Chapter 2
Perspectives of Knowledge Creation and Implications for Education

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Introduction

In the twenty-first century, new ideas and innovative products are the new sources of economic growth, more significant than physical and tangible resources like minerals and land. Knowledge-related economy, supported by a high proportion of information workforce, becomes the new default business model that replaces the conventional manufacturing industries (Castells 2010). The advent of the Knowledge Age has a profound impact on various sectors in modern societies, particularly in the business world. Knowledge management has become a buzzword among leaders in various organizations and a default topic in many business-training programs. Organizational knowledge creation, popularized by the influential work of Nonaka and Takeuchi (1995), is among one of the most sought-after practices among various organizations. Nonaka and Takeuchi theorized how knowledge is created in organizations, through a dialectical process that involves individuals and the team and the cyclical transition between tacit and explicit knowledge.

The influence of organizational knowledge creation could also be felt in the education arena, which saw an emergence of advocates (e.g., Bereiter 2002; Hargreaves 1999; Harris 2008) for knowledge creation practices among school leaders and educators. This clarion call for changes in education is driven by the urgent needs to prepare students for new challenges in the twenty-first century (Partnership for 21st Century Skills 2008). The predominant educational practices and values in the Industrial Age – lecture, accurate reproduction of facts, efficient execution of skills, and conformity to standards – are replaced by advocacy on developing knowledge innovation capacity and digital literacy for the survival and growth of individuals and for contribution to the new economies (Anderson 2008). Beyond economic values, such new capacity and competencies are essential social

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capitals for people to achieve their social well-being, to fulfill their obligations and expectations in a social environment, to enhance civic engagements and political participation, and to develop social ties within a community and across communities (Zinnbauer 2007).

The past three decades also saw the emergence of a new field of research known as the learning sciences. Learning sciences draws upon the theories and research outcomes from various disciplines – information sciences, cognitive science, artificial intelligence, neurosciences, instructional design, and educational psychology (Sawyer 2006) – to gain an in-depth understanding of the conditions and processes for effective learning. Researchers in learning sciences investigate learning and education in both formal and informal contexts, through both face-to-face interactions and computer-mediated learning, with the key goal of designing effective learning environments. The influence of the new economic and social landscape reverberates in this emerging field of study, where research on fostering knowledge creation capacity (Scardamalia and Bereiter 2006) becomes one of the key strands in the learning sciences. Unlike the organizational knowledge creation theory that gears toward development of innovation products and ideas, researchers in learning sciences focus on student learning and design of learning environment. For example, Scardamalia and Bereiter (2006) have developed knowledge-building theory, pedagogy, and technology implemented at elementary to tertiary levels, in and out of school contexts.

The confluence of recent development in knowledge economy and in learning sciences points to the criticality of developing knowledge creation capacity among the youth in preparing them to be confident and contributing citizens of tomorrow. This chapter examines knowledge creation in education through a wide-angle lens. The main purpose is not to prescribe detailed pedagogical principles, but to consider the agenda of knowledge creation in education from a systemic perspective and to identify pertinent social, ontological, and epistemological considerations.

Perspectives of Knowledge Creation

This section presents a summary of four perspectives of knowledge creation that emerged from different contexts and communities. Paavola et al. (2004) proposed a new metaphor of learning by finding common themes among three influential models of innovative knowledge creation: knowledge building (Scardamalia and Bereiter 2006), the organizational knowledge creation model (Nonaka and Takeuchi 1995), and the expansive learning approach (Engeström 1999). While these perspectives are included in this chapter, it serves a different purpose: to identify a range of knowledge creation perspectives in different contexts, with the ultimate goal of identifying implications for knowledge creation in education. In addition to the three models, a review of knowledge creation in scientist communities is also included, since scientists' work is the epitome of knowledge creation.

We are aware that even within a context, competing knowledge creation models might exist. For example, other approaches of organizational knowledge creation have been proposed (e.g., Stacey 2001), and not all researchers agree to a specific perspective (see Gourlay 2006). The main purpose of this chapter is to illustrate differences of knowledge creation in various contexts and, of course, similarities.

This review of the perspectives of knowledge creation is guided by the following questions that could help reveal their differences: (a) What is the context of knowledge creation? What are the underlying driving forces? Who are the participants in knowledge creation? (b) What are the ontological assumptions and outcomes of knowledge creation? (c) How does knowledge creation occur? (d) What are the conditions for knowledge creation? Paavola and Hakkarainen (Chap. 4, this book) also discussed some differences and commonalities among some of these perspectives.

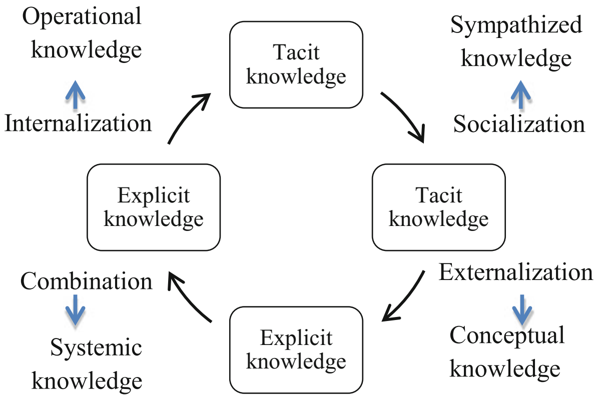
Organizational Knowledge Creation Theory

Organizational knowledge creation theory, popularized by Nonaka and Takeuchi (1995), is situated in commercial organizations. The subtitle of their book – How Japanese Companies Create the Dynamics of Innovation – suggests where the theory was inspired. As a management theory, it advocates an intentional approach by company's management or leaders. The driving force for knowledge creation is to maintain competitive edge of the companies, where new ideas and new products generate commercial values for the wealth and health of a company.

