Education Innovation

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Hyo Jeong So
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Knowledge Creation in Education

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Education holds the key to unlock human resources that a society needs to survive and flourish. This is particularly salient in a borderless knowledge economy. For the past decades, the sterling performance of economies such as Hong Kong, Finland, Japan, Singapore and Taiwan in international studies (e.g., TIMSS, PIRLS and PISA) has channeled much attention away from the traditional centers of education research in America and Western Europe. Researchers, policy makers and practitioners all over the world wish to understand how education innovations propel the emerging systems from good to great to excellent, and how different their trajectories were compared to the systems in America and Western Europe.

The *Education Innovation Book Series*, published by Springer, will delve into education innovations enacted by the Singapore education system and situate them in both the local and the boarder international contexts. Primary focus will be given to pedagogy and classroom practices; education policy formulation and implementation; school and instructional leadership; and the context and interface between education research, policy and practice. We believe that the latter is critical in making education innovations come to bear. Each volume will document insights and lessons learned based on empirical research (both quantitative and qualitative) and theoretical analyses. Implications to research, policy and professional practice will be surfaced through comparing and synthesizing Singapore's experience with those of successful systems around the world.

The audience of the edited volumes and monographs published in this series includes researchers, policy makers, practitioners, and students in the fields of education and teacher education, and public policies related to learning and human resources.

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Series Editors' Foreword

As civilizations move forward, creating knowledge becomes a priority. First-world nations are cognizant of this need, and evidently, many calls have been made to cultivate knowledge creation and building dispositions in students to create more equitable systems and schools. This book on knowledge building is the sixth book in this *Education Innovation* Series, and it depicts the efforts made in this important area of research work. The book continues to delve into signature pedagogies, which are integral to prepare students for the future economy and society. The situating of this effort in Singapore schools is an example of how other school systems can also adopt this pedagogy and learning process.

Knowledge building is not just a pedagogy; it is an epistemology – the very foundation of how students and teachers would view knowledge and how it is constructed. Truth is socially constructed in its very nature, and this epistemology challenges objectivistic assumptions. When knowledge building as an epistemology was proposed some 20 years back by Marlene Scardamalia and Carl Bereiter (University of Toronto), it faced many challenges and oppositions, but such a stance is now mainstream and embraced as crucial. The trajectory of knowledge-building efforts (see the last chapter of this volume) in Singapore (since 2001) is in itself illustrative of the process of how the views of knowledge and culture are intertwined. Knowledge is founded on cultural underpinnings and should be informed by multiple perspectives; the diversity of views is imperative and not just "good to have"!

This book is unique, even from the perspective of proponents, in that it brings together studies across the K-12 spectrum and discusses issues that can potentially translate the research work on knowledge building into practice, both for students in schools and teacher education contexts. Knowledge building is not only featured in primary and secondary schools, but in the preuniversity context in Singapore schools. These studies are compared and contrasted with international perspectives in order to discuss the issues and tensions of implementing knowledge building in schools from an educational system's perspective.

Most international knowledge-building efforts are helmed by individuals – researchers and teachers – but attempts in Singapore have progressed toward considerations of policy and curriculum structures, which can sustain and extend knowledge-building endeavors within and across schools. We thus congratulate the editors and authors of this impeccable volume for skillfully synthesizing these efforts together.

National Institute of Education
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Wing On Lee
David Hung
Laik Woon Teh

Foreword

A growing number of educators want to contribute to the enhancement of the learners' experience in the classroom. They work increasingly with students who have access to the Internet and its resources many hours a day. As their society is making its way into the age of knowledge, or the connected age, they are challenged to transform the sociocognitive dynamics of knowledge acquisition and participation to its production. Knowledge creation is at the classroom activity's high end as it expands classroom-based communities' work with knowledge in an impressive manner. The book *Knowledge Creation in Education* reveals that Singapore's researchers and teachers are among the first to be on task.

The coeditors achieved a wonderful exercise in assembling and interpreting the contributions of researchers, teachers, and educational administrators. They invited the top theorists as regards classroom-based knowledge creation/knowledge building, who took advantage of the opportunity to provide conceptual advances with much clarity. Seng Chee Tan cowrites the first chapter in a way that manifests a powerful capacity in terms of scholarly leadership as Head of the Learning Sciences and Technologies Academic Group at the National Institute of Education in Singapore.

Reading the whole book was a rare experience of witnessing theory-in-practice, one showing the value of an integrated effort between educational partners aiming at installing and perfecting knowledge creation/knowledge-building moments, ones likely to define classroom activity in singular and beneficial terms in tomorrow's schools. For instance, in my Francophone community, it is perceived that students' rapport au savoir (relationship to knowledge) is changing as they put their hands on digital technologies, and CRIRES, a multiuniversity research center dedicated to school success, is identifying its new meanings and emerging patterns. Having recently been a guest speaker on the school of the future at the Quebec's Superior Council of Education, at an event celebrating its 50th anniversary, the book Knowledge Creation in Education inspired and added substance to my allocution. I imagine this will also be the case for other educational leaders engaged in the practice of codesigning and researching on knowledge creation/knowledge building in elementary and secondary classrooms.

For most educational scholars and practitioners, however, this book is likely to be provocative. It is forcing its reader to think beyond what is often understood as being possible in the classroom, even in schools with flexible access to a stable connexion to the Internet. Theory is enacted in practice: (1) The foundational concepts as well as knowledge practices are deployed with rare acuteness; (2) the sociotechnical affordances that classroom-based knowledge creation requires are documented; (3) the relationship between Knowledge-Building Theory and Activity Theory is examined, and "explanatory" synergy grows out of their respective consideration for human agency and for community.

The contribution of this book to the field is also its exemplary character as regards: (1) balance between individual and collective growth; (2) collaboration for innovation, which matters in primary and secondary schools; and (3) continuity of innovation as funding programs and structures evolve. It is also of importance that this innovation is carried by knowledge-creation-minded professional educators who exercise different roles in the educational system. At a time when many school systems all over the world are looking for new directions, *Education for Knowledge Creation* presents a singular in-depth analysis of the process and outcomes of designing knowledge creation environments in a national educational system. One gets a sense that this educational innovation is not only doable but may be sustainable and scalable.

This book, edited by Seng Chee Tan, Hyo Jeong So, and Jennifer Yeo, is a valuable reference for researchers and teacher educators interested in knowledge creation perspectives for enhancing classroom activity. It weaves together projects that make important contributions to research on knowledge creation in education because they bring a remarkable in-depth analysis of classrooms that transformed into knowledge-building communities. Interested graduate students will benefit from the explanatory power of the chapters that present the knowledge-building principles, knowledge creation, activity theory, and the like. Teacher leaders working in networked classrooms and looking to engage students in meaningful activity will find practices to stimulate and push forward their own doings. For all those pursuing isolated efforts in their own country, the Singapore case will stand out to them as forward-looking, substantive, intensive, and long-term.

Université Laval, Québec, QC, Canada Thérèse Laferrière
January 26, 2014

Preface

This book, titled *Knowledge Creation in Education*, highlights our research effort in introducing pedagogies of the knowledge-creation paradigm to Singapore classrooms. It documents our 12-year journey of integrating knowledge-building pedagogies into Singapore classrooms, across school levels from primary schools to high schools, working with both students and teachers. It also records our effort in developing teachers' capacity in building professional knowledge and in facilitating knowledge creation pedagogies. We also draw on the knowledge and research findings within the international community of knowledge innovation.

In the spirit of knowledge building, we are constantly pushing the boundary of knowledge-building pedagogy toward a more inclusive knowledge creation paradigm. We attempt to innovate knowledge building by working at the boundaries of different research fields, including knowledge building in teacher education, knowledge building and mobile learning, and forming collaborative research among researchers and practitioners. For these reasons, we use the term *knowledge creation* in the book title to reflect a more inclusive view of knowledge work in education that goes beyond K-12 classrooms.

Looking back, our journey began in the year 2001, when Seng Chee Tan – the first editor, then a fresh Ph.D. graduate – chanced upon a research project that focused on knowledge-building pedagogy. The initial joy of winning a research grant soon turned into a journey filled with frustration and trepidation. The challenges to make knowledge-building work in authentic classroom settings just seemed insurmountable. Fortunately, rays of light began to appear while Tan was exploring in the metaphorical dark abyss. In 2005, the establishment of the Learning Sciences Lab in the National Institute of Education, Singapore, provided further funding support to continue research into knowledge building and fueled the expansion of the research community. Among them, Hyo-Jeong So (the second editor) ventured into the use of mobile technologies and the integration of knowledge-building pedagogy with out-of-the-classroom learning. Jennifer Yeo (the third editor) joined Tan as a Ph.D. student and began to explore new perspectives of analyzing the data with the Activity Theory and theory of Systemic Functional Linguistics. When the call for the book proposal was announced in 2012, we felt it was an opportune time to document our effort thus far.

Working on this book allows us to reflect on our journey, which, serendipitously, reflects a knowledge creation work in progress. We are able to come this far by "standing on the shoulders of giants." We build on ideas suggested by pioneers like Carl Bereiter and Marlene Scardamalia, who have provided invaluable guidance through their publications and personal interactions. We are grateful to our international collaborators – Ming Ming Chiu, Nobuko Fujita, Kai Hakkarainen, Huang-Yao Hong, Nancy Law, and Sami Paavola – whose unique perspectives have inspired us in many ways; we are heartened and honored to have their contributions in this book. We would like to thank Timothy Koschmann and Peter Reimann, whose insightful and succinct comments have helped to enrich our intellectual discussions and are instrumental in shaping our future journey.

This book does not signify the conclusion of a journey, but a document that records our experience, our insights, and our projective goals for the ongoing research effort. In the knowledge-building vernacular, this is a knowledge artifact that contains ideas to be discussed and improved. We hope to continue with this journey with our international colleagues and many others whom we did not have the chance to work with in this project.

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Chapter 1
Introduction

Seng Chee Tan

This book focuses on knowledge creation work in education, which is built on the central premise that in this Knowledge Age, schools should function as a knowledge creation organization, where knowledge work pervades all levels in schools. It means that schools should focus on developing student's capacity and disposition in knowledge creation work and, at the same time, leaders and teachers alike should continue to develop their professional knowledge as a community.

As one of the books in the Education Innovations Book Series, this book aims to crystallize the collective effort of researchers in the National Institute of Education (Singapore) in integrating knowledge-building pedagogies into Singaporean classrooms, with both students and teachers across school levels, from primary schools to high schools. Our journey started in the early 2000s, when we introduced knowledge building as an approach to foster scientific inquiry skills among secondary school students (Tan et al. 2005a, b). In 2005, we saw the timely establishment of the Learning Sciences Lab, a research center in the National Institute of Education that champions learning sciences research in Singapore. Knowledge Building Community became one of the few flagship projects for the center. Since then, several research projects related to knowledge building were funded: the development of the "Ideas First" model in a primary school (Ow and Bielaczyc 2008; Tan and Seah 2011); the design of pedagogical support for inquiry-based learning in a high school (Yeo et al. 2012); leveraging knowledge building with mobile devices, Web 2.0 tools, and location-based physical objects (So et al. 2012); and professional development of teachers through knowledge building (Chai and Tan 2009; Tan 2010). That said, however, our research projects have included location-sensitive physical objects (in addition to conceptual artifacts) as mediating artifacts in the process of learning (So et al. 2012), and Engeström's cultural-historical activity theory has also been adopted as an analytic lens

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(Yeo et al. 2012). In the spirit of knowledge building, we are constantly pushing the boundary of knowledge-building pedagogy toward a more inclusive knowledge creation paradigm. We also attempt to innovate knowledge building by working at the boundaries of different research fields, including knowledge building in teacher education, knowledge building and mobile learning, and forming collaborative research among researchers and practitioners. For these reasons, we chose to use "knowledge creation," a more inclusive term, in the title of this book. Beyond the shores of Singapore, we have also invited contributions from international scholars. This collaborative effort is directed at the production of knowledge artifacts (book chapters) that could lead to innovation and new knowledge.

