the production and advancement of knowledge; knowledge creation is common in scientific, research, and innovative communities whose goal is to create and expand public knowledge. Scardamalia and Bereiter (2003) postulate that, just as scientists develop inventions, artifacts, and tools, school-aged children can generate ideas and theories as epistemic inventions, which can be inquired about and examined, as they work together to advance the collective knowledge of the community. Knowledge-creating dynamics include students taking agency generating knowledge problems, producing tentative theories and explanations with sustained efforts to improve them, supported by progressive discourse on Knowledge Forum (Bereiter & Scardamalia, 2008).

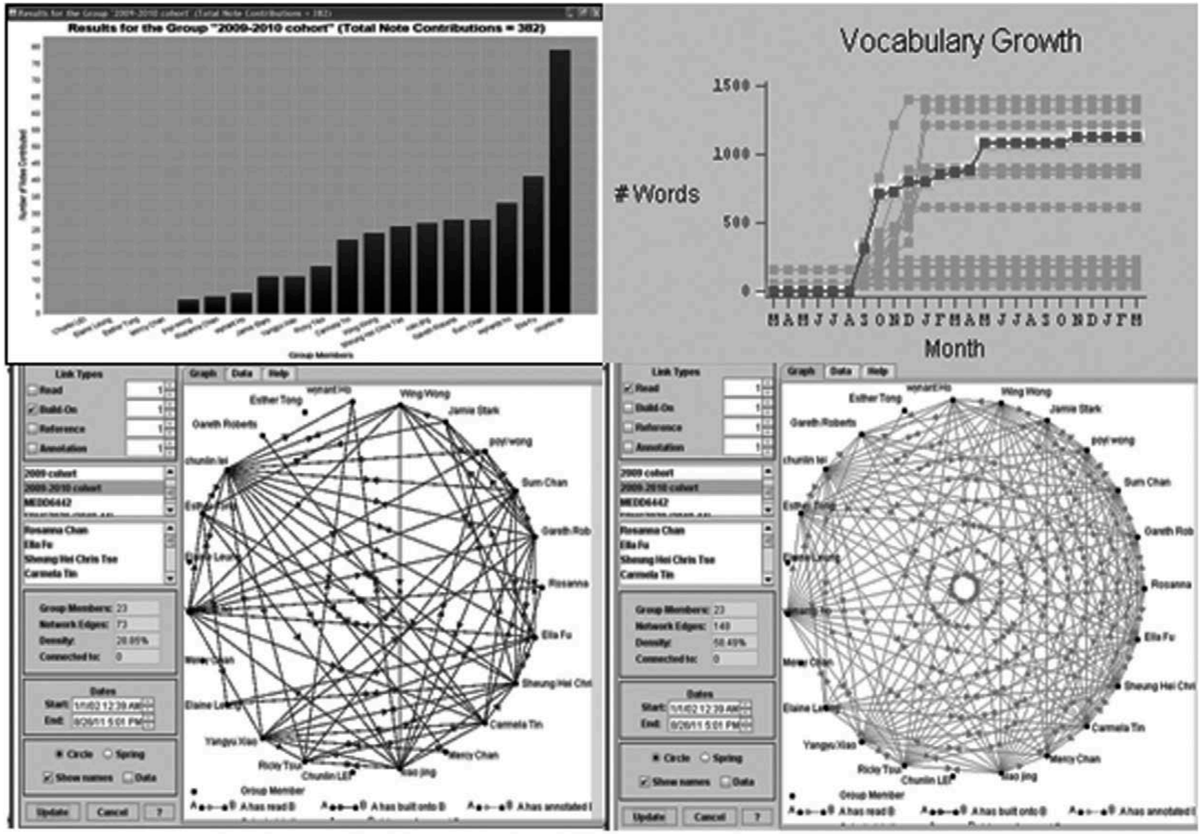

Figure 25.3 Assessment tools for Knowledge Forum: note contribution (top left), vocabulary growth (top right), note build-on density (bottom left), and note-reading density (bottom right).

This section focuses on examining the knowledge-building model, highlighting aspects of knowledge creation. Sfard (1998) distinguished between two views of learning, the acquisition of knowledge and participation in the practices of a community. Paavola et al. (2004) postulated a third view they called *knowledge creation* that integrates the first two views: they analyzed three models including the knowledge-creation company (Nonaka & Takeuchi, 1995), expansive learning (Engeström, 1999), and knowledge building (Scardamalia & Bereiter, 2003); all three focus on innovative processes of inquiry for the creation of knowledge in the community. Expansive learning, knowledge-creation company, and other current approaches focus on sociocultural activity, materials, and practices (Hakkarainen, Paavola, & Seitamaa-Hakkarainen, chapter 3 this volume), but the Scardamalia and Bereiter model of knowledge creation emphasizes epistemic and sociocognitive dynamics for collective cognitive responsibility.