Nonaka and Takeuchi (1995) treat new knowledge as "justified true belief" (p. 58), which entails commitment, goal-directed action, and contextualized meaning. An example is the new "Tall Boy" concept by Honda, which departs from the conventional design of long, low sedans. This new concept aims to maximize comfort for car users, and it leads to consequential production of tall and short cars, prevalent among Japanese-manufactured cars. Nonaka and Takeuchi also suggested types of knowledge within and across units of actors, including knowledge of individuals and intra- and interorganizational knowledge, where an organization "amplifies the knowledge created by individuals and crystallizes it as a part of the knowledge network of the organization" (p. 59). Their theory is also premised on the distinction between tacit knowledge (Polanyi 1966) and explicit knowledge and the possible conversion between these two modes of knowledge. Tacit knowledge is "personal, context-specific, and therefore hard to formalize and communicate," whereas explicit knowledge is "transmittable in formal, systematic language" (Nonaka and Takeuchi 1995, p. 59).

The main engine behind the knowledge creation process proposed by Nonaka and Takeuchi (1995) is popularly known as the SECI model, which stands for the four modes of knowledge conversion: socialization (S), externalization (E), combination (C), and internalization (I). Figure 2.1 summarizes what happens in each mode of knowledge creation.

Fig. 2.1 Four modes of knowledge conversion in SECI model



As a management theory, company leaders assume the responsibilities to create conditions conducive to knowledge creation. Nonaka and Takeuchi (1995) suggested using both "top-down" and "bottom-up" approaches by providing five enabling factors:

1. Intention. The organization's aspiration to achieve its knowledge creation goals is conceptualized as a vision and operationalized into management strategies.
2. Autonomy. Although management theory takes a top-down approach, it is mitigated with autonomy to enhance staff's motivation to produce original ideas and to generate positive unanticipated outcomes.
3. Fluctuation and creative chaos. Fluctuation is created by allowing influence from external environment to enter the organization, and chaos is created when there is a crisis. Such events break down routine to nudge staff out of their comfort zone, which causes the staff to reflect and question existing premises.
4. Redundancy. Redundancy refers to sharing of tacit knowledge that may not seem immediately relevant to individuals or an overlap in work across departments. It provides common ground for ideas to be seeded, comprehended, and later developed into innovation.
5. Requisite variety. This refers to organization structure and information network that allows staff to access and work on a variety of information.

In contrast to the intentional effort by company leaders, the theory of expansive learning (Engeström 1999; Engeström and Sannino 2010) suggests knowledge creation in ordinary work context through day-to-day interactions among members in various communities.

Expansive Learning in Cultural-Historical Activity Theory

The theory of expansive learning (Engeström 1999; Engeström and Sannino 2010), premised on cultural-historical activity theory or CHAT (Engeström et al. 1999), suggests knowledge creation could happen in an ordinary workplace context. The actors refer to a group of people, rather than an individual. Knowledge creation is triggered as an inevitable outcome of interactions within or across activity systems. It is akin to breakdown in work that triggers problem-solving or a repair strategy. It thus represents a bottom-up approach involving ordinary workers; the driving force of knowledge creation is to reduce contradictions.

According to CHAT (Engeström 1999; Engeström and Sannino 2010), new knowledge is manifested in transformation of an activity system. An activity is an object-directed conscious process conducted by subjects acting in relation to the larger community. What distinguishes one activity from another is the motive that drives each activity and the object that the activity is oriented to, for example, a group of physicians (subjects) working on a problem of patient care between a private clinic and a hospital (object) to find out the solutions to the problem (motive). CHAT builds on Vygotsky's theory (1978) that removes Cartesian divide between the actor and the object, with cultural tools (e.g., Internet resources, problem-solving methods) mediating the subjects' actions on the object. The subjects operate within the larger community (e.g., nurse, health center staff) with certain rules or norms, and there is a division of labor where community members work together toward achieving the object. Engeström held that an activity system is the smallest meaningful unit for analysis. A transformation of the activity system could happen to any part of this activity system, and formation of a new theoretical knowledge or concept forms the main outcome. Engeström (2001) provided an example of how a conflict between local health centers and a hospital on patient care was partially resolved with the transformation of the concept (tool) of critical pathway (a prescribed general pathway for certain diseases) to care agreement (communication of plans for patients between health-care providers and the patient's family).

Expansive learning (Engestrom 1999; Engeström and Sannino 2010) differs from traditional conceptions of learning that focus on changes in individuals' behaviors or cognitive structure as the manifestation of learning. CHAT's focal point is on changes of object in collective activities, which could eventually lead to transformation of the activity system. Contradictions are the driving force for knowledge creation according to CHAT (Engeström et al. 1999), but it forms only half of the equation. It is the resolution of contradictions that leads to formation of new object and consequently transformation of the entire activity system. It is known as expansive learning because of its focus on "new expanded object and pattern of activity oriented to the object" (Engeström 1999, p. 7). Expanded objects are not the only forms of knowledge creation, Engeström and Sannino (2010) suggested that expansive learning could be manifested in movement in the zone of proximal development (Vygotsky 1978) or boundary crossing and network building. The zone of proximal development could be redefined as the "space for expansive transition from actions to activity" (Engeström and Sannino 2010, p. 4).