The chapters in this book are grouped into two sections. Section I focuses on theoretical, technological, and methodological issues, where sources of justification for claims are predominantly theories and extant literature, although empirical evidence has been used extensively in one of these chapters. Section II reports knowledge creation practices in schools, with teachers, students, or both; the key sources of justification for claims are predominantly empirical evidence and narratives of experience.

In the second chapter, Tan and Tan examine perspectives of knowledge creation with the aim to suggest an agenda of knowledge creation in education from a systemic perspective and to identify pertinent social, ontological, and epistemological considerations. Four perspectives of knowledge creation are examined: organizational knowledge creation theory by Nonaka and Takeuchi (1995), expansive learning in cultural-historical activity theory by Engeström (2001), epistemic culture in scientific communities by Knorr-Cetina (1999), and knowledge building by Scardamalia and Bereiter (2006). These four perspectives were compared in terms of their contexts, actors, driving forces for knowledge creation, types of outcomes of knowledge creation, and knowledge creation processes. Based on the comparison, they suggest several areas of exploration for knowledge creation in education. First, research could examine knowledge creation as a lifelong education trajectory. Second, knowledge creation could be enacted across multiple levels in learning institutions, which include students, teachers and instructors, school leaders, and possibly policymakers. Third, research could study various outcomes of knowledge creation, including building of knowledge creator identity. Fourth, there is a need to identify the competitive-collaborative tension and examine ways to alleviate or strike a balance between competition and collaboration. Last, there is a need to expand the epistemic practices for knowledge creation in education.

As explained in Chap. 2, the term knowledge creation has been used primarily in professional work settings whereas knowledge building in K-12 settings. In Chap. 3, Bereiter and Scardamalia clarify the unifying characteristics related to knowledge creation and knowledge building, in that "knowledge is the product of purposeful acts of creation and comes about through building up a structure of ideas. . .out of simpler ideas." They held that student communities, beyond learning and using existing knowledge, can work like organization to create knowledge with a feed-forward effect. Several conditions are critical to nurture students' knowledge creation/building effort. First, educators need to go beyond the concern with evaluation of truth claims. There is a need to develop design thinking disposition among students, shifting the focus from evaluating, validating, or refuting a knowledge claim toward production and improvement of knowledge. Second, there is a need to engage students in knowledge-building discourse and to use technologies to support their representation and collaborative improvement of knowledge artifacts. Third, educators need to overcome the beliefs that knowledge creation/building is only for high-ability students and that "transmission" of knowledge to students is necessary before knowledge creation can take place.

In Chap. 4, Paavola and Hakkarainen explain knowledge creation from the perspective of the trialogical approach to learning, which emphasizes collaborative work with knowledge artifacts and practices. Six design principles are presented as well as the background in the knowledge creation metaphor of learning. They analyze the main theoretical elements of the approach: mediation, knowledge artifacts, knowledge practices, and object-oriented activities. Similar to Chap. 2 and 3, they compare the trialogical approach with other theories on knowledge creation.

Taken together, Chaps. 2, 3, and 4 crisscross the terrain of knowledge creation in education from different perspectives. Chapter 1 analyzes four different perspectives of knowledge creation to propose possible areas for exploration; Chap. 2 presents key ideas that unify the concept of knowledge creation and knowledge building; Chap. 3 foregrounds knowledge creation from the trialogical perspective, which highlights the critical role of collaborative work with knowledge artifacts; Chap. 4 reinforces the notion that epistemic objects and their associated practices are central to knowledge creation.

There is an intricate relationship between technology advancement and the advent of knowledge creation paradigm. Chapter 5 examines technologies supporting knowledge creation practices. Tsai, Chai, and Hoe synthesized a new model of knowledge creation from three perspectives of knowledge creation that were also discussed in Chap. 2 – expansive learning, organizational knowledge creation, and knowledge building. Based on this synthetic model, they suggested features of a knowledge creation platform and provided some suggestions with respect to technological and pedagogical dynamics that could provide real-time analytics to support learners in knowledge creation. These analytics could also assist teachers in tracking and analyzing learners' learning behaviors and learning strategies related to the knowledge creation processes. This proposed platform consists of four platforms: teachers' management space, knowledge construction space for epistemic artifacts, collaborative knowledge creation space, and personal space for building of individual e-portfolio.

As suggested in Chap. 5, development and application of learning analytics in CSCL are gaining momentum, for example, as measures to analyze online discourse. However, many research studies that include quantitative methods of studying online discourse take a snapshot of aggregate counts of some measures of messages in an online forum (e.g., the number of messages, the number of words, or the number of times the message was read). Chapter 6 introduces statistical discourse analysis (SDA) as a method to study the temporal and causal relationships among messages in an online forum. Chiu developed an SDA to statistically model large data sets of knowledge processes during asynchronous, online forums, which could address analytic difficulties involving the whole data set (missing data, nested data, and the tree structure of online messages), dependent variables (multiple, infrequent, discrete outcomes, and similar adjacent messages), and explanatory variables (sequences, indirect effects, false positives, and robustness). Chiu and Fujita illustrated SDA by analyzing 1,330 asynchronous messages written by 17 students during a 13-week online educational technology course. Through this analysis, they were able to reveal how attributes at multiple levels (individual and message) could affect knowledge creation processes.

We conclude Section I with a commentary from Tim Koschmann. He highlights the processual aspects of creating knowledge, vis-à-vis treating knowledge as a thing or product. Using three accounts of discourse among participants, he illustrates the phenomenon of "knowing" and "discovering" in progress and highlights the role of referential practices in creating knowledge. Koschmann's examples also provide a glimpse into the genesis of a new idea through the interactions of participants and not just how ideas can be improved. Koschmann's commentary is a timely reminder for us to examine our ontological assumptions about knowledge or, more accurately, the nature of knowing, which could also influence the choice of methods in studying the phenomenon of creating knowledge.

In Section II, we turn our attention to knowledge creation practices in school's settings. In Chap. 8, So and Tan describe their attempts in "designing the situation" (Dillenbourg 1999) for pervasive knowledge building in a Singaporean Future School. By pervasive knowledge building in the context of their research study, they refer to continuous improvement and progressive advancement of knowledge beyond the four walls of the classroom to embrace both formal learning situation in the classroom and informal learning. There are two elements in their design of the situation. First, they describe design of the learning context where learning trails were developed for field trips. Second, they discuss pedagogical design that incorporated technology-mediated cognitive tools. Employing design-based research as a methodological tool, they trace how the design of knowledge-building activities evolved over a 3-year period toward their research goal of promoting pervasive knowledge building among students. As an attempt to make their tacit design ideas explicit, they pay particular attention to unpack and elaborate the complexity of design features that guided the overall design of knowledge-building activities. Their studies revealed some tensions and issues, which led to three principles of design as repair strategies: first, design for intentional learning experience that weaves the formal and informal learning spaces; second, design activities or tasks that lead to deep discussion and collaborative meaning making; and, third, design activities that integrate concepts and skills in multiple subject areas to promote interdisciplinary thinking and discourse.

Chapter 9 describes an attempt by Yeo, who worked with school teachers to design and enact knowledge creation pedagogy in a Singaporean high school. This chapter provides an account of the transformation from problem-based learning (PBL) to knowledge creation (KC) for science learning in the school. Through a design research methodology, teachers and researchers worked jointly in an attempt to bring theory and practice together to support students in learning science. The initial implementations of PBL showed contradictions between content and process. Knowledge creation pedagogy was introduced to address the perceived gap between school science content learning and process development. This chapter describes the contradictions in each research cycle using cultural-historical activity theory and explains how the incorporation of knowledge creation pedagogy helped to address these contradictions.

Paavola and Hakkarainen's trialogical approach is heavily influenced by the social-cultural-historical activity theory (CHAT). Similarly, in Chap. 10, Lee draws implications from CHAT to explain knowledge creation. Lee argues that although knowledge creation rather than knowledge reproduction paradigms carry more weight in present-day discourses about improving education, the former has remained a formidable challenge for implementation. One reason for this is because social practices in complex systems such as schools operate squarely within Pickering's (1995) mangle and hence are usually resistant to large-scale transformations. By showing how cultural-historical activity theory and knowledge creation both privilege object-oriented activity, this sociomaterial account of knowing provides a way to understand knowledge creation, specifically its focus on epistemic objects and their associated practices. He describes four case studies from the perspective of knowledge creation that underscore how the formation of epistemic objects and the co-transformation of learner/institutional agency are often emergent, fragile, and unpredictable. He concludes this chapter by providing some suggestions for educators to navigate or work within the mangle of practice.

The other chapters in Section II focus on knowledge creation work with teachers. In Chap. 11, Hong reported a study in a Taiwanese teacher education college. His study investigated the effects of engaging prospective mathematics teachers in knowledge building. Hong examined multiple sources of data, including a belief survey, participants' discourses recorded in an online database, and video recording of their teaching practices. The results indicate that the teaching practice of prospective teachers generally became more adaptive, their teaching strategies progressively diversified, and, more importantly, their mathematics teaching beliefs became more constructivist centered.

Chapter 12 explores knowledge-building practices within a teacher community in a Canadian Lab School. Teo studied teachers' continual improvement of practices, while they fostered continual improvement of students' ideas. After reviewing various models of teacher thinking and development, a problem space model was developed to guide the investigation and provide a theoretically and empirically based description of changes teachers underwent as they gained skill in knowledge-building pedagogy. This model consisted of five main problem spaces: (a) curriculum/standards, (b) social interaction, (c) student capability, (d) classroom structures and constraints, and (e) technology. Teo found three key shifts among the teacher participants in the knowledge-building community: (a) surface to deep interpretation of problem and processing of information, (b) routine to adaptive approach to classroom activities and student engagement, and (c) procedure-based to principle-based reflective action.

Similar to Teo who studied changes in teachers in a teacher community, in Chap. 13, Law followed the trajectory of a teacher participant in a learning community over 3 years. The teacher was engaged in pedagogical design to facilitate sustained student engagement in deepening discourse that would result in their learning of key concepts as stipulated in the science curriculum and in productive knowledge building to tackle authentic problems. Using Technological-Pedagogical-Content Knowledge (TPCK) framework, Law analyzed the advances in knowledge evidenced by the teacher through her planning, teaching, and facilitation activities in her efforts to implement the knowledge-building (KB) approach in her teaching of one science class. Law found that the substantive advancement of the teacher was related to effective knowledge building in the areas of pedagogical knowledge and pedagogical content knowledge, rather than technology-related knowledge.

In order for schools to nurture learners who are able to engage in knowledge creation, teachers need to design learning experiences that reflect the educational philosophies advanced by school reformers. To do so, they first need to experience for themselves the very kinds of learning experiences that they have been called to design for their students. This responsibility has fallen on the shoulders of teachers with the advent of school-based professional development approaches such as professional learning communities. In Chap. 14, Lee and Tan used Engeström's (2001) activity theory as a framework to study the contradictions experienced by teachers in a professional learning team within an elementary school, as the teachers embarked on book discussion sessions as part of the school's efforts in becoming a professional learning community. The expansion of action possibilities (expansive learning) within the book discussion activity system is considered as a means for considering how book discussions may be redesigned to help teachers ascend from being consumers of pedagogical knowledge to being creators of pedagogical knowledge.