Theoretical and Epistemological Foundation

Learning versus Knowledge Building. There are now major theoretical shifts from individual to social views of learning; how groups engage in constructing shared understanding is central to CSCL research (Stahl, 2006). Schooling is often about individual learning, however, and even the goal of group learning is often to improve students' individual outcomes. Drawing on Popper's (1979) theory of objective knowledge, Scardamalia and Bereiter (1994) distinguished between "learning" and "knowledge building." Learning refers to the improvement of the mind and mental capacities (World 2), whereas knowledge building refers to the improvement and creation of *public knowledge* (World 3). These authors advocated bringing World 3 into the classroom: The ideas of students can be "public knowledge" that can be improved by their own collective efforts (Scardamalia, Bereiter, & Lamon, 1994). In knowledge building classrooms, children are not merely learning or acquiring existing knowledge; they are *working to extend the frontiers of knowledge of their community.*

How Scardamalia and Bereiter describe knowledge building highlights a focus on knowledge creation. They note that knowledge building goes beyond constructing understanding; while that may be part of it, the goal is to add value to, improve, and advance community knowledge. This is echoed by research that distinguishes three modes of knowledge-building discourse: knowledge sharing as information flow, knowledge construction as coconstruction of understanding, and knowledge creation as the social practices within a community that advance the frontiers of its knowledge (van Aalst, 2009). Knowledge-creation discourse goes beyond the cognitive aspects of problem solving; it may embed knowledge construction but additionally reifies how a community comes to be interested in certain problems and how collective knowledge is advanced. A key emphasis of knowledge creation is *theory building*, which supports the advance of public and collective knowledge in scientific communities. Importantly, although emphasis is given to *collective* knowledge in knowledge creation, students also learn *individually*. The notion of knowledge creation that examines sustained pursuit for advancing public knowledge may help to address questions about the nature of these models (e.g., fostering communities of learning versus knowledge building; see Scardamalia & Bereiter, 2007) and enrich conceptualizations of learning communities (Hakkarainen, 2009).

Belief Mode vs. Design Mode. How are complex new concepts developed? How do people learn something more complex than what they already know? Bereiter and Scardamalia (2006) postulated a distinction between belief mode and design mode. Current education practice primarily emphasizes the former; for example, how children make claims, justify their beliefs, and use reasoning and evidence to support their arguments. Argumentation, construed as debates and persuasion, although popular in schools, may not generate new knowledge. While there is much interest in argumentation, it would be useful to consider other forms of discourse that have potential for the creation of new knowledge. Scardamalia and Bereiter (2006) asserted that an understanding of discourse beyond "discussion" and "argumentation" is needed. Design mode involves viewing ideas as conceptual artifacts and continually improving on them for theory building (Bereiter & Scardamalia, 2006). Drawing on Thagard's research (1989), Bereiter and Scardamalia postulated that knowledge creation dynamics involve constructing theories for "explanatory coherence"—how students theorize, construct explanation, and account for conflicting evidence, much as scientists build theories. In design-mode thinking, each cycle opens up problems to new possibilities; when a problem is solved, efforts are reinvested to tackle deeper problems, for bootstrapping and for knowledge advancement (Bereiter & Scardamalia, 1993). In addition to belief-mode thinking (e.g., "what are the reasons?" or "what is the evidence?"), these authors call attention to the role of design-mode thinking (e.g., "What is this idea good for?" or "How can this idea be improved upon?") in theory revision. While these researchers have raised concerns, different forms of argumentation, persuasion-based and inquiry-based, have been identified (Chinn & Clark, chapter 18 this volume). Persuasion discourse is limiting for new ideas but inquiry-oriented collaborative argumentation may align more with knowledge generation. The differences and dialectics of belief-mode and design-mode thinking may shed light on different forms of knowledge building in CSCL and need to be examined further.

Knowledge-Building Principles

Scardamalia (2002) has postulated a system of 12 principles to characterize and design knowledge building. This chapter outlines the most often examined ones, from the lens of knowledge creation, and relates them to other approaches.

Epistemic Agency. Metacognition, reflection, and agency are emphasized in inquiry and collaborative models (e.g., problem-based learning; Hmelo-Silver & De Simone, chapter 21 this volume); epistemic agency includes these while emphasizing *dialectics of personal and collective agency.* Scardamalia (2002) noted that epistemic agency involves students setting forth their ideas and negotiating a fit between their personal ideas and ideas of others, using contrasting models to spark and sustain knowledge advances. There is now increased interest in social metacognition in CSCL; for example, the self-regulation of one's own cognition, regulation with others, and collective regulation (Winne, Hadwin, & Perry, chapter 26 this volume). While there are similarities with other approaches that focus on sociometacognitive processes, there are also differences. CSCL research examines shared goals and understandings, while epistemic agency involves students having an overall sense of purpose and commitment to making their ideas better collectively beyond completing tasks.

Idea Improvement. Contrary to school practice, which sets curriculum, standards, and objectives as end-states, knowledge creation focuses on scientific progress and the sustained pursuit of ideas. Although student ideas improve over time with strong design in CSCL and learning sciences, what distinguishes improvable ideas is the notion of *intentionality* and explicit goals of the community to *pursue* idea improvement, which makes knowledge-creation efforts closer to goals and dynamics in research communities (Scardamalia, 2002). This principle emphasizes metacognitive and epistemic components, with students examining what is known, what needs to be known, and why and how a given idea can be improved upon. Key to the principle of improvable ideas is the epistemic understanding that ideas are knowledge objects that can be explored, examined, and improved upon, and this may also involve the volition to engage in complex knowledge work discussed in the framework of epistemic cognition (Chinn, Buckland, & Samarapungavan, 2010).