The typical process of expansive learning (Engeström and Sannino 2010) could be depicted as a spiral of epistemic actions that include (1) questioning some aspects of existing practices, recognizing the contradictions; (2) analyzing the situation to explain the contradictions; (3) modeling by constructing new idea or resolution to resolve the problem; (4) examining new model to develop operating procedures and detect limitations; (5) implementing the model; and (6) reflecting and evaluating new model to stabilize new form of practice. It is a process that bears resemblance to problem-solving processes (Jonassen 1997), but beyond problem resolution, it has a strong focus on developing new theoretical ideas and testing these ideas.

Since CHAT focuses on object-oriented activity, a community sharing a common motive and working on common object forms the most fundamental condition for knowledge creation. The actors must personally experience (Vasilyuk 1988) or personally engage in actions and material objects and artifacts and, in so doing, recognize the contradictions and have the agency to transform the activity system. The actors must be able to develop complex and culturally new concepts that are future oriented toward new activity system.

Organizational knowledge creation theory and expansive learning theory apply to settings where the knowledge created is intended for immediate practical applications. Scientist communities, on the other hand, are known for intentional knowledge creation that enhances fundamental principles and understanding of this world.

Knowledge Creation in Scientist Communities

The above two sections review knowledge creation in professional communities of adult work settings, where new knowledge is a mediating product in service of another goal (enhancing organizational competitiveness or resolving contradictions). How about intellectual communities whose primary goal is knowledge creation? According to Becher and Trowler (2001), contemporary disciplines can be classified under one of the four groups, pure sciences, technologies, humanities, and applied social sciences, and each of the four groups is underpinned by distinct epistemologies and ontologies because of the nature of knowledge each group is associated with. In this chapter, we attempt to examine scientists working on pure sciences.

To scientists, new knowledge could be new laws or theories that help us understand, explain, predict, or control natural phenomena. For example, a particle physicist would regard new knowledge as theory about basic components of the universe, and a molecular biologist would regard new knowledge as novel understanding of living organization from the characteristics of their genetic materials (Knorr-Cetina 1999). Even though Stokes (1997) suggested that scientists' work could also engage in applied research or use-inspired basic research, Nagaoka et al. (2010) found that research projects motivated by "pursuit of fundamental principles/understandings" (p. 1) are still highly valued in scientist communities, at least in Japanese context.

One of the most prominent theories of knowledge creation for science is Popper's epistemology of falsification. To Popper (1959), scientific theories, created to solve a problem or provide an explanation, are conjectural in nature. He opposed to the classical empiricism method of using observational evidence to inductively justify for a scientific theory. To him, no amount of empirical evidence is sufficient to prove a theory, but a counterexample is conclusive in falsifying a theory. Lakatos (1978) built on Popper's theory with a less critical stance toward eliminating a theory. Lakatos examines a series of theories (rather than a single theory) within a course of scientific inquiry, which he referred to as "scientific research program." To Lakatos, scientists do not abandon a theory just by the presence of a counterexample. He suggests that a body of beliefs can be tinkered with and reshaped, if necessary, in the light of refuting evidence without affecting the "hard core" of a theory. A progressive shift in theories happens when a new theory can explain and predict more, and sometimes the new predictions can be confirmed.

Owing to the attention given to inquiry science (National Research Council 2000) in K-12 curriculum, most people might be familiar with the idealized scientific inquiry processes, epitomized by the processes of "asking questions, collecting evidence from investigations, constructing explanations, and the documentation and presentation of claims and evidence for debate and validation" (Poon et al. 2010, p. 305). Nevertheless, it is increasingly evident that a universal scientific method of knowledge creation may not exist. Science is as much a cultural process as is a rational thinking process. Knorr-Cetina (1999) described the striking differences among laboratories of different scientific disciplines on what is valued as scientific evidence and ways to justify knowledge claims. She suggested that different scientist communities possess different epistemic cultures, which are "amalgam of arrangements and mechanisms – bonded through affinity, necessity and historical coincidence – which in a given field, make up how we know what we know" (p. 1). This disunity in sciences suggests that the quest for a unified theory of knowledge creation might be in vain. Extrapolating this argument, different disciplines, different research communities, or different knowledge creation organizations are likely to operate with their unique epistemic cultures, valuing different epistemic tools and criteria.

Up to this point, we have examined knowledge creation theory in professional communities. As we begin to draw implications for education, it is pertinent to review one of the most prominent theories of knowledge creation in education: the knowledge-building theory pioneered by Scardamalia and Bereiter (2006).

Knowledge Building

Although knowledge-building theory proposed by Scardamalia and Bereiter (2006) has been implemented in professional communities, this line of research has been predominately conducted in elementary to tertiary educational settings. In this sense, knowledge building seems to be different from the other three theories that feature creation of knowledge related to authentic work experiences.

Intuitively, learners' main role in school is to learn. The common wisdom is that school children will learn knowledge and skills, with curriculum prescribed by experts, with the belief that these knowledge and skills will make them a better citizen in the world, for humanity and economic reasons. Scardamalia et al. (1994) argued that learning is a necessary and natural by-product of knowledge creation, but not vice versa. Scardamalia and Bereiter (1999) further argue for schools to operate as knowledge-creating organizations, with students engaged directly in sustained, creative work with ideas. In this sense, if knowledge-building ideal is achieved, knowledge creation becomes an intentional activity integral to classroom life, not different from knowledge work as conducted within scientist communities and other knowledge-creating organizations. In all cases – professional contexts as well as schools – participants contribute ideas new to their community and work toward continually improving those ideas.