Section II concludes with a commentary by Peter Reimann. Reimann's commentary could serve as a good perturbation for researchers who are deeply entrenched in the research of knowledge building; it challenges some implicit assumptions that many researchers hold. First, from a Deweyan perspective, we could view the goal of knowledge building as not only to enhance individual or collective problem-solving capacity but also to expand the learner's capacity in experiencing. Ideas are possibilities that guide future experiences. Second, besides looking at idea improvement, more attention could be directed to how new ideas are generated in the first place, for example, by abduction. Third, to understand knowledge-building practices, we need to go beyond the World 3 knowledge objects, to look at sociomaterial practices around the knowledge objects. Finally, Reimann applauds the research effort in engaging teachers as knowledge builders, which could be a mechanism for building the capacity and culture of teachers in their continual improvement in pedagogical knowledge.

In the concluding chapter, we reflect on the journey some researchers have taken thus far in integrating knowledge-building pedagogies into Singaporean classrooms. We take the opportunity to also introduce some other research projects that for one reason or another were not featured in this book. We also introduce some of the current projects and possible research direction we will be heading toward in the near future.

This book culminates from research in Singapore and in the international community. In the knowledge-building vernacular, the chapters are knowledge artifacts – artifacts that not only document our findings but also mediate future advancement in this area of work. We hope that this book will inspire new ideas and illuminate the path for researchers of similar interest in knowledge creation in education.

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Section I
Theoretical and Methodological Foundations for Knowledge Creation

Chapter 2
Perspectives of Knowledge Creation and Implications for Education

Seng Chee Tan and Yuh Huann Tan

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.

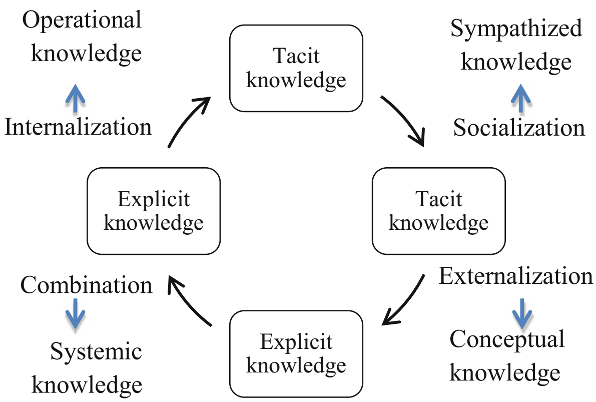
Organizational Knowledge Creation Theory

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 Contradictions as the sources of change and development	Intentionality Autonomy Creative chaos Redundancy Requisite variety	Funding	

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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Chapter 3
Knowledge Building and Knowledge Creation: One Concept, Two Hills to Climb

Carl Bereiter and Marlene Scardamalia

Early in the 1990s, the term "knowledge creation" entered the organizational sciences literature, conveying the idea that companies can not only accumulate and use but literally create knowledge that enables them to progress (Nonaka 1991; Nonaka and Takeuchi 1995). At about the same time, the term "knowledge building" appeared in the learning sciences literature, representing the same idea (Scardamalia and Bereiter 1991; Scardamalia et al. 1994). The core idea is suggested by the conjunction of the two key words, "creation" and "building": Knowledge is the product of purposeful acts of creation and comes about through building up a structure of ideas (for instance, a design, a theory, or the solution of a thorny problem) out of simpler ideas. Nonaka called the process "combining," which though true scarcely does justice to its complexity. (That is like saying Shakespeare wrote his sonnets by combining words.) In later decades the self-organizing character of knowledge creation/knowledge building was to become better appreciated (Bereiter and Scardamalia 2013; Li and Kettinger 2006), but its recognition as purposeful action persists.

Educators were already familiar with the concept of constructivism, more accurately termed "psychological constructivism," as represented in the expression "learners create their own knowledge." Mainly based on the research of Piaget and his school, this version of knowledge construction is an internal process, usually taking place spontaneously and without awareness. Children building up a cognitive structure that recognizes conservation of number under rearrangements of tokens do not know that is what they are doing and are not purposefully striving to achieve it. Knowledge creation/knowledge building is, in strong contrast, a type of deliberate, conscious action, which produces knowledge that has a public life. This is not to discount chance discoveries, insight, and the importance of internal cognitive activity in knowledge creation. It is, rather, to emphasize that the products

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of knowledge creation are public ideas and artifacts embodying them and that their production is an overt activity that can within limits be planned, guided, motivated, and evaluated much like any other kind of work. As Lindkvist and Bengtsson (2009, Abstract) put it, “Once created, such knowledge is seen as having something of a life of its own, pregnant with possibilities for further development and use—to be explored collaboratively—in ways which are unimaginable and unfathomable.” It is this kind of overt collaborative activity that knowledge managers promote in the workplace and that we have tried to promote in education.

Knowledge creation/knowledge building may be considered to take place in a problem space—a conceptual space that contains goal states, intermediate states, constraints, and possible moves (Newell 1980). We suggest that in practice the problem space for knowledge building is larger and more complex than the problem space for knowledge creation. It contains a wider range of goal states. Whereas the scope of corporate knowledge creation tends to be limited by the nature of the organization’s business, educational knowledge building has the whole world of human knowledge as its intellectual workspace. Knowledge creation in the corporate sector often consists of coming up with a promising idea or concept, which is then passed on for development to other groups within the organization, whereas knowledge builders in educational settings are generally expected to do the development themselves. “Ideas are the easy part,” says creative design group Fahrenheit 212 (2009). This is as true in schools as it is in businesses. Knowledge building is very much concerned with “the hard part.” Idea improvement is a core knowledge-building principle. Knowledge building as an educational approach is fundamentally an idea improvement challenge; it is students taking collective responsibility for improving their ideas rather than leaving this as a task for the teacher.

Because knowledge creation and knowledge building have developed as separate research programs based on the same or related concepts, there is potential for the two research programs and the communities of practice growing out of them to learn from each other. Paavola and Hakkarainen (2005) and Chan (2013) have examined the shared conceptual basis, mainly from the standpoint of what education could learn. As part of a Canadian “Initiative on the New Economy,” we launched a project intended to investigate knowledge-building practices in both schools and adult places of creative knowledge work. However, a wave of militant anti-corporatism at our home institution made it necessary to abandon the “knowledge work” part of the project. European researchers were more fortunate, launching “KP-Lab,” which did successfully carry out studies on knowledge practices in both the educational and the corporate world (Moen et al. 2012). But it is probably fair to say that the potential for cross-fertilization has yet to be fully exploited and that the obstacles to doing so are more attitudinal than scientific.

Distinctions That Matter

The idea of knowledge creation caught on easily among innovation-minded business and government people. In education, knowledge building similarly received a positive reception. However, the semantic proximity of "knowledge building" to such more familiar terms as "constructivist learning" and "inquiry learning" made it difficult for many educators to see what was distinctive about this particular kind of constructivist and inquiry-oriented activity.[1] This view of knowledge building essentially obliterates the idea of students engaging in actual knowledge creation, in the sense that that term is used outside of educational settings. Yet that is precisely what "knowledge building" is intended to imply. In Phillips' (1995) multidimensional classification of constructivist viewpoints, one of the dimensions has "individual psychology" at one end and "public discipline" at the other. Knowledge building and knowledge creation, as we use the terms here, are far out on the "public discipline" end of this dimension. Although individual psychology is relevant to any practical approach to knowledge creation, the history of science and the history of ideas often recount important instances of knowledge creation (e.g., Watson 2005), without reference to the psychology of the actors involved. This is most obvious in the case of achievements of the distant past—invention of writing or the wheel, for instance—of which there is no historical record on which to base a psychological explanation.

A distinction between knowledge creation/knowledge building and learning is obvious in work settings: Except in special circumstances, people are paid to produce, not to learn. The distinction is worth making in educational activities as well, however. It allows us to distinguish activities whose sole value is in what they do for the learner from activities that have some larger epistemic value such as advancing the state of knowledge in a community. Just as research advances the state of knowledge in a discipline or in a corporation, it is possible for research, theorizing, and creative knowledge representation to advance the state of knowledge in a classroom community. Knowledge building, as an educational approach, focuses on the advancement of community knowledge, with individual learning as a by-product (Scardamalia and Bereiter 2006, in press).[2] Students assume collective

[1] Interestingly, critics of constructivist learning practices seem to have grasped the distinction, arguing that the problem space of learning and the problem space of knowledge production are not the same (Kirschner et al. 2006; Mayer 2004). We agree that a distinction needs to be made. It cannot be assumed that knowledge creation/knowledge building is going on just because learning is taking place through constructivist activities such as inquiry and guided discovery. And it is equally a mistake to infer that because community knowledge is advancing, individual learning for all students is progressing with it. Individual learning needs to be verified independently of the work that brings it about.

[2] There is nothing unusual about learning being a by-product. That is how learning comes about in most of our daily experience and also how it comes about in most kinds of schoolwork, including activity and play-based methods and even such traditional schoolwork as worksheet exercises, assigned problems, and course papers. The exceptions are approaches in which learning is the

responsibility for advances in community knowledge, with support for taking charge at the highest levels, including problem definition, goal setting, monitoring advances, setting work on to a new and unexpected course, and so forth. Those are all part of knowledge creation as a cultural practice. Because many other educational approaches do not engage students in this manner, although they are similar to knowledge building in being "constructivist" and involving "inquiry," the distinction between knowledge creation/knowledge building and learning is important for any in-depth description of contemporary approaches to education.

Paavola and Hakkarainen (2005) called knowledge creation a metaphor. In our view, there is nothing metaphorical about it (except in the sense that all abstract terms have metaphorical roots). In a given dialogue, knowledge is either literally created or it is not, although determining which is the case is often difficult, especially with the sketchy evidence provided by records of student discourse. Computerized text analysis holds promise of making assessment of group cognition more tractable (Rosé et al. 2008) and seems likely to figure in the next wave of research on knowledge building/knowledge creation.

We believe knowledge-building research and development need to distinguish between what we have termed "belief mode"[3] and "design mode" in work with ideas (Bereiter and Scardamalia 2003). Belief mode comprises all kinds of activities that are concerned with evaluating, questioning, accepting, or rejecting knowledge claims. Design mode comprises a broad range of activities concerned with knowledge production and improvement: theorizing, invention, design, identifying promising ideas, and searching for a better way—in short, all the kinds of activities that mark a knowledge-creating organization. The distinction is blurred, however, in the writings of Nonaka and his collaborators. This is probably not so important for innovative work in organizations, where design mode clearly prevails. In

explicit goal on which classroom strategies are focused. They include direct instruction (Gersten et al. 1987) on one side of the methodological spectrum and on the other side what is called "intentional learning" (Bereiter and Scardamalia 1989) or "intentional cognitive change" (Sinatra and Pintrich 2003), in which students themselves pursue learning strategically.