Constructive Use of Authoritative Information. A common challenge with online discussion in CSCL is fragmented discourse and "everyday talk" (Hewitt, 2005). *Constructive uses of authoritative information* underscores that students should consider "authoritative sources" of the discipline, such as empirical evidence, experiments, and academic resources, but examine them critically in the context of what they know and the relevance to their problem solving. In practice, student discourse is frequently devoid of such sources or they are treated uncritically. Constructive use of authoritative information may address problems of "everyday talk" as students bring information directly to bear on the problems to enrich the discourse. CSCL research also examines and scaffolds students to search for new information; in knowledge creation, constructive use of information is needed for *theory revision.* Participants in the community have a responsibility to enrich the pool of information necessary for community advances, and that brings them closer to the kind of knowledge creation practice of scholarly and research communities.

Community Knowledge. The participants' commitment to advance community knowledge is central to knowledge creation. Creative work with knowledge involves not only personal learning, but also communal work on problems the community deems important. Working together allows improved ideas and theories to diffuse through the communal knowledge space; community knowledge is extendable to connected communities and multiple communities through technology (Scardamalia, 2002). Community knowledge resembles CSCL's emphasis on group cognition—the whole is more than the sum of the parts (Stahl, 2006). While CSCL research also examines collective work beyond small groups supported by technology (e.g., Wikis; Cress & Kimmerle, 2008), community knowledge goes beyond representing the *current* state of knowledge and includes theory building and design-mode efforts to *advance* the current state of knowledge.

Taken together, these principles may shed light on examining and scaffolding for productive discourse in CSCL. A common challenge in CSCL and online forums is that putting students together may not bring about productive collaboration (Kreijins, Kirschner, & Jochems, 2003); students may consider collaboration as knowledge sharing rather than knowledge-creating efforts to advance the quality of their discourse (van Aalst, 2006). Using a knowledge-creation perspective, students can engage in *epistemic agency*, reflecting on personal and collective knowledge, and comparing different ideas (models) to spark advances. Such agency is possible only with the epistemic belief that *all ideas are improvable* as objects of inquiry via collective efforts. Students need to take on epistemic and metacognitive roles, considering gaps in discourse and how ideas can be improved. It is important to be aware of the cutting-edge of the discipline—students need to make *constructive use of information* for explanation, evidence, and theory revision for the community. The goals are collective advancement and the creation of useful *community knowledge* which facilitates further knowledge creation. These principles illuminate knowledge creation dynamics with implications for advancing CSCL.

This knowledge-building model, with a focus on knowledge creation, has similarities to other prominent models of collaborative inquiry, including project-based learning (Krajcik & Blumenfeld, 2006), Learning by Design (Kolodner et al., 2003), and Problem-Based Learning (Hmelo-Silver & De Simone, chapter 21 this volume), all of which focus on problems or questions as a starting point, and the centrality of discourse, metacognition, inquiry, and problem solving. However, there are also differences. At a more general level, these approaches are sophisticated and invaluable pedagogical models that examine and scaffold deep understanding, collaboration, and knowledge construction. Knowledge creation is a pedagogical model, but it is also a more general model that seeks to characterize and explain phenomena and processes observed among innovative communities for knowledge production. When comparing these models as pedagogical models, they also differ. Primarily these approaches focus on small groups, whereas knowledge creation emphasizes the class community (see section on "Classroom Design and Pedagogy for Knowledge Creation"). As these inquiry-based approaches emphasize knowledge, inquiry skills, and epistemic growth, knowledge creation focuses on advancing community knowledge. As well, less attention is given to structured inquiry and curricular goals, with a strong emphasis on emergent processes. Knowledge creation places centrality on student agency and the sustained pursuit of idea improvement and collective advances; problems generate new problems and knowledge generates new knowledge (Bereiter & Scardamalia, 2010). There may be different views as to whether an educational model needs to be dependent on technology; in this model, theory, pedagogy, and technology are integral to one another. The following sections review empirical studies in this research tradition. This chapter focuses on research that is congruent with the conceptualization of knowledge building as knowledge creation.

ANALYZING KNOWLEDGE BUILDING: SCIENTIFIC PROCESSES OF KNOWLEDGE CREATION

Different approaches have been employed to analyze the nature, evidence, and development of knowledge building focusing on knowledge-creation processes. In comparison to most analyses in the field of CSCL, data sources are usually based on student work for a prolonged period, from a few weeks to a few months, and sometimes spanning several years.

Contribution, Interactions, and Connectedness on Knowledge Forum: Sociocognitive–Behavioral Indices

Sociocognitive and technological processes are intertwined (Scardamalia, 2002). Students' contributions, participation, and networking patterns on Knowledge Forum can be examined using server log data from a set of analytic tools (Figure 25.3); these indices can be generated for individuals, discussion views, and the classroom community. A set of commonly used "Basic Knowledge-Building indices" (e.g., numbers of notes written/read, scaffolds, revisions, keywords, references) from the Analytic Toolkit (Burtis, 1998) measure participation and contribution patterns. The numbers of authored and coauthored notes illustrate contributions to the knowledge space and the use of scaffolds and revisions reflects metacognition and recursive processes. These quantitative indices have shown changes in participation over time, and demonstrate correlations with note quality and domain understanding (Lee, Chan, & van Aalst, 2006; van Aalst & Chan, 2007). Another major set of analyses involves indices derived from Social Network Analysis (SNA; e.g., who read and build onto whose notes, note-reading and note-linking percentage and density, in-degree and out-degree, and clique) that examine the extent of "community awareness" and "community connectedness" and dynamic patterns of collaboration. SNA has been used to examine participation patterns to illustrate changing patterns toward collective cognitive responsibility (Zhang, Scardamalia, Reeve, & Messina, 2009) and knowledge networking among researchers (Hong, Scardamalia, & Zhang, 2010). Analyses that employ these indices provide basic measures of interaction and connectedness. For example, Zhang et al. used SNA to examine participation patterns in three different pedagogical designs, and found that the design in which the teacher was least central was the most effective in terms of knowledge advancement and the diffusion of new knowledge. Although measures from SNA do not assess the quality of ideas or interactions, there is no basis for community knowledge advances without a high level of connectedness. Assessing changes in quantitative indices provides useful background information to guide further qualitative analyses.