Scardamalia and Bereiter (1999) have elaborated parallels between the work of scientists, designers, and young students in creating knowledge: it is necessary for all to reconstruct knowledge, for example, to interpret findings of other researchers and to make sense of existing theories. Knowledge building is premised on the existence and possibility of working on epistemic artifacts (Sterenly 2004) or what Popper (1978) regarded as the World 3 object. The key mechanism of knowledge building is idea improvement (Scardamalia and Bereiter 2006). To Scardamalia (2002), ideas are "systematically interconnected – one idea subsumes, contradicts, constraints, or otherwise relates to a number of others" (p. 72). Scardamalia and Bereiter (1992) suggest investigation on the "question of wonderment," that is, problem of understanding the world. Questions of wonderment trigger students to put forth their ideas about the phenomenon. If made accessible on a public platform (e.g., Knowledge Forum), these ideas can be worked on and improved, through productive talks known as knowledge-building discourse. In short, knowledge-building discourse reflects intentional action on improving ideas by assessing ideas with appropriate epistemic criteria. Idea improvement is the key mechanism for knowledge creation, and improved ideas represent a deep understanding of the students about a phenomenon or a particular topic.

Scardamalia (2002) suggested 12 socio-technical determinants for knowledge building, which have been used as principles to design knowledge-building environments. To summarize, they are presented as three sets of tenets:

1. Idea-centric knowledge building. The focus should be on real ideas and authentic problems, with ideas students really care about captured as epistemic artifacts and having an "out in the world" (Popper's World 3) existence (Scardamalia et al. 1994) so others can build on them. The diversity of students' ideas on the same phenomenon could be a natural outcome, with all ideas treated as improvable, and the goal is "rise above" where better ideas (e.g., deeper understanding, more complete explanation) are created.

2. Knowledge-building practices. To achieve idea improvement, students should be engaged in productive knowledge-building discourse; authoritative sources of knowledge are important, but they should be used constructively and critically to work on the ideas; to use epistemic criteria for idea improvement means that assessment is a necessary and integral part of the process rather than a separate activity; such knowledge-building practices should be pervasive rather than a sporadic and random intervention.
3. Knowledge-building identity. While students achieve deep understanding of a phenomenon as an important learning outcome, it is equally important to develop their identities as a knowledge builder. This includes developing epistemic agency to work on ideas, assuming collective cognitive responsibility, democratizing knowledge-building practices, and achieving knowledge advancement collectively and for all individuals in the community. While the community to which knowledge contributions are made is normally the community of peers, just as in the corporate and research worlds, this does not exclude making contributions to world knowledge. Examples from K-12 contexts are rare, but that is true of all contexts. Engaging students in process by which knowledge is advanced greatly increases the opportunities and possibilities.

Comparison of Knowledge Creation Perspectives

Following the outline of the four perspectives of knowledge creation, this section analyzes the similarities and differences among the four perspectives, which is summarized in Table 2.1.

Contexts, Actors, and Driving Forces for Knowledge Creation

Among the four perspectives of knowledge creation, three relate to adult in work settings, including professional scientist communities. Workers in a professional community or an organization possess authentic work experience related to their field of expertise. Theory of situated cognition suggests that knowledge is part of the "product of the activity, context, and culture in which it is developed and used" (Brown et al. 1989, p. 32). It helps to explain why creation of knowledge is associated with work activity (expansive learning), tacit knowledge (organizational knowledge creation), and to the epistemic cultures of the scientist communities. The fourth perspective, knowledge-building community, has been implemented predominately in educational settings.

The differences in contexts and actors suggest different motivation for knowledge creation. The organizational knowledge creation theory suggests that knowledge creation is necessary to maintain the competitive advantage of a company,

Table 2.1 Comparison of the four perspectives of knowledge creation

	Expansive learning	Organization knowledge creation	Scientific methods and epistemic cultures	Knowledge building
Actor	Workers of specific professions	Workers in organizations	Scientists	Students (and professional communities)
Context	Authentic work context involving a community	Authentic work context involving a community	Research laboratories, universities	Educational settings
Driving forces	Contradictions in activity systems	Enhanced competitiveness of an organization	Fundamental mission of scientists	Intentional development of collective cognitive responsibilities and epistemic agencies of participants
New knowledge outcomes and ontological assumptions	New theories or ideas as outcomes of transformation of the activity system	Knowledge as justified true beliefs Novel ideas and innovative products Types of knowledge Individual and intra- and interorganizational knowledge Tacit and explicit knowledge Contextual and universal knowledge	New laws or theories that could help us understand, explain, predict, or control natural phenomena	"Rise-above" ideas/explanatory coherence Types of knowledge Popper's three worlds of knowledge objects or epistemic artifacts
Process of knowledge creation	Identification and resolution of contradictions and tensions	Process of socialization, externalization, combination, and internalization (SECI)	A series of progressive theory advancement through falsification of earlier versions of the theory; epistemic culture sanctioned by the specific scientist community	A collaborative process from the collective effort of a group of students in producing and improving their epistemic artifacts mediated through knowledge-building discourse that uses appropriate epistemic criteria to improve ideas