[3] The term "belief mode" is derived from the traditional definition of knowledge as "true and justified belief" and thus is very broad in scope. However, we have encountered two misunderstandings that undermine the point of the distinction: Some equate belief mode with rote as opposed to meaningful (or constructivist) learning; but attaining "true and justified belief" requires meaningful learning. Even the most authoritarian teaching in belief mode presumes something beyond rote memorization of word strings. Others equate "belief" with faith-based or authority-based knowledge, seeing it at odds with more reflective and critical bases of knowledge that "justified belief" is intended to include. Belief mode encompasses everything from dogmatic proclamation and indoctrination on one hand to the most reflective and skeptical thinking on the other hand. We have tried alternative terms including "proposition mode" and "argument mode," which avoid some misconceptions but promote others; so we remain with "belief mode" as the technically most accurate term. It is well to keep in mind that the wisdom of the past, whatever its source, comes down to us in belief mode, and it is in that mode that we interpret, argue about, and evaluate it. The paradigm of active work in belief mode is, in Western civilization at least, Socrates, whose method of questioning tested the limits of how far one can progress toward knowledge solely by working in belief mode.

education, however, classroom work with ideas, whether employing traditional didactic or modern inquiry methods, is almost exclusively carried out in belief mode, as it has been for millennia. Bringing design mode activity into disciplinary study, which in an operational sense is what knowledge building in the schools is about, therefore needs a higher degree of conceptual clarity than may be required in most knowledge work settings. Furthermore, education must give serious thought to issues of epistemic agency, to the gradual transfer to students of the kinds of epistemic responsibilities traditionally reserved for the teacher: formulating knowledge goals, identifying problems and difficulties, assessing knowledge progress, revising questions, revising strategies, and bolstering intellectual engagement and equality of opportunity. Workplace managers may make decisions about epistemic agency on a purely pragmatic basis, but teachers must look ahead to the long-range benefit of the students. Studying knowledge-creating discourse, bringing sustained creative work with ideas into the curriculum mainstream, and promoting epistemic agency sensibly together make up a research agenda that we hope the new generation of learning scientists will carry forward, aided by the new tools and new scientific knowledge rapidly coming available.

The "Design Thinking" Mindset

Closely related to the concept of design mode is a concept rapidly gaining traction in knowledge management circles: "design thinking" (Martin 2009). In simplest terms, it means taking the kind of thinking that goes on in design labs and applying it to the full range of problems that require thought. It is the kind of thinking that characterizes working in design mode. Some writers treat design thinking as a methodology, comparable to "design-based research" in the learning sciences. Many others, however, treat it as a mindset, a way of thinking that becomes habitual and not something to be turned on only for certain purposes. This way of regarding design thinking is especially appropriate for knowledge building in schools. Instead of "doing" knowledge building in selected subjects at selected times, students should always be alert to the possibility of better ideas, better explanations, better ways of doing things, never quite satisfied with final answers, always looking for opportunities to design and redesign and to act on the basis of well-constructed ideas and understandings. A design thinking mindset, if reinforced through years of experience, should be something they carry with them into adult life. It would serve them in life's daily challenges and in whatever occupations they enter. It could be the most important thing they get out of school.

Unlike a belief mode mindset, a design thinking mindset is inherently social. A surprising number of bloggers identify empathy as an essential part of it. When community members value idea improvement and see idea diversity as a source of energy for the enterprise, they are more appreciative of the diverse ideas of group members. They build on, find new syntheses, explore authoritative sources, and find problems with current explanations. When this becomes part of the classroom ethos, not dependent on the proclivity of a few students or the teacher, a new norm is established. Students simultaneously help each other and request more of each other. There is excitement in discovery, but almost as soon as a discovery is celebrated, someone notes the next thing to be understood—the challenge beyond where they are at present. This is not experienced as defeat but as the very thing that makes a journey of discovery a journey. Students are not working independently on their own or group projects, although they may be working on their individual contributions to a common enterprise. The idea diversity that comes from their different contributions advances the collective state of the art in their community.

Epistemology of Knowledge Creation/Knowledge Building

In recent decades, epistemology has moved beyond its traditional concern with the evaluation of truth claims to a concern with how novel claims come about—hence, with knowledge creation or what philosophers refer to as the logic of discovery (Nickles 1980). Research on students' epistemologies, however, has largely remained locked into epistemology's traditional concerns and thus with issues such as relativism, authority, and certainty. Taken in its largest sense, Piaget's "genetic epistemology" is a wide-ranging epistemology of knowledge creation, but in the simplified version that prevails in education and child development, it scarcely addresses knowledge creation at all. Can the epistemological side of Piaget's theory of knowledge be made accessible to educators? A workable theory of knowledge is needed to help both educators and students deal with what Piaget (1971) saw as epistemology's main challenge: "How can one attain to something new?"

From an intellectual standpoint, the relevance of epistemology to knowledge building/knowledge creation is obvious. If we are in the business of creating knowledge or educating other people to create knowledge, we ought to know something about this stuff we are supposedly creating (including knowing whether it is admissible to call knowledge "stuff" or whether such reification starts us off down a wrong path). From a socio-cognitive point of view, whatever functions as knowledge is knowledge. This view had a practical consequence in the design of expert systems, which sought, for instance, to embody the knowledge—both explicit and tacit—of expert medical diagnosticians in a database where it could be used in computer programs to perform diagnoses or train students. This broadened conception of knowledge is one within which equally broad theories of knowledge creation may be developed.

Polanyi's (1966) concept of "tacit knowledge" has a central role in Nonaka's theory of knowledge creation, which posits a cyclical process by which tacit knowledge is made explicit, combined with other explicit knowledge to produce new knowledge, which is then assimilated into tacit knowledge to start a new cycle of transformations. Polanyi (1966) characterized tacit knowledge by the maxim "we know more than we can tell"—examples being skills and intuitive understandings. Lindkvist (2005) has pointed out, however, that we can also "tell more than we can know"—examples being conjectures, hypotheses, models, thought experiments, and design concepts, which are in the nature of potential rather than actual knowledge. This part of knowledge creation is not well developed in the work of Nonaka and his collaborators, leading some to assert that Nonaka does not really have a theory of knowledge creation (e.g., Gourlay 2006; Tsoukas 2009). There are, however, alternative models: models based on complexity theory, which treat knowledge as an emergent of self-organizing processes (Li and Kettinger 2006); models incorporating Popper's (1972) concept of "world 3," which treats knowledge as having a sort of external, object-like existence (Gourlay 2006; Lindkvist and Bengtsson 2009); and models based on studies of dialogue and which recognize dialogue as not only a medium but a driver of concept creation and revision (Tsoukas 2009). Our own efforts to develop a theoretical basis for knowledge creation incorporate all of these alternative conceptions, which happen to be highly compatible (Scardamalia and Bereiter in press).

In education, it is common to think of knowledge as a psychological state—as something in the individual brain. However, there is knowledge such as that possessed by an expert surgical or sports team that can only be described at the group level (Stahl 2006). There is yet a third way of characterizing knowledge, which is implied by terms such as "intellectual property" and "state of the art." This is knowledge that is not embodied in any particular individuals, groups, or documents but that has a sort of life of its own (cf. Popper 1972). Knowledge-building theory, as we have developed it, is more in harmony with this third conception of knowledge than with Nonaka's more mentalistic model, with its emphasis on tacit knowledge. There is no denying the importance of tacit knowledge and tacit-explicit knowledge conversion, but we see these as belonging more to a theory of knowledge mobilization (Levin 2011) than a theory of knowledge creation.

Knowledge-Building Communities and Technologies

The products of knowledge building/knowledge creation can be understood as advances in the collective state of knowledge. It must be emphasized that these are advances in the Popperian type of knowledge referred to above—amounting to the creation of intellectual property or something analogous to it—and different from an advance in what people individually know. Individuals will learn in the process of advancing community knowledge, of course, and this will happen in any situation, not just in educational situations, but this learning is a by-product that needs to be evaluated separately from the collective knowledge advances. Collective advances may take the form of theories (explanations of the previously unexplained), inventions, problem solutions, and a variety of types of knowledge that add to the capabilities of the community, including especially its capabilities for further knowledge advances. Individual talents, imaginativeness, and curiosity and cognitive skill necessarily play a part, but the knowledge creation itself is a collective phenomenon affected by such group-level characteristics as morale, norms, and community goals.

In order for knowledge building to succeed among students and others new to the process, both social and technological supports are needed. Two major kinds of innovation are required to provide such support:

(a) *Social innovation: transforming school classes into knowledge-building communities*. Every well-functioning school class is a community of some sort, but there are differences in the kind of function the class is organized around. Some are organized around the performance of schoolwork—completing assigned work in a timely and responsible manner. Some are organized around learning—advances in individual achievement related to specified knowledge and skill objectives. Knowledge-building communities are, as indicated previously, organized around the creation and improvement of community knowledge. Functioning as a knowledge-building community means not only that the main work of the class is knowledge building but that students identify themselves as a group dedicated to advancing the state of knowledge and develop norms and practices and a team spirit that supports collaborative knowledge building and that they socialize new students (and sometimes new teachers) into the community and its values and practices. Creating such a cohesive community is something to which knowledge-building teachers devote considerable effort, because it pays big dividends in enabling students to take over more and higher levels of responsibility.

(b) *Technology innovation: knowledge-building technology*. Although knowledge creation/knowledge building can go on without technological assistance—and often does in adult knowledge work—technology can provide a number of supports that could be helpful in many work contexts but that have proved essential in enabling school students to carry through efforts at knowledge creation. Knowledge Forum® is a web-based environment in which knowledge-building discourse is supported through the use of multimedia notes entered into graphical views, where they can be linked, commented on, and subsumed by higher-level syntheses (Scardamalia and Bereiter 2006). Knowledge-building discourse is "scaffolded" by user-selected epistemic markers customized to support theory building and other forms of idea-centered discourse. Teachers who have tried to implement knowledge building without a supportive digital environment have simulated these environments with lower-tech devices such as sticky notes and pockets on a bulletin board. This demonstrates that, valuable as oral discussion may be in creative work with ideas, something beyond it is required in order to keep students' ideas alive as objects of inquiry.

The technology design challenge is to produce more powerful supports for creative work with ideas while keeping agency in the hands of the students rather than micromanaging the process the way "scripts" are prone to do (cf. Dillenbourg 2002). There are now many ways of representing and communicating content digitally that go beyond asynchronous written communication. There are also network and semantic analysis technologies that can provide meaningful feedback to people engaged in collaborative knowledge work. The hoped-for result is greater and more varied interaction among students and between students and ideas, facilitating self-organization at both social and conceptual levels, along with better-informed metacognitive control of knowledge processes. Effective designs need to overcome the danger of loss of continuity—separate and only loosely connected discourses scattered across wikis, blogs, text messages, online forums and appearing on a variety of devices—and black-box intelligent technologies taking over thinking that students should be doing for themselves. In a redesign and rebuilding of Knowledge Forum that is currently in progress, we are striving to support inputs from a variety of sources coming together into a coherent discourse. We are also opting for feedback technologies that are maximally transparent to users and that favor emergence of new ideas (Scardamalia and Bereiter in press).

Authentic Knowledge Creation by Students?

One of the ironies of knowledge creation in schools is that it tends to be judged against the standard of historically recognized geniuses (and therefore found lacking), while out in the world knowledge creation is judged according to whether it constitutes an advance over what has gone before. Authentic knowledge creation can range from tiny increments to world-changing discoveries and inventions. What students produce ought to be credited as authentic knowledge creation so long as it falls somewhere in that large range. Our experience assures us that students from the youngest years of schooling on can operate in design mode—typically producing small increments in community knowledge but occasionally major leaps to a new conception.

Every successful act of problem solving, no matter how trivial, creates knowledge of some sort, even if it is only knowledge that the answer to a particular algebra problem is $x = 12$. However, a problem solution that advances the state of community knowledge must meet higher-level criteria than just any run-of-the-mill problem solving. For example,

- It must have value to people other than the solver(s).
- It must have application beyond the situation that gave rise to it.
- Its value must endure beyond the moment.
- It must represent an improvement over solutions already available.