Quality of Notes: Conceptual and Epistemological Processes

A key approach to analyzing knowledge creation with a focus on theory building pertains to how children can engage in scientific research similar to that of scientists in pursuit of scientific advances. Oshima, Scardamalia, and Bereiter (1996) compared CSILE Grade 5 students who had low and high degrees of conceptual progress; the more advanced students focused on *problem-centered knowledge*, whereas their counterparts pursued *topical knowledge*. Hakkarainen (2003, 2004) analyzed the quality of CSILE notes (idea units) in terms of explanatory-driven inquiry: how students generate and improve their intuitive theories as they formulate problems, develop hypotheses, and generate explanations. These analyses indicate that the discourse of CSILE students changes over time, from fact-based to explanatory-based inquiry. Several mechanisms were identified, including generating research questions, using scientific information, and comparing one's own naïve models with scientific models. Such analyses emphasize epistemological inquiries, going beyond superficial distinctions coding "what" versus "how and why" questions. Lee et al. (2006) focused on epistemic quality, identifying depth of inquiry and depth of explanation that distinguished between general questions and those that identified gaps in understanding with hypotheses, conjectures, and the formulation of explanations; more sophisticated explanations include the synthesis of different ideas, which is similar to metadiscourse. Analyses have shown that epistemic levels of questions and explanations are correlated with domain knowledge (Lee et al., 2006). Although analyses of questions are commonly examined as collaborative processes, these analyses reflect concerns for epistemic inquiry—questions are analyzed in terms of varying depths as conceptual artifacts subject to inquiry and explanation.

Quality of Discourse: Conceptual, Epistemological, and Sociocognitive Processes

Researchers have examined how students engage in progressive discourse to explain natural phenomena. Bereiter, Scardamalia, Cassells, and Hewitt (1997) analyzed Grade 5 students' group-notes on Knowledge Forum and identified four themes characterizing collective inquiry as *scientific progress*: mutual advances in understanding, empirical testability, expanding the basis for discussion, and commitment to openness. In the light of controversies surrounding postmodernism, these researchers argued that scientific inquiry is neither *relative* nor a grand march toward some *truth* or accepted scientific theory; rather, it is characterized by continual efforts to improve on existing theories. Although these students may not be creating scientific knowledge, they are engaged in the kinds of productive discourse that demonstrate commitment toward scientific progress for knowledge creation.

Whereas earlier analyses examined idea units or individual notes, now considered limited on their own for collective cognition, parallel with changes in CSCL (Puntambekar, Erkens, & Hmelo-Silver, 2011), current work focuses on the analyses of connected discourse. A major approach adopted by many researchers in this tradition involves using a set of knowledge-building principles to analyze the discourse (Scardamalia, 2002). One analytic tool is the use of *inquiry threads*, conceptual clusters focusing on problems that demonstrate idea development (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007); analyses include examining the problems students are working on, and the epistemic complexity and sophistication of their scientific explanations. Qualitative and quantitative analyses demonstrate how Grade 4 students are engaged in the sustained pursuit of ideas, illustrating the principles of authentic problems, idea improvement, community knowledge, and constructive uses of information. Another approach examines e-portfolio with metadiscourse, in which high school students create a rise-above note that documents how their collective knowledge has advanced (E. Y. C. Lee et al., 2006; van Aalst & Chan, 2007). Similar to inquiry threads, e-portfolios were analyzed to illustrate idea development important for knowledge creation; the portfolio narratives range from general descriptions to analysis of processes and metadiscourses, and demonstrate the interaction of individual and collective understanding.

The notion of knowledge creation has been examined directly in research that identified three different kinds of discourse modes—knowledge sharing, knowledge construction, and knowledge creation—among Canadian high-school students working on Knowledge Forum (van Aalst, 2009). Students worked in four groups and they collectively inquired into infectious diseases. Analyses were conducted for different discourse moves pertaining to information, questions, ideas, emergence, metadiscourse, and social dynamics. Comparing different groups working on Knowledge Forum, the researcher found that student groups identified as making more knowledge gains (through group summary notes) made more discourse moves coded as social processes and community dynamics compared to their counterparts.

Classroom Discourse: Sociocognitive, Sociocultural, and Other Processes

Classroom discourse and process can illuminate the broader aspects of collaboration and show how authentic knowledge work can take place in classroom. Caswell and Bielaczyc (2001) examined how Knowledge Forum alters the relations between children and scientific knowledge—children see themselves as contributors to knowledge in a community. Zhang and Sun (2011) analyzed online and offline discourse to examine reading for idea improvement and constructive use of authoritative information. Other studies have examined different processes relevant for understanding knowledge-creation discourse, such as metaprocedural comments and collective regulation (Cohen & Scardamalia, 1998); semantic analyses and idea diversity (Teplovs & Scardamalia, 2007); and lexical process in domain-specific vocabulary and epistemic verbs (Sun, Zhang, & Scardamalia, 2010).