Conditions for knowledge creation	Collective, artifact-mediated, and object-oriented activity system	Company leaders responsible for creating conditions, using both top-down and bottom-up approaches	Existing knowledge related to research focus	Intentionality
				Collective responsibility
				Idea-centric pedagogy
	Multi-voicedness		Appropriate machines or tools	Epistemic capacity and agency
			Communication with other scientists	Availability of tools and resources
	Historicity	Intentionality	Funding	
	Contradictions as the sources of change and development	Autonomy		
		Creative chaos		
		Redundancy		
		Requisite variety		

where new ideas and new products generate commercial values for the company. The theory of expansive learning, on the other hand, suggests that knowledge creation is triggered when contradictions develop as a natural outcome of interactions among individuals, within or across activity systems. The scientist communities represent a unique type of work context mainly because the scientists' mission is to generate new knowledge; knowledge creation is intentional and it is the very reason for scientists' existence. Knowledge-building community suggests developing among learners the collective cognitive responsibilities of improving the epistemic artifacts accessible to all learners in the community. One key difference between knowledge-building community in schools and other communities is that having collective cognitive responsibilities among students is not a necessary condition for students to stay in schools; it requires intentional effort to foster and develop this attribute.

One factor that is not explicitly discussed among the four perspectives is the intricate competitive-collaborative tension. In scientist communities, for example, competing to publish research findings and claiming to be the first to pioneer a new discovery is a common practice. Yet, all scientists know that the published work could be built on by others to generate new findings, which, from a broader perspective, results in mutual advancement of knowledge among members. Similarly, in a commercial organization, collaboration among workers presupposes the trust that it would be mutually beneficial and eventually benefit the company. We cannot, however, ignore the hidden competition among workers, especially in organizations where individuals are ranked in yearly appraisal. Likewise, in some education systems and culture that privilege students who can perform well in high-stakes placement examinations, competition, rather than collaboration, seems to be a more natural disposition for a student to fight for a better position in the bell curve.

Outcomes of Knowledge Creation and Ontological Assumptions

The four perspectives of knowledge creation define knowledge differently, which suggests the nuanced differences of underlying ontological assumptions. New knowledge can be regarded as (a) new theoretical knowledge or ideas as outcomes of transformation of an activity system (Engeström 1999); (b) justified true beliefs that lead to new products or processes (Nonaka and Takeuchi 1995); (c) new laws or theories that could help us understand, explain, predict, or control natural phenomena; or (d) new ideas or conceptions about the world (Scardamalia and Bereiter 2006).

Ontological classification of knowledge is most explicit in the theory proposed by Nonaka and Takeuchi (1995), who proposed ontological levels of knowledge within and across units of knowledge creators. They include knowledge of individuals, knowledge within an organization, and knowledge across organizations. An organization "amplifies the knowledge created by individuals and crystallizes it as a part of the knowledge network of the organization" (p. 59). The theory by Nonaka and Takeuchi (1995) is premised on the ontological distinction between tacit knowledge (Polanyi 1966) and explicit knowledge and the possible conversion between these two modes of knowledge.

Another explicit discussion on ontological assumptions comes from Scardamalia and Bereiter (2006). Popper's (1978) three worlds formed the ontological basis for knowledge-building communities. Students' ideas, captured as epistemic artifacts (World 3 objects), provide the permanence of record that allows students to work on their ideas or work on real objects. In other words, it affords the possibility of design mode of thinking that leads to continual improvement in students' ideas.

What has not been explicitly discussed in these four perspectives of knowledge creation is the goal of developing the participant's identity as a knowledge creator (ontological transformation of the participants). Scientists, perhaps, have the most established identity as a knowledge creator. Without a keen interest in a particular field of research, it is difficult to imagine how one would invest time, effort, and financial resources to conduct research. In expansive learning, knowledge creation seems to be a natural product of problem resolution, but there could be alternative outcomes in the face of a problem. For example, different parties could initiate a blaming game, get entangled in political struggle, or simply avoid the problem and find ways to cover up the problem. Creating new concepts or ways of working may not be a natural process. In knowledge building, while learners create and contribute knowledge to the community, they gain the key dispositions that may allow them to become the knowledge creators of tomorrow belonging to the other three perspectives.

Knowledge Creation Processes

The four perspectives suggest different mechanisms for knowledge creation. Organizational knowledge creation explains knowledge creation as a process of transformation between tacit and explicit knowledge, at both individual and collective levels. It involves coworkers sharing experience and ideas, representing knowledge, and organizing knowledge and the embodiment of knowledge through actions. Expansive learning theory, on the other hand, suggests a problem-solving process consisting of a spiral of epistemic actions that aim at resolving contradictions. It engages participants in recognizing contradictions, analyzing the situations, developing new ideas to resolve the contradictions, examining viability of new ideas, implementing new ideas, and evaluating the outcomes. In scientist communities, rather than to wait for emerging contradictions through interactions, knowledge creation involves intentional identification of knowledge gaps, design of investigations, collection of evidence, construction of new explanations, and presentation of claims. Different fields of sciences have unique epistemic cultures that sanction acceptable methods of investigation and epistemic criteria for knowledge claims. In other words, scientists' knowledge creation entails very specific epistemic tools and criteria. Knowledge creation in knowledge-building communities involves iterative process of idea representation, knowledge-building discourse among students that aims at idea improvement, and a system (e.g., an online forum) that records this historical development of knowledge representations.