Problem solutions meeting these criteria usually also merit recognition as creative. These are minimal criteria for problem solving to be recognized as knowledge creation, yet they are sufficient to rule out most problem solving in everyday life and almost all problem solving as carried out in ordinary schoolwork. (With the problems normally assigned as schoolwork, the solution serves only as proof of competence; the value of work on such problems lies only in what individual students get out of the process.) The important point for the present discussion is that meeting criteria for knowledge creation is within the capabilities of even quite young students—provided the problems they work on are authentic ones and not merely exercises of academic skills.

Although academic subject matter may have potential practical value or value in relation to public issues, the main utility of most academic knowledge is to enable the acquisition of more advanced knowledge. For most students, that is the only instrumental value in learning algebra and physics, for instance (allowing that it may also have personal value in terms of intellectual development). When a group of elementary school students produces what they perceive as an adequate explanatory account of rainbows, there may be immediate gratification in feelings of accomplishment, but the usefulness of their theory is in serving as a starting point for a better theory and for helping advance in broader efforts to understand light and vision. This is what advances in science and other basic knowledge-creating enterprises amount to and are generally something to be celebrated, not belittled. Furthermore, an advance that sets the stage for another tends toward more real-world issues of application when work proceeds in design mode. The examples of such knowledge creation by young students have never ceased to amaze us and to boost our faith in the future of civilization.

Educational Knowledge Building and Problems of Explanation

Knowledge creation may be concerned with a wide range of practical, conceptual, moral, and other kinds of problems. As a general rule, however, all problems calling for knowledge creation have underlying problems of understanding which either must be solved or the solution of which will aid in solving the focal problem. One mark of novices in a domain is that they tend to plow ahead with seeking solutions to focal problems without attending to underlying problems of understanding. We have commonly seen this in classroom discussions. For example, in studying problems of endangered species, students are quick with proposed solutions: ban hunting, stop cutting down forests, and so forth. They may take sides and argue about solutions, perhaps seeking evidence to support their positions, but they neglect the question of why the species is in danger of extinction in the first place. That is a problem of explanation, often a complex one, but solving it will often reveal what is wrong with the simple solutions that arise immediately in discussion.

While understanding may be a personal, tacit matter, in the context of collaborative knowledge building, understanding means explaining. “Explanation-driven” learning (Sandoval and Reiser 2004) recognizes this connection, as does Schank and Abelson’s (1977) concept of “failure-driven” learning, according to which the failure of things to behave or turn out as expected drives a search for explanation.

Failure-driven explanation has one serious limitation, however. We are inclined to pursue explanation only to the depth necessary to deal with the problem at hand and then stop; or, as E. O Wilson put it (1998, p. 61), our brains evolved “to survive in the world and only incidentally to understand it at a depth greater than is necessary to survive.” But understanding at a level sufficient for dealing with the problem at hand is liable not to be sufficient for advancing the state of the art or knowledge in a community. Hence it is not sufficient for knowledge building.

It is quite understandable that in their daily lives people do not do the extra work needed to push explanation beyond the minimum necessary for dealing with problems at hand. But knowledge building/knowledge creation generally requires such extra work. Where are people going to acquire the necessary explanation-building practices and skills to become knowledge creators? For all its drawbacks, school is the ideal place, precisely because it is insulated from many of the external pressures that militate against reflection and pursuit of deeper explanation. Students considering whether to preserve the habitat of an endangered bird species or turn an area over to oil drilling do not have to come up with an immediate decision. They can have time (if the curriculum allows it) to pursue a thorough understanding of the problem situation, which includes problems of what constitutes an adequate habitat for the bird and what effect oil drilling has on the surrounding ecosystem. Focusing educational knowledge building on problems of understanding achieves two goals at once: It leads to deeper, more generalizable understanding of the “big ideas” that modern curricula endeavor to teach, and it cultivates the ability and disposition to push explanation seeking to the level necessary for innovative knowledge creation.

The Centrality of Knowledge-Building Dialogue and the Need for Supportive Technology

The creative role of dialogue is widely recognized in the knowledge creation literature (e.g., von Krogh et al. 2000) and is the centerpiece of Tsoukas’ (2009) theory of organizational knowledge creation. The importance of dialogue is no stranger to educational thought, either, dating as far back as Socrates and the type of understanding-seeking dialogue that still bears his name. The kind of dialogue of most interest in knowledge creation/knowledge building is dialogue that actually constitutes collaborative knowledge creation rather than only reflecting or contributing to it. Although it must be recognized that there is more to knowledge creation than discourse, it is also true that if knowledge-building dialogue fails, knowledge building fails, and conversely if a dialogue succeeds in advancing from one shared knowledge state to a more advanced knowledge state, knowledge has been created.

Sustained, goal-directed, knowledge-building dialogue is not something that comes naturally and easily to people (van Aalst 2009). There is a variety of software applications designed to support extended and deeper argumentation (Andriessen et al. 2003). However, this favors belief mode, as previously discussed. While it involves critical evaluation of ideas and the marshaling of evidence to support or disconfirm them, it is not a mode of discourse suited to producing and developing new knowledge. That calls for discourse conducted in design mode. Such discourse is the norm in research teams and calls for different kinds of support. For instance, Dunbar (1997) found collaborative research teams making extensive use of analogies, not for purposes of argument but for purposes of explaining and developing ideas. Knowledge Forum is a software environment, expressly designed to provide support for problem-oriented knowledge-building discourse, through scaffolds and mechanisms for building higher-level structures of ideas. It is evolving, with help from an international open-source team, to provide stronger supports for such knowledge-creating processes as problem analysis, analogy creation, strengthening of explanations, and meta-discourse (discourse about progress and difficulties in the main knowledge-creating effort). In more general terms, supportive knowledge-building technology should help users move up the rungs of the ladder leading from encyclopedic knowledge presentation to increasingly powerful knowledge creation.

Fun in Knowledge Building

We often hear phrases such as "knowledge is power," or "knowledge is wealth," but seldom "knowledge is fun." Many education students in our university courses have reacted with fear when given an assignment that calls for designing something new or tackling a novel problem. This may go some way toward explaining why they are reluctant to institute authentic knowledge building in their classrooms and prefer instead to stick with more routine project-based or inquiry methods. They see knowledge creation as risky, which of course it is. It can fail, as every inventor, theoretician, or design-based researcher knows. Failure is part of the process and is valued as such by knowledge creators of all kinds.

For people anxious about the possibility of failure, it is hard to believe that knowledge building can be much fun. But what we see in hundreds of classrooms is a rather peaceful sort of absorption enlivened by occasional flashes of excitement and joy—characteristic of the mental state that Csikszentmihalyi (1990) calls "flow." When we have asked students to compare knowledge building with other school experiences, they speak about the pleasure of working together, finding new information that helps advance an idea, seeing their theory taken up by someone else, discovering that the more you know the more you know what you don't know, understanding that learning is not so much a matter of the right answer as putting the pieces together in a way that makes sense, and viewing the knowledge advances they have made as team successes. Students themselves have also been responsible for the spread of the pedagogy and technology to new classrooms, subjects, and schools. And when knowledge building is the norm, with students supporting each other, teachers report the class runs easily and enjoyably, for themselves as well as the students, with the students supporting one another and doing much of the correcting and reminding because they view the ideas that arise as community property.

"Play-based learning," which has been known by different names over the past century, seems to be making a comeback. As a reaction against excessive emphases on achievement standards and test preparation, its revival is quite understandable, but as so often happens in the pendulum swings of educational ideology, the reaction can go to excess as well. The excess we are hearing about from colleagues who encounter it is an insistence that play must exclude anything that might be called instruction or academic work. Of the almost two million web documents referencing "play-based learning," a mere 250 mention "play with ideas," and there is a great deal of duplicated text among the 250. And even in those documents there is hardly any mention of what play with ideas would mean or how it might occur. The most elaborated treatment we find is in a blog outlining 11 steps toward improving schooling, step 10 being "Build a Sandbox" (Duncan 2012):

> Every subject in school needs a "sandbox"—time set aside each week—to play with ideas and concepts learned in class. Let that sandbox be where students take apart and reassemble concepts, and find new and creative ways to anchor their learning.

The sandbox metaphor suggests students left alone to play however they wish, yet taking apart and reassembling concepts and finding creative ways to "anchor" their learning (possibly a reference to "anchored instruction"; Bransford et al. 1990) would seem to require substantial teacher or technological support and not to be things children would do spontaneously.

To naïve students, numbers are real things, and play with numbers can be entertaining, quite apart from any concrete representations of the numbers. Play with numbers as such is play with ideas. Similarly, play with words is play with real things, and so is play with phonemes, which can have a vital role in learning to read an alphabetical language. Finally, children can treat ideas themselves as real things to play with. "Playing" with ideas means loosening the normal reality-based or task-based constraints and enjoying the freedom to make new combinations. For instance, a group of elementary school students, intrigued by the notion that people in Australia are upside-down, started playing with explanations of how this could be. So they came up with the idea that people in Australia are inside the globe rather than on the outside and, an even more fanciful theory that the earth is like a Ferris wheel, so that even though it turns, the passengers are always right side up. It cannot be supposed that the children took these ideas seriously. The students were carrying out abductive reasoning, inventing hypotheses which, if true, would explain the phenomenon in question. This is an essential kind of reasoning for knowledge creation (Paavola 2004), but the children were treating it as play. The students, we have suggested, were playing at it "in much the way that a kitten plays at catching mice" (Bereiter and Scardamalia 2013, p. 515).

Given enough freedom, young students will turn almost any academic activity into play. The challenge for pedagogy and technology designers is to provide supports and constraints that will shape the play along lines of useful knowledge creation without eliminating the spontaneity and fun. This is a challenge that the social and technological innovations alluded to earlier can help to meet. They need to provide an environment that is enjoyable to be in while helping knowledge building to progress.

Conclusion: A Place for Everyone in a Knowledge-Creating Culture

We have said that knowledge creation as carried out in adult knowledge work and knowledge building as carried out in education are conceptually the same but with different hills to climb. The distinctive hill that education must climb has to do with the long-term future of the ones creating the knowledge. On one hand, knowledge building needs to make students more knowledgeable and competent (that is the learning effect) while on the other hand providing them with a knowledge base and conceptual tools for further knowledge building. This is a “knowledge age” way of saying something very similar to what John Dewey was saying throughout his long career. “Experience,” as Dewey (1928) defined it, has a progressive, feed-forward character like knowledge building. It is growth that enables future growth. Dewey’s concept of experience has been a hard idea to keep hold of and put into practice, however; Dewey himself grew discouraged with the extent to which the concept was misunderstood and misapplied (Seaman and Nelsen 2011). Knowledge building, once the concept is pried loose from learning, gives Deweyan “experience” an objective embodiment. It is observable behavior and its products—ideas—though intangible, can nevertheless be specified and described. It is possible to visit a classroom and judge whether knowledge building is taking place; judging whether Deweyan “experience” is taking place is much harder.

Not every student will go on in life to be a knowledge worker. Knowledge building in schools must not be geared only to preparing students for such work. Education must take a larger view. The prospects are that in an innovation-driven knowledge society, it will become increasingly difficult for everyone to find valued and satisfying roles. This is the really difficult hill education must climb; the problem cannot be wished away with homilies about everyone deserving a chance. That is true, but very far from being a solution. Knowledge building is not a solution either, but it can be a very positive step in the direction of enabling everyone to make a fulfilling place for themselves in whatever future unfolds. The positive step is helping every student to function in design mode and to bring a design thinking mindset to all kinds of situations, major or minor. Moreover, knowledge building in the classroom can help students learn to collaborate in design thinking, which is often necessary for it to succeed, and to hone communication and media skills that facilitate productive collaboration in design mode.