Analyses of knowledge creation have encompassed different approaches, often used in combination, and both individual and collective processes have been examined. Current CSCL schemes for analyzing collaboration generally focus on interaction processes and pay relatively less attention to the conceptual quality of ideas. On the other hand, analysis of knowledge creation, as described, while encompassing sociometacognitive processes, tends to focus on conceptual-epistemological aspects. More broadly, to enrich research on the analyses of collaboration, it may be helpful to examine how analytic schemes can be developed to examine more closely the intertwined relationships between collaborative interaction and conceptual quality of ideas.

EVALUATING THE EDUCATIONAL EFFECTS OF KNOWLEDGE CREATION

Since the model of knowledge creation emphasizes collective and community advances, there may be questions as to whether this model has educational benefits for individual students. This section reports on empirical research that illustrates the educational benefits for students experiencing knowledge creation in different areas.

Scientific Inquiry, Reflection, Epistemic, and Conceptual Understanding

The previous section has suggested that even young students can engage in scientific inquiry and knowledge work, including formulation of problems, generation of models and theories, and sustained pursuit of knowledge. Evaluation studies have shown that CSILE students outperform non-CSILE students in scientific understanding; they construct deeper explanations with coherent accounts rather than merely listing facts, and their understanding is not hampered by misconceptions in the CSILE database (Scardamalia et al., 1994). Research comparing Grade 5 students working in the face-to-face condition versus the CSILE condition has shown that students make more group-regulated metacomments in CSILE-supported discourse compared to more self-regulation comments without CSILE (Cohen & Scardamalia, 1998). Research has indicated that CSILE students are more reflective in their portfolios, while interviews have revealed beliefs about learning with higher epistemic levels compared to non-CSILE students (Scardamalia et al., 1994). In a design-based study, students in CSILE classrooms were shown to move from listing information to formulating better theories (Hewitt, 2002). Research on conceptual change indicated that high-school chemistry students working on knowledge building shifted to higher levels of epistemic beliefs compared to their counterparts (Chan & Lam, 2010).

While focusing on design and process, researchers have also obtained outcome measures using portfolio notes (Zhang et al., 2007) and demonstrating substantial pre- and posttest gains on scientific concepts (Oshima et al., 2004; van Aalst & Truong, 2011).

Few studies have included comparison groups, but there are exceptions: several studies have shown that students working on Knowledge Forum outperformed other students on domain understanding (Lee et al., 2006; van Aalst & Chan, 2007). There is also some evidence linking collective and individual advances; analyses of collective inquiry threads demonstrating the use of problems and explanations have been related to individual student's scientific knowledge in personal portfolio notes (Zhang et al., 2007). Furthermore, the extent to which students engage in collective agency and social metacognition (reflection on principles, metadiscourse) while working on Knowledge Forum has been found to predict their individual achievement in essay writing (E. Y. C. Lee et al., 2006) and gains in epistemic and conceptual-change scores (Chan & Lam, 2010).

Reading Processes, Textual, and Graphical Literacy

While this research model has been used primarily in science domains, research has also shown positive benefits in language and literacy. CSILE students were found to outperform their non-CSILE peers in reading difficult scientific texts, have more sophisticated beliefs about learning, and show deeper text understanding (Scardamalia et al., 1994). Recent research has examined the reciprocal advantages of literacy and knowledge work, and how literacy is best developed in academic discourse. Collaborative reading, transformative writing, and dialogic literacy are important for generating new knowledge and supporting high-level literacy (Zhang & Sun, 2011). In analyses of textual literacy—including the amount of writing, distinctiveness and frequency of words used, domain-specific vocabulary, and *epistemic* words (e.g., wonder, hypothesize, experiment, explain)—students who used Knowledge Forum consistently performed above their grade levels (Sun, Zhang, & Scardamalia, 2010).

In Knowledge Forum, students can use graphics within their notes and views to represent their ideas; graphical literacy refers to their ability to use visual and communication skills in building knowledge. Grade 3 and 4 students with Knowledge Forum experiences have demonstrated greater graphical literacy than do their Grade 6 counterparts, producing graphical representation of knowledge with more dynamic information, interpretive summaries and advanced causal explanations (Gan, Scardamalia, Hong, & Zhang, 2010).

Curriculum Standards and Educational Attainment

Although knowledge-building environments are not designed primarily to improve test scores, there is evidence that they do have positive benefits. Evaluation studies have shown that CSILE students outperformed comparison groups on standardized tests on language and literacy, with these advantages persisting over years (Scardamalia et al., 1994). However, there have been no differences reported in standardized math test scores; as discussed above, reading and writing undertaken in Knowledge Forum account for the advantages. As the knowledge-creation approach has spread to Asian countries, researchers have assessed student knowledge using national curriculum standards (Oshima et al., 2004). Students have outperformed their counterparts on public examination results when their teacher has integrated the sociometacognitive aspects of the knowledge-creation approach with the sociocultural milieu of the Asian classroom (Chan, 2008).