Despite the differences, one commonality among the four perspectives is that knowledge creation is a social-cultural enterprise. All four perspectives describe and explain knowledge creation in a community, rather than knowledge creation as an individual's work. The four perspectives, however, offer some nuanced differences why this social-cultural dimension is critical: (1) socialization is needed in sharing tacit knowledge among individuals and in combination of explicit shared knowledge to create new knowledge in organizations; (2) social interactions are necessary in both the identification of contradictions in an activity system and the solution of the contradictions that engenders knowledge creation; (3) communication is necessary among scientists, within and across research teams; within a community, the epistemic tools and criteria for new knowledge creation are cultural products; and (4) knowledge building involves collective cognitive responsibilities in advancing shared knowledge artifacts through knowledge-building discourse among individual students.

Another commonality among the four perspectives was highlighted by Paavola and Hakkarainen (2005; 2014): the critical role of mediating artifacts in knowledge creation. Extending beyond the dialogical interactions among learners, they suggest learning is "trialogical" because

> . . .by using various mediating artifacts (signs, concepts and tools) and mediating processes (such as practices, or the interaction between tacit and explicit knowledge) people are developing common objects of activity (such as conceptual artifacts, practices, products, etc. (p. 546)

In all four of the approaches, epistemic artifacts provide shared focus for the community to work on, which could represent the motive of the community that channels the effort of the members. Epistemic artifacts have dual roles – they act as both mediating artifacts for knowledge improvement and the outcomes of knowledge creation. In other words, epistemic artifacts mediate knowledge creation process, yet they are "knowledge in the making," leading to creation of further knowledge advances. Paavola and Hakkarainen (2014) provide detailed explanation on the rationales and strategies of trialogical approach for knowledge creation.

Implications for Education

Among the four perspectives of knowledge creation, knowledge building (Scardamalia and Bereiter 2006) is the most closely associated with education. Extensive research on knowledge-building pedagogies has been conducted, and a set of pedagogical principles (Scardamalia 2002) has been studied. This section explores how varying perspectives of knowledge creation could help illuminate knowledge creation in education. The intention is not to prescribe specific pedagogical principles, but to examine knowledge creation through a wide-angle lens.

Implications from Varying Contexts, Driving Forces, and Actors of Knowledge Creation

In this overview, we consider context-dependent factors raised by research reviewed above. It is important to stress that while different models are associated with different contexts, researchers have been committed to elaborating general models. There is sufficient research to suggest that there are parallels across contexts and disciplines, as well as important differences.

Knowledge Creation as a Lifelong Continuum Versus Dichotomous Expert-Learner Divide

Kirschner et al. (2006) stress differences between how experts create knowledge and how learners acquire knowledge. While the distinction may appear stark if we compare knowledge creation in professional communities and K-12 classrooms, the debate on expert-learner divide could be attributed to how the term "knowledge creation" is defined. The focus on individual genius and creation of artifacts new to the world as the defining feature of knowledge creation leads to a limited conception of knowledge creation. This distinction could preclude the possibility of uncovering untapped potential on the part of young students. Bereiter and Scardamalia (2010, 2014) argue that the distinction may well say more about school practices than student capabilities. Conventional pedagogy is not a good testing ground for students' knowledge-creating capacities. Knowledge building provides an approach in which students themselves are committed to pursuing deeper understanding through idea improvement. Thus, knowledge creation and knowledge acquisition are fused; as a noted philosopher of science, Sir Karl Popper proposed that creating a theory and understanding the theory are essentially the same process.

Bereiter and Scardamalia (2010, 2014) have been advancing knowledge building across disciplines, sectors, and contexts, with the unifying feature of working in design mode of thinking to constantly improve ideas significant to the community. To them, engaging young children in knowledge creation or design mode of thinking is in alignment with the development of knowledge creation capacity across contexts and disciplines. We concur with Scardamalia and Bereiter and recommend a program of research to uncover the many and significant issues underlying knowledge creation across contexts and within a lifelong perspective.

Creating a lifelong knowledge creation framework will require an active program of research to disentangle the many issues surrounding different contexts and driving factors underlying models of knowledge creation.

Knowledge Creation Across Multiple Levels in Learning Institutions

Much of the research work on knowledge building has been focusing on transforming classrooms into knowledge-building communities with associated efforts involving teachers, administrators, and leaders, whose professional works focus on improving classroom practices and student's learning (see, e.g., articles in the special issue of Knowledge Building published by the Canadian Journal of Learning and Technology by Scardamalia and Egnatoff 2010). Transforming schools, or learning institutions, into knowledge-building organization requires changes at several levels, including students, teachers, and school leaders.

Tan (2010) suggested that schoolteachers could engage in discussing theoretical professional knowledge, not only to solve problems related to teaching practices but also to seed ideas for innovation and breakthrough. Tan (2011) amalgamated the learning study approach (Marton and Pang 2006) and knowledge-building approach (Scardamalia and Bereiter 2006) to suggest a model where researchers and teachers contribute their respective expertise in codesigning classroom lessons that are based on learning theories and pedagogical principles. Hargreaves (1999) drew upon organizational knowledge creation theory by Nonaka and Takeuchi (1995) to argue for knowledge-creating schools where teachers treat students as active partner in knowledge co-construction. Harris (2008) further suggested the development of D&R (development and research) networks among schools that focus on achieving deep learning among students, deep enriching experience to engage learners, deep support within schools and among schools, and deep leadership that restructures school leadership teams for more effective distributed leadership (Harris 2008). In short, Hargreaves and Harris tackle the school transformation at the level of the school leader.