The answer to individual differences is not the kind of differentiation we once observed in a “model” classroom, where part of the class was engaged in preparing to perform a Shakespearean tragedy, while those with lower academic performance built a model of the Globe Theatre. Knowledge building is something for the whole class to engage in together, with everyone being a contributor. But ways of contributing can vary, depending on individual strengths and dispositions, and they can include not only contributions in the form of ideas but contributions to the community's morale, enthusiasm, and pleasure in accomplishment (Resendes 2013). These are all essential aspects of a successful knowledge-creating culture, whether in the classroom or in the workplace. Some student contributions can facilitate knowledge building without actually introducing substantive ideas: "I don't understand." "What does that mean?" "I found information we should consider." "How can you explain . . .?" "We need more information about. . .." "Let's do an experiment to . . .." These are kinds of contribution that help sustain work with ideas and move knowledge-building discourse forward. Classroom knowledge building can on one hand give students experience in a wide variety of ways of contributing; on the other hand, it can help students develop their individual styles and skills of contributing so that each one has something distinctive to offer in any collaborative knowledge-building effort. That is perhaps the surest way of enabling everyone to find fulfilling roles themselves in a knowledge society and to feel part of the knowledge progress that is reshaping the world.

There are formidable barriers to instituting knowledge building in education. Some of these are the barriers any intellectually serious approach faces: excessive amounts of material to cover, excessive emphasis on test scores, and so on. But knowledge building also faces two barriers in the form of conventional beliefs: a belief that ordinary students lack the motivation and the ability to deal with ideas as such and a belief that basic academic skills and knowledge must be acquired before higher-level knowledge work can proceed. The weight of the evidence we and our collaborators have accumulated over past decades (summarized, for instance, in Scardamalia and Bereiter 2006 and Scardamalia and Egnatoff 2010) contradicts these beliefs, but they are so firmly implanted in conventional educational wisdom that no amount of evidence is likely to dislodge them. Knowledge creation in businesses has also had to contend with conventional beliefs, but pressures to innovate have helped to overcome them.

Much of the business-oriented literature on knowledge creation and innovation consists of examples of how different corporations met this twin challenge. Educators also need examples, images of student groups successfully and happily developing such examples and explicating the principles behind them. There need to be examples from a great range of curriculum areas and student populations. "Building Cultural Capacity for Innovation" is a new international initiative that not only will develop the pedagogical and technological advances needed to make knowledge building work effectively in all areas but will provide images such that any teacher anywhere can look at them and say, "I could do that. With my help my students could do that."

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Chapter 4
Trialogical Approach for Knowledge Creation

Sami Paavola and Kai Hakkarainen

Introduction

Trialogical learning refers to a novel approach on collaborative learning where the aim is to support participants' sustained activities on developing knowledge artifacts (documents, models, design artifacts, etc.) and cultivating related knowledge practices. The trialogical approach emerged originally from research on technology-mediated collaborative learning and inquiry learning. Information and communication technologies (ICTs) provide tools and instruments that make deliberate building and creation of knowledge accessible even for elementary school students. The terms "trialogues" and "trialogical learning" (or "trialogical inquiry") are quite new in the context of academic discourse related to learning and knowledge creation.[1] The trialogical approach itself is, however, rooted in the theoretical traditions on learning where practices, object-oriented, and artifact-mediated processes are emphasized as a basis for understanding human cognition and epistemic activity more generally. The trialogical approach has an interventionist emphasis.

[1] Dictionaries define trialogues usually as a conversation, colloquy, or discussion between three people or three groups, but the term has been used in different senses (see Wiley 1994). Our use of the term (see Paavola and Hakkarainen 2009) highlights that the interaction between people does *not* happen only through words and concepts and by communicating and changing ideas (like in dialogues) but through developing shared "objects" (artifacts and practices) where the role of shared objects and their iterations have a more prominent role than traditionally recognized.

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Rather than giving exact pedagogical formulas, it aims at giving guidelines for developing existing pedagogical practices so that collaborative advancement of knowledge artifacts and practices is emphasized.

The Trialogical Approach

The trialogical approach has emerged on the basis of both practical and theoretical considerations on technology-mediated collaborative learning. The aim has been to promote those kinds of processes where students (or participants) are focusing their efforts on developing concrete knowledge-laden artifacts together. This is different from traditional views on learning as knowledge acquisition or participation to social practices. Instead of emphasizing intersubjective dialogue in the way characteristic of meaning-making traditions, the aim of trialogical approach is to promote focused, collaborative work with knowledge artifacts and practices (Paavola and Hakkarainen 2009) and to appropriate associated practices of working productively with knowledge (Hakkarainen 2009a).

Although the trialogical approach has been developed for facilitating advanced processes of learning in education, it is *not* a full-blown pedagogical model with specific stages or guidelines of implementation. It is rather a conceptual framework for examining learning and inquiry processes related to systematic creation and advancement of knowledge. It can be implemented in various ways and gives guidelines for transforming educational practices to facilitate shared efforts of working with knowledge artifacts (Paavola et al. 2011). The aim is to enhance processes on collaborative knowledge creation with concrete outcomes. The trialogical approach has been developed and investigated especially in a large (2006–2011) project called the *Knowledge Practices Laboratory* (KP-Lab) (see especially articles in Moen et al. 2012; cf. also Paavola and Hakkarainen 2005). A specific virtual environment called the *Knowledge Practices Environment* (KPE) was developed for supporting various aspects of collaborative knowledge creation (Bauters et al. 2012; Lakkala et al. 2009).

The focus on the KP-Lab project was on higher education courses where students produced knowledge artifacts (project documents, project works, etc.) in groups. The courses and contexts had quite a lot of variation. For example, there were training courses in medicine where medical students used advanced technologies (with a small manikin having functionalities of a newborn baby) for learning teamwork in cases simulating authentic settings (Karlgren 2012). However, there were also more “mundane” higher education courses (mundane in a sense of not needing any specialized technologies) involved. Students were, for example, producing small design assignments for real customers in a media engineering course, or producing concept maps in pairs on the basis of their own research interests in a course on qualitative methods (see Lakkala et al. 2012), or producing business ideas and technological solutions for customers (Kosonen et al. 2012). These courses were *not* designed originally according to the trialogical approach; rather, they were chosen for investigation because they already had characteristics of the trialogical learning (see design principles below) and had potential to be developed further (see in more detail Karlgren 2012; Kosonen et al. 2012; Lakkala et al. 2012).

Similarly, the present investigators and their collaborators have promoted knowledge creation practices and trialogical learning by using technology-mediated learning environments to support *collaborative design*. Designing appears be a trialogical process almost by definition because of the importance of a shared object of designing from conceptual ideas to prototypes and actual design artifacts. Together with our collaborators, we have carried out a series of investigations that involve students from elementary (Kangas et al. 2011) to higher education (Lahti et al. 2004) levels designing artifacts in collaboration with domain experts. *Learning through Collaborative Design* (*LCD,* Seitamaa-Hakkarainen et al. 2012) model guides participants to iteratively develop their design ideas and determine design constraints but diverge from the inquiry learning in terms of engaging participants in prototyping and working with materially embodied artifacts. Such experiments have allowed us to extend the inquiry learning approach from conceptual domains to material cultures of artifact creation (Kangas et al. 2007).

Basic characteristics of the trialogical learning have been formulated with six *design principles* (Hakkarainen and Paavola 2009; Paavola et al. 2011; see also Karlgren 2012; Lakkala et al. 2012). They have a dual nature: (1) They point out characteristics that can be called “trialogical” (many existing courses have these features in various degrees); (2) they give broad guidelines for enhancing trialogical features of the learning settings in question.

DP1: Organizing Activities Around Shared Objects

The first DP explicates the central idea of the trialogical approach, emphasizing practices through which participants organize their collaboration for developing “shared objects.” These shared objects can be various kinds of knowledge artifacts (documents, plans, designs, models, prototypes, products, etc.) but also shared practices and processes (i.e., ways of working or organizing the collaboration) that may be systematically developed and transformed together. This focus on developing practices and processes appears to be a central characteristic of innovative knowledge communities. “Sharedness” does not mean that participants are necessarily agreeing on objects, but rather that they are focusing on producing concrete things together. One vital feature of the trialogical approach is that the work and versioning of external knowledge artifacts – created for some subsequent purpose and use – are seen to structure human interaction essentially. These shared objects and versioned knowledge artifacts provide a concrete common ground and mediating element for collaboration. At the same time, participants are encouraged and supported in developing and reflecting their processes of organizing their collaboration and ways of working.

DP2: Supporting Integration of Personal and Collective Agency and Work (Through Developing Shared Objects)

In order to understand and support knowledge creation processes properly, the dichotomy between individualistic approaches to learning and purely social interaction is to be transcended (see metaphors of learning below). Efforts and expertise of individual participants often play a crucial role in knowledge creation and advancement processes. As Ritella and Hakkarainen (2012) argued, productive participation in knowledge creation process presupposes transformation of personal operating systems of activity (Donald 2000) in a way that supports technology-mediated knowledge practices. Personal transformation, however, takes place through participation in a community that provides a fertile ground for creative efforts. This means that when people are involved in creative processes, the role of individual expertise is tuned with fertile social and cultural processes (and vice versa). Personally and collaboratively constructed artifacts and practices become resources on which social communities and individuals may build their inquiries. Participants are encouraged to take the agency of their own work, collaborative processes, and those objects that they are developing (see Damsa and Andriessen 2012).

DP3: Fostering Long-Term Processes of Knowledge Advancement with Shared Objects (Artifacts and Practices)

Processes of developing something new together or developing knowledge practices usually require from individuals, groups, and social institutions iterative efforts spanning across relatively long periods of time. The focus of the trialogical approach is on practices and tools that support work with a longer time frame than is often done in educational settings, but it is still focusing on shorter time frame than long-term cultural changes. The focus is on extended processes addressing practices and tools needed for going beyond individual courses. These include various aspects like doing things that are meant for some subsequent use, encouraging links between different courses, creative reuse of previous practices and knowledge artifacts, and providing enough time for iterative cycles needed in knowledge advancement. A focus on sustained processes of knowledge creation is one difference to many dialogical approaches that focus on microanalytic studies of here-and-now discourse interaction. The advancement of knowledge-creating inquiry is not possible without iterative efforts that involve pursuing investigations, getting feedback, redirecting subsequent efforts, and gradually reaching novelty and innovation (Bransford et al. 2006).

DP4: Emphasizing Development and Creativity on Shared Objects Through Transformations and Reflection

A central weakness of various inquiry learning approaches is an exclusive focus on conceptual entities and ignoring materially embodied and practice-related aspects of knowledge creation. The trialogical approach, in contrast, emphasizes development and knowledge creation through interaction between various forms of knowledge and between practices and conceptualizations. Interaction and transformation between such things as explicit knowledge, under-articulated (tacit) knowledge, knowledge practices, and conceptualizations are seen as driving forces in knowledge creation processes. The processes of developing and formulating shared objects together provide mediating elements of knowledge creation. By capitalizing on distributed cognition (Hutchins 1995), the trialogical approach examines knowledge artifacts as materially embodied entities that are worked on in various "external memory fields" (Donald 1991) rather than reduced to their conceptual content (Paavola and Hakkarainen 2009). Elaborating ideas in mind and working on paper are mutually dependent and co-constitutive processes (Ritella and Hakkarainen 2012). In the design of technology-mediated learning environments, it is especially important to provide tools that enable users in externalizing and materializing their intangible hunches and ideas and transform them to digital artifacts than can be subsequently built on, commented on, and raised above by relying on collective cognitive efforts (Bauters et al. 2012; Scardamalia 2002).