Equity Issues and Different Learners

It is commonly believed by educators that inquiry approaches benefit only high-achieving students, despite evidence to the contrary (Zohar & Dori, 2003). The knowledge-creation approach stresses community advancement, emphasizing that all students can contribute. In a study of social studies students, for instance, Niu and van Aalst (2009) reported similar progress with knowledge-building principles among both regular and honors high school students. Similarly, So, Seah, and Toh-Heng (2010) demonstrated that both high- and low-achieving students in an elementary classroom in Singapore made gains assessed with knowledge tests based on the National Curriculum Standards when using Knowledge Forum. Moss and Beatty (2010) explained scaffolding in terms of the principle of democratizing knowledge and showed how low-achieving Grade 6 students incorporated and reinterpreted the mathematics solutions presented by their high-achieving peers.

Although most research has been conducted with Canadian elementary science students, this model has been examined in a variety of research contexts for different learners in different cultures, including preschool children (Pelletier, Reeve & Halewood, 2006), Aboriginal students (McAuley, 2009), tertiary students (de Jong, Veldhuis-Diermanse, & Lutgens, 2002), nursing community practitioners (Russell & Perris, 2003); and students in Asian classrooms (E. Y. C. Lee et al., 2006; Oshima et al., 2004).

This section has reviewed studies reporting various educational benefits. Compared to other technology-enhanced inquiry-based programs (e.g., H. S. Lee, Linn, Varma, & Liu, 2010), this research tradition has made less progress evaluating children's learning of specific science content. While some questions may be raised as to whether this model, which emphasizes emergent and collective processes, is an effective way of learning science content, a different view is to consider what science learning encompasses; innovative programs may have different theoretical goals reflecting knowledge acquisition, acculturation, and knowledge creation (Chan & van Aalst, 2008). As the research program focuses on process and designs, most of the studies have not included comparison groups. Moreover, it is useful to note that it is insufficient to just assign students to work on Knowledge Forum when examining the effectiveness of the program; all the reported studies have involved careful curricular designs aligned with the goals of knowledge creation. There has been considerable interest in using the technology of Knowledge Forum, often in interventions of short duration, and the results can be disappointing without sustained implementation (Hurme & Järvelä, 2005). For advances to occur, classroom and technological designs need to be aligned with principles of knowledge creation.

CLASSROOM DESIGN AND PEDAGOGY FOR KNOWLEDGE CREATION

How can knowledge creation be designed and supported in classrooms? Knowledge-creation pedagogy focuses on open and emergent approaches and design-based research that support improvable designs and practices (Collins, Joseph, & Bielaczyc, 2004). Rich descriptions of classroom work are reported in another chapter (Bielaczyc, Kapur, & Collins, chapter 13 this volume).

Task-Based versus Idea-Centered Approaches

A major theme in supporting creative knowledge work in the classroom is to shift focus from *tasks* to *ideas*—Knowledge Forum is designed to give a central role to student ideas. As discussed earlier, students put forth ideas and problems and propose theories to explain them; they continually improve on these theories by making constructive use of information and working for collective advances. Hewitt (2002) reported an expert teacher's changing designs and identified several ways in which this teacher scaffolded idea development: problem-centered collaboration; productive queries; making student thinking central; iterative progression of learning; and a focus on understanding. Idea-centered approaches need to be accompanied by a *progressive curriculum*. Caswell and Bielaczyc (2001) described how students collectively pursued inquiry beyond the goals defined by the curriculum in ways that resemble the trajectory of Darwin's inquiries. Scardamalia (2002) noted that students working on inquiry are often engaged in task completion without *intentionality* or goals. Caswell and Bielaczyc explicitly presented the notion of idea improvement to Grade 5 and 6 students ("Ideas are pretty neat things. We've all got ideas and the thing about ideas is that they can be improved," 2001, p. 288); even young students can take on agency to pursue idea improvement.

Fixed Groups versus Emergent Groups and Communities

Knowledge building is often examined in small groups in CSCL; it is useful to examine how to scaffold authentic knowledge work that emerges beyond fixed groupings. Zhang et al. (2009) reported a 3-year study of how a teacher changed his collaborative design with progress toward knowledge creation. In Year 1 students worked in fixed groups, in Year 2 they worked in interactive groups, and in Year 3 the whole class worked collectively in opportunistic ways to inquire into emerging problems. Knowledge Forum affordances such as views and rise-above supports make it more possible for students to come together as opportunistic groups working on emerging problems. Social network analyses showed that the teacher was central in Year 1 but, by Year 3, was just a member of the community. These longitudinal findings show that the shifts toward flexible groups are associated with more knowledge advances. Such pedagogy and design, with emergent goals and problems, also reflect the knowledge-creation dynamics in scientific communities. One implication for CSCL pedagogy is that there can be more flexible use of small groups, emergent groups, and the whole class for knowledge diffusion in the community.

Procedure-Based versus Principle-Based Design

How do teachers go about understanding knowledge creation so they can implement and sustain the pedagogy in the classroom? A major problem in implementing innovation is that teachers often follow surface procedures while distorting the underlying key principles (Brown & Campione, 1996). Scardamalia and Bereiter (2006) advocated the importance of a principle-based approach rather than one that focuses on procedures, routines, and sequences of activities. In such an approach, teachers are encouraged to inquire into classroom practice from the lens of knowledge-building principles, which is consistent with the notion of adaptive expertise (Lin, Schwartz, & Hatano, 2005). Knowledge Forum provides a workspace for the realization of these principles;

students work with their teacher in flexible ways rather than follow structured guides and scripted activities (Reeve, Messina, & Scardamalia, 2008).