From a systemic perspective, Chan (2011) reported the case study of implementing and sustaining knowledge building in Hong Kong classrooms. She illustrated "how the macro context of educational reform can bring about meso-level changes in the emergence of a teacher network to support innovation and how the research-based innovation can be practiced in the classroom when the teacher aligns the model with the socio-cognitive and social-cultural underpinning of the classroom" (p. 182). Moving forward, we could adopt the lens of the activity theory to analyze students' knowledge building as an activity system that is nested within the larger school community and interacts with teacher's communities and leader's communities. Each higher level could be a knowledge creation community, with multiple responsibilities of creating professional knowledge with the ultimate goal of helping the subordinate levels to become knowledge creators. For example, the teacher's community has dual responsibility of creating teacher's professional knowledge while enhancing students' knowledge creation capacity and learning. This multilevel approach (see also Laferrière et al. 2010) opens up possibilities for various perspectives of knowledge creation to operate at different levels within the system. For example, a school leader could adopt an organizational knowledge creation approach to engage teachers to create innovative strategies for enabling knowledge building among students. Alternatively, with the goal of enacting knowledge-building classrooms, several groups of teachers within the school might encounter contradictions that trigger resolutions using innovative ideas. This holistic approach toward school change is important because without understanding the perspectives of knowledge creation and their challenges, it is unlikely that a teacher could help foster knowledge-building community within a class. Likewise, at higher level, school leaders who are sold to the idea but not possessing deep nuanced understanding of what it means to foster knowledge building might resort to "top-down" coercive strategies. The consequence could be "lethal mutations" (Brown and Campione 1996, p. 292) to the well-intended pedagogical intervention.

In short, for an educational institution to be a knowledge-building organization, we could think of vertical transformation, which entails knowledge creation practices that pervade throughout various levels of the organization.

Implications from Types of Knowledge and Outcomes

The knowledge-building perspective (Scardamalia and Bereiter 2006) regards new knowledge as new ideas or conceptions about the world. Popper's (1978) three worlds of objects formed the ontological basis for knowledge-building communities. Students' ideas, captured as epistemic artifacts (World 3 objects), provide the permanence of record that allows students to work on their ideas or real objects. In other words, it affords the possibility of design mode of thinking (Bereiter and Scardamalia 2003; Cross 2007) that leads to continual improvement in students' ideas, rather than belief mode of learning that attempts to know the absolute truth. The recognition of epistemic artifacts as a World 3 objects and the assumptions that this object can be manipulated and improved form the key argument of why online forum supports knowledge-building effort among students. Knowledge Forum, for example, has been used as a tool for creating of knowledge artifacts, facilitating knowledge-building discourse, and supporting collaborative idea improvement.

The creation of artifacts, however, could also constrain the potential of knowledge creation. If we subscribe to Polanyi's (1966) assertion that we know more than we can tell, knowledge creation entails more than idea improvement through creation and improvement of artifacts. Acknowledging the existence of tacit knowledge and its roles in knowledge creation has few implications. First, provide more avenues for knowledge representations. The Knowledge Forum affords textual representations of ideas, as well as graphical representations, and has been extended to include a broader range of knowledge representation, including voice, video, and multimodal representations. There are existing tools like concept maps, VoiceThread, or CmapTools that could potentially expand the modes of knowledge representation. Second, recognize the importance of holistic learning experience through multiple senses to harness the tacit dimension of knowing. Knowledge-building pedagogy (Scardamalia and Bereiter 2006) can be considered a blended approach that traverses both face-to-face and online environments. While attention has been focused on fostering epistemic agency and supporting collaborative epistemic discourse, due attention could be given to learner's experience and interactions with the phenomenon under investigation. In inquiry science (Kelly 2008), for example, students interact with physical phenomena through empirical investigations and interact with others in epistemic discourse and reasoning around the phenomena. From Deweyan pragmatic epistemological perspective (Brinkmann 2011), interacting with phenomena provides the necessary experience for a learner that might be beyond explicit cognitive knowledge representation.

Finally, beyond deep understanding of phenomena through idea improvement, the ontological transformation (Packer and Goicoechea 2000) in students' identities as a knowledge creator could be a critical learning outcome. In knowledge building, fostering epistemic agency among learners is listed as one of the key goals. Scardamalia and Bereiter (2006) noted that

> . . . young students are delighted to see their inquiry connect with that of learned others, past or present. . .they see their own work as being legitimated by its connection to problems that have commanded the attention of respected scientists, scholars, and thinkers. (p. 98)

In other words, the students, steeped in culture of knowledge building, begin to see their own identity as a knowledge builder. This identity transformation could be a critical success factor in communities where participants' readiness and intentionality for knowledge creation are low. There is, however, a paucity of research on how knowledge creation identity among students is developed and how to support such development.

Implications from Competitive-Collaborative Tension

One of the key principles in knowledge-building community in classroom is to develop collective cognitive responsibilities among students to collaboratively improve shared knowledge artifacts (Scardamalia 2002). However, in education systems that privilege students who can perform well in high-stakes placement examinations, competition, rather than collaboration, seems to be a more adaptive disposition to put one in a better position in the bell curve. How to foster and develop collective cognitive responsibilities among students remains a challenge. As discussed earlier, such competitive-collaborative tension also exists in professional knowledge creation community like scientist communities.