DP5: Promoting Cross-Fertilization of Various Knowledge Practices and Artifacts Across Communities and Institutions

In order to provide students with skills and competencies that prepare them to encounter future challenges, it is critical to engage them in solving more varied and complex problems than traditional narrow and impoverished textbook problems (Bransford et al. 2006; Marton and Trigwell 2000). Toward that end, the trialogical approach focuses on learning settings in which students solve complex, "authentic" problems, that is, challenging problems, that have significance and relevance outside the educational setting in question and that are often intended to be used and utilized outside educational institutions (like design assignments or products for real customers, or documents to be used in one's own subsequent research practices). Crossing boundaries between knowledge communities is considered to provide critical experience for knowledge advancement because it makes participants reflectively aware of implicit and partially nonconscious aspects of knowing. This kind of "cross-fertilization" between education, research-related and professional institutions, and practices is an important motivation for students and teaches the competence needed in modern knowledge work.

DP6: Providing Flexible Tools for Developing Artifacts and Practices

As explained above, the trialogical approach capitalizes on the novel affordances of digital technologies to facilitate collaboration around shared objects and organizes activities around advancement of a joint creative endeavor. Information and communication technologies (ICTs) have, as the concept itself suggests, for a long time been seen to support either “the information genre” or “the communication genre” in people’s activities (Enyedy and Hoadley 2006); that is, existing ICT is mainly suited for sharing information (“monologues”) or for supporting social interaction (“dialogues”) as respective social activity. Web-based technology, however, gives new means for collaboratively developing and creating knowledge artifacts and related practices (Hemetsberger and Reinhardt 2006; Lee et al. 2008; Miettinen 2006). The present trialogical approach entails, however, expanding perspective to technology-mediated and knowledge-laden practices of jointly working for creating and extending knowledge artifacts and supporting related object-oriented processes (Bauters et al. 2012; Lakkala et al. 2009).

These design principles above are quite general and leave room for different interpretations. When taken literally, these design principles are also quite demanding. They are meant to give guidelines or be “vehicles of innovations” when ways of promoting trialogical aspects of learning are elaborated. For example, there are different ways of fostering long-term processes of knowledge advancement (DP3) (e.g., by using knowledge artifacts or templates produced by earlier participants as a basis for your own collaboration or trying to implement ways of working found successful by others). It is then up to the participants to decide which parts and how they are to promote these aspects of trialogical learning.

Also in the KP-Lab project, the central focus on “shared objects” ended up having different meanings and interpretations (see Paavola et al. 2012, pp. 10–11):

1. The basic theoretical idea of the trialogical approach has been to support collaborative and iterative work with external artifacts and develop concrete ways of doing things together.
2. In pedagogical cases, a broader and a more abstract interpretation of “shared objects” was emphasized. A central concern was to organize students’ activities on shared topics and meaningful assignments where the work with collaboratively developed artifacts (meaning 1 above) can be one central means.
3. Other interesting “object-bound” activities in between trialogues and dialogues were also found which are often used for promoting collaboration. For example, object-bound discussions mean that commenting or discussions are targeted at specific parts of a document instead of more general discussions (see also van der Pol 2007). On the other hand, knowledge artifacts (e.g., visualizations) were developed collaboratively by projecting them onto a screen and then discussed in a face-to-face meeting. So the focus was on developing knowledge artifacts

together (i.e., trialogues), but it required various kinds of supporting object-bound dialogues.

A Background for the Trialogical Approach in the Knowledge Creation Metaphor of Learning

The trialogical approach builds on an emerging trend in theories of learning to understand processes where something new is developed collaboratively (Paavola and Hakkarainen 2005). Preparation to the advanced knowledge society appears to require improved understanding of personal and collaborative processes related to pursuit of innovation and novelties. We have previously referred to these theories and approaches with the term *knowledge creation metaphor* of learning and human cognition (Hakkarainen et al. 2004; Paavola et al. 2002, 2004). Anna Sfard has made a well-known distinction between an *acquisition* and a *participation metaphor* of learning (Sfard 1998). Roughly speaking, the acquisition metaphor of learning refers to traditional theories of learning where information processing within the human mind and the transfer of conceptual and factual knowledge are emphasized. Thus, learning is seen as something where individuals acquire already existing bodies of knowledge. The participation metaphor refers to sociocultural theories of learning that have challenged and questioned the acquisition approaches. Such approaches examine learning as a process of socializing and growing up to social communities and appropriating their shared norms, values, and practices and gradually transforming identity as well. Learning is not seen so much as acquiring something but as a more holistic developmental transformation through doing things in actual contexts.

The knowledge creation metaphor of learning is based on a claim that if theories of collaborative creativity and joint development of novelties are considered, neither acquisition approaches nor participation approaches are sufficient in themselves (see also McLoughlin and Lee 2008; Tynjälä and Häkkinen 2005). We have analyzed (Paavola et al. 2002, 2004) prominent theories on learning and human cognition that represent the knowledge creation metaphor of learning, that is, Bereiter and Scardamalia's (2003) knowledge building, Engeström's (1987) theory on expansive learning, and Nonaka and Takeuchi's (1995) theory of organizational knowledge creation. We maintain that they transcend dichotomies related to the acquisition and the participation metaphors of learning in terms of addressing collaborative processes of pursuing novelty and innovation. People create novelties by organizing their long-term efforts for developing "shared objects," which can be very diverse things like theories, documents, designed and manufactured products, and shared practices being reflected on and transformed.

The trialogical approach has emerged from our efforts of trying to understand commonalities across these approaches that highlighted knowledge creation processes in learning. The aim has been to widen *dialogic* theories and *meaning-*

making traditions prevalent within computer-supported collaborative learning to encompass collaborative work with shared artifacts and practices as well (Paavola and Hakkarainen 2009). The idea is not to make a stark contrast to dialogic approaches but to maintain that there is a need to take the role of collaboratively developed artifacts and objects and associated collaborative practices into account when developing theories of learning.

An important basis for the trialogical learning has been the experiences of developing the inquiry learning model called *progressive inquiry* (Hakkarainen 2003, 2004; Hakkarainen et al. 2004). This pedagogical model is rooted in Bereiter and Scardamalia's (2003) *knowledge building* approach and engages students in systematic efforts of building and creating knowledge related to various aspects of their school learning. Students are engaged in investigative study projects driven by students' questions and intuitive working theories. In the background of progressive-inquiry model is an assumption that learning is similar to inquiry processes where interrogative processes (questions and answers) guide the search for more specific hypotheses and advancement of communal knowledge (Hakkarainen and Sintonen 2002). Research and development efforts of technology-mediated learning environments, such as Future Learning Environment (www-fle3.org), have been engaged to support progressive inquiry (Muukkonen et al. 2005). The investigative practices of learning and instruction based on the progressive-inquiry model have become a very influential model in Finland.

Our investigations indicate that in educational contexts, teachers and tutors play a crucial role in guiding knowledge-creating activity related to progressive inquiry and collaborative designing (Viilo et al. 2011). It was noted early on that it is quite challenging for teachers and students to implement knowledge-creating inquiry cultures (Hakkarainen 2009b, 2010). This is because establishing a successful inquiry culture requires transformation of teachers' and students' social practices; such cultures channel and guide the participants' activities in a way that elicit inquiry. Technology enhances learning only through transformed social practices. The learning of these kinds of technology-mediated practices requires time. The cultivation of *social practices* supporting inquiry learning is as important as the understanding or models on inquiry processes as such (Hakkarainen 2009a). Collaboration should then not be seen just as an *epistemic* issue (around knowledge) but also as a matter of developing collaborative ways of working together.

Even though trialogical processes can be implemented without novel technology, digital technology has provided new means for trialogical processes and collaborative knowledge creation; people can more easily than ever share their work with others and collaboratively and iteratively develop things forward (Shirky 2010). And this is just not happening in traditional educational contexts. The Internet appears to provide novel instruments and methods that allow people to use their free time and efforts (cognitive surplus) to make and share their creations and experience being connected to creative communities. Social media provides novel instruments and methods for functioning as communities, where it did not use to be possible, for developing and advancing shared objects across spatial and temporal boundaries (Rheingold 2002). Open-source development communities are prime examples of object-oriented distributed knowledge-creating communities (Hemetsberger and Reinhardt 2006; Weber 2004). Wikipedia reveals the creative strength of distributed but coordinated efforts for making and sharing knowledge (Tapscott and Williams 2006). New interest groups emerge in the Internet that involves participants pursuing shared interests (Gee and Hayes 2011). Trialogical activity appears to go beyond mere friendship-driven social exchange ("hanging out") and involves serious development of expertise with extended networks of more experienced peers and expert communities ("geeking out," Ito et al. 2010). Educational investigators are, however, worrying about the existence of a *participation gap* that involves the unequal access to learning opportunities and formative experiences that advanced and creative use of digital technologies requires. In order to provide learners an access to cultivation of creative capabilities that the emerging knowledge society requires, we need to achieve much deeper understanding of the development and dynamics of innovative knowledge communities. The aim of the trialogical approach is to engage teachers and educational institutions with academic researchers and professional communities in collaborative efforts for improving the quality of education by utilizing novel possibilities provided by digital technologies.

Elements of Trialogical Learning

As we see it, the trialogical approach is an outgrowth of many existing long-term developmental paths concerning collaborative learning and human cognition. We will unpack shortly four important theoretical aspects of the trialogical approach: (1) mediation, (2) artifacts, (3) knowledge practices, and (4) object-oriented practices. These are connected to the design principles of the trialogical learning (see above) that bring forth general discussions on knowledge creation.

Mediation

The trialogical approach has its basis on theories of mediation (Paavola et al. 2012). There is a variety of approaches building on mediation as a basis for human activity (see, e.g., Engeström 1987, pp. 37–73). Central influences to the trialogical approach have been activity theory, Popper's (1972) theory of cultural artifacts, and Peirce's (1992–1998) semiotic and pragmatistic theory of mediation. Cultural-historical activity theory builds on Vygotsky's (1978) seminal approach that all human activity is mediated by tools and signs. In activity theory, changes in activities are considered to happen through retooling and remediation where artifacts and tools are used as means of transformation of activities and practices (Engeström 1987; Miettinen and Virkkunen 2005), whereas, the knowledge building approach has its basis on Karl Popper's (1972) theory that maintains that, besides mental and material realm, there is a realm of cultural artifacts (Bereiter 2002) and these cultural artifacts can be seen as central mediators of human knowledge. According to knowledge building theory, collaboration can be supported with new technology designed for supporting collaborative creation of ideas and construction of local cultural knowledge (Scardamalia et al. 1994). Starting with the Peirce's semiotic pragmatism it can, further, be maintained that human activity is mediated through and through with various kinds of sign processes and embedded in activities and practices. Peirce was also emphasizing the role of external artifacts in "augmenting" human intelligence and cognition (Skagestad 1993) bringing it close to modern ideas on distributed cognition.