Oshima et al. (2004), comparing activity structures common in Japanese classroom with more open, emergent designs, reported gains in deeper student understanding. Van Aalst and Chan (2007) used four knowledge-building principles in e-portfolio assessment and asked high school students to document their own trajectories of growth; students developed insights into the nature of knowledge-building discourse because these principles provide criteria for monitoring their work (see Winne et al., chapter 26 this volume). Students using principles demonstrated more knowledge gains than did their counterparts. At the school level for teacher development, Zhang, Hong, Scardamalia, Teo, and Morley (2011) examined principle-based innovation over 8 years and explored how teachers focused on principles as they continually improved their practice. While this model originated in Canadian classrooms, there are now examples of how it can be implemented by teachers new to the approach (van Aalst & Truong, 2011). A principle-based approach may also address the question of appropriating collaboration, technology, and innovation across cultural contexts; surface activities may vary, but deep principles are needed to inform the designs (Chan, 2011).

Knowledge creation is a complex approach and the focus on ideas and principles rather than scripted activities makes it even more challenging. Pedagogy and technology design should align with the theoretical foundation of the model (Hong & Sullivan, 2009). Given the epistemic focus, principles, rather than procedures, are needed to allow for emergent processes in knowledge creation. Current controversies exist regarding structured instruction versus inquiry-based learning (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006). It may be useful to consider different goals of the pedagogical models; for learning of content and skills, more structure may be useful, but less structured pedagogy may be more appropriate for emergent processes; and there may be a continuum for different approaches. Moreover, knowledge-creation pedagogy, as well as other models, also requires consideration of the broader sociocultural dynamics of classroom implementation. Bielaczyc (2006) discussed creating a social infrastructure framework to support knowledge creation in the classroom, and this can be applicable to other CSCL models (see also Bielaczyc et al., chapter 13 this volume).

TECHNOLOGY FOR KNOWLEDGE CREATION AND KNOWLEDGE COMMUNITIES

Technology Embedded in Theory and Pedagogy

The earlier section has introduced the features of Knowledge Forum; this section focuses on key themes that characterize the design of technology environments in support of knowledge creation (Scardamalia, 2004; Scardamalia & Bereiter, 2003).Whereas many CSCL environments focus on knowledge construction, networking, and communication, CSILE/Knowledge Forum is designed to *embed* theory and pedagogy to support advances in ideas and theories. Unlike CSCL environments using fixed inquiry guides, Knowledge Forum uses an *open* environment with flexible and opportunistic prompts for emergent goals; for example, "scaffolds" have epistemic purposes different from sentence openers in many CSCL environments. The communal knowledge space supports students' work on theory improvement: "Citing" and "referencing" others' notes is key to scholarly work; these trajectories and historical records provide accounts of children's growth of ideas (analogous to evolution of ideas in science). Unlike threaded discourse, Knowledge Forum notes "live" in different views that allow students to represent knowledge and reformulate ideas in different ways. Research on e-portfolios capitalizes on such affordances (i.e., "reference links") to characterize and to scaffold collective knowledge (van Aalst & Chan, 2007). Knowledge Forum technology emphasizes superordination and higher level structure to support emergence and bootstrapping. Opportunistic searching and linking of ideas, persons, and groups help participants connect with others and to identify the cutting-edge of inquiry in the community.

In terms of further development of Knowledge Forum, Bereiter and Scardamalia (2011) highlighted several recurrent themes: (a) one discourse, multiple access points; (b) metadiscourse as discourse about discourse (where are we heading?); (c) Web objects as objects of inquiry; (d) supports for tagging, citing, and referencing work for the evolution of ideas; (e) developing idea tools and idea spaces, for collective advances; and (f) support for rise-above, ubiquitous theory building and self-organization. Although Knowledge Forum supports many advanced processes, some teachers and students may not understand the affordances and continuing classroom design studies are needed. In light of new technological advances in CSCL, how Knowledge Forum will continue to develop also poses fruitful and challenging questions for further inquiry.

Technology for Concurrent, Embedded, and Transformative Assessment

How does technology designed for assessing knowledge-creation processes both examine and scaffold the process? Knowledge Forum technology includes analytic tools and assessment tools, including Analytic Toolkit (Burtis, 1998) and Java-based Applet tools for analyzing contribution, interaction, and connectedness (Figure 25.3). While usage statistics are common for online forums, these tools are premised on the principle of concurrent, embedded, and transformative assessment. Assessments are "concurrent" in that they provide instantaneous feedback; are "embedded" into the pedagogy; and are "transformative" in that they can change the process (Scardamalia, 2002). Knowledge-creation communities assess and monitor their own progress as well as difficulties so as to chart new advances (van Aalst, chapter 16 this volume). CSCL assessment technology usually involves the researchers designing tools to analyze student discourse after the study has been completed. Knowledge Forum assessment tools, however, are designed to be used not only by researchers for analysis but also by teachers and students, who use the tools and indices formatively for monitoring progress for new cycles of improvable work. As an example, students working with their teacher can use the indices (e.g., use of scaffold; who has read whose notes) to reflect and to monitor how they have been making progress individually and collectively and what changes are needed for advances. While these assessment tools are specific to Knowledge Forum, the idea can be relevant to designing other CSCL tools for students to monitor their collaboration and metacognition.