Knowledge-building pedagogy suggests the principle of symmetric advancement of knowledge where all participants make progress through knowledge-building activities. A learning environment that encourages such behavior is (1) one that recognizes the rights of every participant in contributing to the knowledge creation effort, (2) an environment that develops individual's capacity in productive knowledge creation practices, (3) an environment where participants feel safe to make public his or her personal understanding through knowledge representations, and (4) an environment where participants receive reciprocal feedback from peers. Ultimately, this individual-collective effort leads to individual and collective knowledge advancement.

There are other ways that could help resolve the competitive-collaborative tension. First, a policy review could be conducted to minimize competitive behaviors that only benefit one self, toward behaviors that engender mutual benefits. For example, an assessment policy that places individuals on a bell curve regardless of criterion-referenced achievement would likely lead to self-centered competitive behaviors. Conversely, an assessment policy or system that recognizes variances among participants, yet provides flexibility to recognize achievement of minimum standards, would likely encourage collaborative behaviors.

Second, as a pedagogical practice, competition could be a means toward collective benefits. For example, groups of students could compete to develop the best coherent scientific explanation for experimental data (best within the curriculum time boundary). The process of deliberating on the best explanation entails discussion on epistemic criteria to assess the quality of explanation, and the best answer is made accessible to all participants. This game-like activity contains competitive element, yet it works toward collective benefit of all students and achieves the epistemological goal of knowledge creation.

Implications from Differing Epistemic Practices

Knowledge-building pedagogy has been well developed along the two common characteristics of knowledge creation perspectives: the critical roles of epistemic artifacts (as discussed in the Section *Knowledge Building*) and social collaborative processes of knowledge creation. Several principles of knowledge building (Scardamalia 2002) contain elements of collaboration, for example, developing collective cognitive responsibilities among learners, engaging learners in knowledge-building discourse, democratizing knowledge building among learners, and achieving symmetric knowledge advancement.

Knowledge-building pedagogy privileges collaborative process of idea improvement toward improving shared knowledge artifacts, with individuals contributing to community knowledge. Nonaka and Takeuchi (1995) acknowledge individual-social dialectics, which involves individual participants sharing experience and ideas, representing knowledge, and organizing knowledge and the embodiment of knowledge in individuals through actions. This individual-social dialectics in the knowledge creation is elaborated in Stahl's (2004) theory of collaborative knowing. Compared with the four-stage SECI model, Stahl provided a finer examination of the key processes of personal knowing and how personal belief is reified through texts that enter into a public domain, how social knowledge building ensues through argumentation and meaning making, and how the collective knowledge is embedded in knowledge artifacts, which eventually enters into personal realm of understanding as individuals use the knowledge in activities.

In knowledge-building pedagogy, knowledge-building talks refer to productive discourse among participants that focuses on improving understanding of a phenomenon. It seems consistent with Mercer's (1995) notion of exploratory talks in classrooms, where all ideas are respected, ideas are challenged with reasons, and there is progressive improvement of ideas building on what has been discussed. Knowledge-building discourse appears to be a generic type of talks for all subject domains. Other perspectives of knowledge creation, in particular, scientist communities, suggest very specific epistemic tools and criteria, even among different branches of hard sciences. While developing specific epistemic cultures among students may not be realistic, particularly among the K-12 students, discipline-specific epistemic talks for learners could have been established. For example, in inquiry science, several models of inquiry processes have been proposed, including the BSCS 5E (engage, explore, explain, elaborate, evaluate) instructional model by Bybee et al. (2006) and the predict-observe-explain sequence suggested by Tien et al. (1999). These discipline-specific epistemic processes could be consulted to enrich students' epistemic repertoire.

Concluding Remarks

This chapter sets off as an attempt to review perspectives of knowledge creation with the ultimate goal of drawing implications for knowledge creation in education. It is evident that there exist complexity and nuanced differences of various perspectives, which provide pertinent ideas to enrich education. This chapter focuses on macro-level issues rather than specific pedagogical principles. Table 2.2 summarizes the key ideas that emerged from the comparison of the four perspectives, the strengths of the current model of knowledge building, and the potential that could be explored.

This chapter suggests broad directions to bring forward the agenda of knowledge creation in education. While emerging research effort is evident in some of these areas (e.g., see teacher knowledge creation communities, Section II of this book), there remain research opportunities in many other areas, some of which are outlined in this chapter. Given its relevance in the twenty-first century, we believe research on knowledge creation could engender real impact in education.

Table 2.2 Potential areas for exploration for knowledge creation in education

Comparison of four perspectives	Current focus of knowledge-building pedagogy in education	Potential areas for exploration
Differences in context, driving forces, and actors	Knowledge building in educational context	Knowledge creation as a lifelong trajectory
		Knowledge creation across multiple levels and actors in an educational institution
Ontologies and ontological outcomes	Improvement of epistemic artifacts as Popper's World 3 objects	Expansion of modes of knowledge representation
		Holistic experience with phenomenon to leverage tacit knowing
	Develop learner's epistemic agency	Explore identity transformation of learners as knowledge creator as a significant learning outcome
Competitive-collaborative tensions	Symmetric knowledge advancement among various groups of learners	Policy or systemic change to assessment that recognizes both individual and group changes
		Leverage competitive forces for positive learning outcomes, for example, gamification of knowledge creation or collaborative argumentation
Different epistemic processes	Privilege collaborative process of idea improvement	Examine individual-social dialectics in knowledge creation
	Generic knowledge-building discourse	Introduce discipline-specific epistemic practices appropriate to the levels of education

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