There is other work analyzing knowledge creation using technology; for example, automatic coding and visualization techniques (Law, Yuen, Wong, & Leng, 2011). Teplovs and Scardamalia (2007), using Knowledge Visualizer, investigated the use of latent semantic techniques and visualization tools to identify notes with semantically linked ideas for examining idea diversity. Other ongoing development continues to focus on designing assessment tools that both "examine" and "transform" the process. Van

Aalst and colleagues (2012) have developed the Knowledge Connection Analyzer which allows participants (teachers and students) to query their work including the prompts: (a) Are we collaborating? (b) Are we putting our knowledge together? (c) How do our ideas develop over time? (d) What is happening to my idea? Development of these and other tools may support students to monitor, regulate, and take collective responsibility for advancing their knowledge work. A broader question for CSCL tool development is to consider how tools can be designed to be employed by participants themselves, thus allowing both *assessing* and *scaffolding* collaboration in knowledge communities.

Knowledge Networks and Communities for Knowledge Creation

Collaboration, conceptualized as knowledge creation, provides the opportunity to understand how knowledge can be created and sustained in knowledge communities supported with technology. Laferrière et al. (2010) examined knowledge-creation partnerships and designed school innovation with networks of schools using the research model. Chan (2011) discussed how knowledge creation can be sustained in a teacher network supported by Knowledge Forum, with the teachers working as a knowledge-creating community to create community knowledge that helps them to pursue further knowledge.

A major initiative for developing knowledge-creation communities is the Knowledge Society Network (KSN), based at the University of Toronto, which consists of a worldwide knowledge innovation network and is supported by Knowledge Forum's flexible structure and affordances. The model of knowledge creation is now implemented in many countries. KSN participants include researchers, scientists, engineers, teachers, policymakers, and professionals from various sectors; they research on knowledge creation in their own sites, while contributing to the meta database as members of a knowledge creation community. A key goal of the KSN is to realize the vision of knowledge creation in multiple networked communities. Hong, Scardamalia, and Zhang (2010) have analyzed the growth of the KSN network over a period of 4 years, identifying a variety of network patterns for sustained knowledge innovation. There are major barriers and sustainability challenges; nonetheless, it demonstrates Knowledge Forum's potential to support theories of knowledge creation with symmetrical community advances.

RESEARCH DIRECTIONS AND CONCLUDING REMARKS

The importance of working collaboratively with knowledge is now recognized widely in the knowledge era (e.g., Organisation for Economic Co-Operation and Development [OECD], 2004), and designing collaborative learning supported by technology is a major research theme. This chapter has reviewed the knowledge-building model from the perspective of knowledge creation. A key theoretical focus of this educational model is to examine and foster the goals and dynamics for generating and advancing community knowledge, similar to those in scientific and innovative communities, and Knowledge Forum is designed to support the knowledge-creation processes. A review of the literature suggests that students from different ages and different cultures are able to move beyond surface forms of constructivism and engage in knowledge-creation dynamics. There is also some evidence of educational gains in scientific inquiry, reflection, epistemic understanding, textual and graphical literacy, and educational attainment. This model is commonly known as knowledge building, but examining the model from the lens of knowledge creation may suggest areas of further research.

There are now increasing research interests in knowledge building in CSCL, referring generally to how students collaborate to construct knowledge and to learn in groups. Knowledge building as knowledge creation, focusing on sustained theory-building efforts and community dynamics, may help to address issues related to the complex process of creative work with ideas in knowledge communities; further work can be conducted on different and related approaches and models of knowledge building (also see Hakkarainen et al., chapter 3 this volume). Research on CSCL has examined the importance of collective cognition mostly in small groups, usually over short time spans, and knowledge creation may examine further how collective cognition can be developed, sustained, and *advanced* in communities. Conceptualizing knowledge building more broadly and examining collaboration as knowledge creation will raise new questions for CSCL theories and designs.

This chapter has reviewed different approaches to analyzing knowledge building, focusing on knowledge creation processes. While there are some illuminating accounts, stronger evidence of knowledge creation is needed. Development of this model necessitates more analysis of what constitutes knowledge-creation discourse, as well as the identification of indicators and discourse mechanisms in emergent processes, metadiscourse, and social dynamics. A broader question for CSCL methodology is to examine the analyses of collaborative interactions with the conceptual quality of idea development.

Knowledge-creation pedagogy emphasizes ideas, emergence, and principles. This research model has now been implemented in many different countries and contexts, but it is one that is difficult to implement well without a deep understanding of its epistemology. The creation of new ideas is key, but scaffolding for emergence and self-organization needs further investigation across different research settings and contexts. In light of the debates between structured instruction versus inquiry learning, the polarized tensions, such as principles versus procedures, can be examined more closely, and to explore their dialectics to shed light on technology-enhanced designs for different goals and forms of collaboration.

The review shows positive educational benefits of knowledge creation but that there also is a need to develop stronger evidence. More broadly, for this model and others in CSCL, the dynamics of how collective knowledge can be diffused in the community need to be investigated further. This model emphasizes the roles of technology that need to *embed* theory and pedagogy, and highlights the design of CSCL assessment technology that both *examines* and *scaffolds* collaboration. The nature and dynamics of knowledge creation also need to be tested in networks and communities supported by technologies that go beyond classrooms to knowledge communities and international networks. These challenges and directions suggest many fruitful areas of research that may enrich theories and practices of CSCL, as researchers both examine knowledge creation and work to create knowledge.

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