The trialogical approach is not so much meant to be a new theory of mediation, but it builds on previous theories on mediation and is targeted for understanding the role of collaboratively developed, concrete artifacts and the new technology for enhancing human collaboration and creativity. New digital technology has provided novel multifunctional tools and artifacts that are changing people's ways of working and collaborating. When designing technology-mediated learning environments, investigators deliberately create new types of external memory fields for supporting trialogical activity. In order to provide adequate support for trialogical learning, such environments need to be designed to provide *multimediation*, that is, integrating and supporting collaborative working with shared objects from different perspectives. In this context, we have found useful Pierre Rabardel's analysis of the four forms of mediation (see Rabardel and Bourmaud 2003; about Rabardel's theory, see Lonchamp 2012; Ritella and Hakkarainen 2012), such as epistemic, pragmatic, social, and reflective mediation. *Epistemic mediation* is related to a process of deliberately creating, organizing, and working with artifacts aimed at knowledge advancement. Crystallization, externalization, and materialization of ideas to knowledge artifacts facilitate advancement of inquiry. Learners may appropriate knowledge-creating practices to the extent that pursuit of epistemic mediation relevant for knowledge creation becomes their second nature, that is, an integral aspect of their operational activity system. *Pragmatic mediation* is involved when providing adequate support and structuring for organizing, planning, and coordinating collaborative knowledge creation processes. *Social* (or *collaborative*) *mediation*, in turn, is related to building and managing networks and social relations around shared objects. Finally, *reflective mediation* emphasizes the importance of making knowledge practices visible and aims at transforming them. In well-designed technology-mediated learning environments, all these aspects of mediation support one another (see Bauters et al. 2012).

Developing Artifacts

As explained above, the trialogical approach emphasizes the role of concrete artifacts as a basis for collaboration (Paavola and Hakkarainen 2009). These mediating artifacts are anchoring and directing collaboration in many ways. Very diverse approaches have emphasized a fundamental meaning of artifacts for human evolution and cognition. The emergence of external representations and artifacts that allowed overcoming the limitations of human working memory has been crucial in human cognitive evolution (Donald 1991; Sterelny 2004). The artifacts constructed may be interpreted to have "pointers" (hints or implicit directions) regarding what is missing from the picture and providing intuitive guidance for directing subsequent inquiry efforts (Knorr-Cetina 2001). It appears to us that inquirers use deliberately created knowledge artifacts as "stepping-stones" for advancing knowledge and gradually extending boundaries of established knowledge and understanding (Ritella and Hakkarainen 2012).

Cultural-historical activity theory emphasizes artifact-mediated activities that are grounded on practical, everyday activities (Cole 1996) and remediation with novel tools and artifacts when existing activities and routines are not working anymore (Engeström 2001; Knuuttila 2005; Miettinen and Virkkunen 2005). Popper (1972) emphasized the role of cultural or conceptual artifacts for human evolution that is a basis for the knowledge building approach. Wartofsky constructed a program for "historical epistemology" where he pointed out that "[a]rtifact is to cultural evolution what the gene is to biological evolution" (Wartofsky 1979, p. 205). Burkitt (1999, p. 4) combines artifacts to bodily activities: "Artifacts are prosthetic extensions of the body and their use makes possible new ways of knowing the world, along with re-formed bodies with new capacities." These extensions are emphasized also in approaches on extended mind (Clark 2003; Clark and Chalmers 1998). The trialogical approach builds on these approaches highlighting a fundamental sense of artifacts for human cognition. It has, however, a narrower and a more specific focus on those processes where people organize their collaboration for iteratively developing concrete knowledge artifacts and cultivate corresponding knowledge practices.

Developing Knowledge Practices

In the social sciences and organizational learning, there has been for some time discussions on a "practice turn" (Schatzki et al. 2001) that has implications also for learning theories. There is a variety of practice theories (see Miettinen et al. 2012), but in general according to them, practices are seen as materially mediated and/or embodied activities, which transcend traditional dichotomies to human and nonhuman entities (Schatzki et al. 2001). Instead of emphasizing science and research mainly through thinking and representations of ideas, the focus is on context-bound human activities. The trialogical approach aims at supporting similar kind of practice turn in learning even when it is a question of advancing students' work with ideas. Hakkarainen (2009a) has crystallized the perspective with the slogan, "technology enhances learning only through transformed social practices." In order to work as an instrument of learning and teaching, educational technologies have to be integrated, "fused," with the social practices enacted by participants.

This is a reason for introducing the concept of *knowledge practices*. Technology in itself does not change human activities but only through those social practices or "knowledge practices" which it entails. Knowledge practices refer here on socially-historically created behavioral patterns, routines, or ways of working with knowledge and knowledge artifacts. These practices comprise multilevel, complex arrays of activities.

It is then essential to expand the perspective from mere technological tools to social practices of their usage (Hakkarainen 2009a; Hakkarainen et al. 2009). It appears to us that otherwise attractive visions regarding the emergence of collectively intelligent Metaweb (Nova Spivack[2]) are "flat" because these are assumed to arise from increased information connectivity, on one hand, and social connectivity, on the other hand. Visions of *the pragmatic web* (see Hakkarainen et al. 2009 for references) guide one to examine social practices related to the historical-developmental use of technology, as the topography or a third dimension of the Metaweb, a dimension that reveals an extremely rough terrain of the surface.

In order to transform technological artifacts as instruments of their activity, participants have to go through a developmental process of "instrument genesis" (Rabardel and Bourmaud 2003; see also Ritella and Hakkarainen 2012) that only intensive use of technology in practice brings about. Ideas and visions of the pragmatic web underscore the crucial role of social practices for gradual learning and socialization for using ICT. Going through instrumental genesis in learning to use a new technology and appropriating associated knowledge practices initially requires an investment of both personal and collective efforts like climbing to the top of a steep mountain. Required cognitive adaptations do not take place without an effort of adapting, tailoring, and reformatting technology-mediated competences. After going through such an effort, the participants may be reluctant to start climbing another mountain without good, motivating reasons. Personal appropriation of even relatively simple technology, such as email, is initially challenging because it requires appropriating new social practices in gradually adapting and changing one's cognitive-cultural operating system of activity.

Remediating practices of classrooms or whole educational institutions by ICTs appears more challenging than transformation of personal knowledge practices. Going through transformation is challenging because there are no ways of moving directly from present to new practices; an iterative process of remediating and transforming practices gradually, step-by-step, is needed. The participants cannot plan exact route across an unknown territory beforehand but have to learn to negotiate partially unexpected challenges and obstacles. Consequently, novel technology-mediated practices of learning and instruction are likely to consolidate very slowly, and progressions tend to take place in courses and practices of enthusiastic and committed teachers with a high level of technological fluency (Barron 2006).

[2] See http://novaspivack.typepad.com/nova_spivacks_weblog/2004/04%20/new_version_of_.html

It seems that successful cultures of trialogical learning are simultaneously also expansive-learning communities (Engeström 1987) focused on problematizing current practices, envisioning changes, and gradually, step-by-step, consolidating novel knowledge practices (Hakkarainen 2004; Hakkarainen et al. 2008). New practices do not emerge from scratch but require deliberate and iterative efforts of transformation under the guidance of teachers and students. Hakkarainen (2013) argued that learning across cohorts or generations of inquirers is one of basic mechanisms of human collective creativity. Such expansive community-appropriate new ICT tools go through personal and collective developmental processes and cultivate "information ecologies" (Nardi and O'Day 2000) for creating innovative local practices of using technology.

Object-Oriented Activities

Objects and object-orientedness of human activity are basic concepts in activity theory (see Engeström and Blackler 2005; Kaptelinin and Miettinen 2005; Miettinen 1998). In activity theory, objects have thinglike characteristics, but they are also something to which actions are directed. This idea of object-orientedness of human activity is used also in many other approaches nowadays although, not in a similar, basic theoretical meaning than in activity theory. According to Knorr-Cetina (2001), knowledge-centered practices of modern professionals are not to be understood as iterative and habitual routines, but more dynamically oriented toward epistemic objects. For Knorr-Cetina, these epistemic objects are material in some sense, but more importantly for her, they are open ended and always in the process of being developed and also materially defined (pp. 181–182). Another influential approach in social scientific and organizational studies on object is the notion of *boundary objects* (Star and Griesemer 1989). Boundary objects are objects that are used in boundaries of different actors or organizations or within intersecting social worlds. Objects have a broad meaning here; as examples of boundary objects, Star and Griesemer have analyzed, for example, repositories, ideal types, and standardized forms. Boundary objects are "both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" (p. 393).

The trialogical approach highlights the object-oriented nature of human activities and work with shared objects (cf. also Lund and Hauge 2011; Muukkonen-van der Meer 2011). Analogously to what was said on mediation above, the trialogical approach aims not to be a new theory on object-orientedness but highlights those processes where collaboration is organized for developing collaborative knowledge artifacts and practices. Collaboratively developed knowledge artifacts are "intermediate objects" constructed for advancing knowledge in a specific situation. Artifacts created for such specific purposes guide and provide stepping-stones for subsequent knowledge-creating efforts. Hence, knowledge artifacts constructed are oriented toward the “final” object of the work, including various unforeseen uses and effects. Accordingly, these shared objects have similarities to boundary objects by being concrete things that are structuring the collaboration. Shared objects and artifacts are making such cooperation possible, which does not require consensus to begin with (in contrast to many other approaches) (see Star and Griesemer 1989, p. 604). As a difference to boundary objects, these shared objects do not need to be necessarily in between boundaries, and they are dynamic from the start. They are meant to be developed and modified collaboratively, while boundary objects are often conceived as quite static in themselves (see Ewenstein and Whyte 2009).

Trialogical Approach in Relation to Other Theories on Knowledge Creation

The trialogical approach has taken influences on different approaches, representing the knowledge creation metaphor of learning like the theory of *organizational knowledge creation* (Nonaka and Takeuchi 1995), *knowledge building* (Bereiter and Scardamalia 2003), and *expansive learning* (Engeström 1987). It has been maintained that even when showing general commonalities between educational and cognitive theories, there is a risk that the knowledge creation metaphor ends up being eclectic (Engeström and Sannino 2010, p. 18). There are clear epistemological and ontological differences among these theories on knowledge creation that these differences should not be ignored. We agree with this. In *organizational knowledge creation*, the focus is on how organizations process knowledge from the point of view of business, and the theory emphasizes the interplay with tacit and explicit knowledge and knowledge conversions at different levels (individual, group, organization, interorganizational level) (Nonaka 1994). *Expansive learning* is a theory on communities of learners and transformations on activity systems where learners construct and implement wider and more complex objects for their activities (like professionals redefining their ways of working when new challenges and risks threaten their work). *Knowledge building* is basically an educational approach, arising from computer-supported collaborative learning, and entails knowledge builders working with improvable ideas with the educational technology supporting their work.

The underlying *epistemology* is also quite different in the three theories representing the knowledge creation metaphor. The starting point for the organizational knowledge creation is tacit knowledge developed in relation to organizational learning and Japanese intellectual tradition emphasizing “onenesses” (humanity and nature, body and mind, self and other), which is in contrast to Cartesian rationalism and dichotomies (see Nonaka and Takeuchi 1995, pp. 27–32). Expansive learning has a rich background in the Russian cultural-historical school where contradictions, object- and future-oriented activities, as well as mediation by cultural tools and signs play a crucial role (see more in Engeström and Sannino

2010, pp. 4–5). Knowledge building leans on theories related to the use of technology to scaffold expertise in writing. It builds especially on Karl Popper's theory on "World 3" of public knowledge and conceptual artifacts in distinction to the material and mental realms ("World 1" and "World 2"). Knowledge building focuses more on intellectual problems, whereas expansive learning focuses on practices and contradictions on activities (and activity systems). In organizational knowledge creation, the focus is on product and process innovations in business (Nonaka and von Krogh 2009, p. 646).

While acknowledging differences among these theories, we think that it is worthwhile looking at their commonalities. It would be totally unrealistic to think that there could be a metatheory on knowledge creation. Different approaches of knowledge creation are built on different traditions of research and focus on different aspects on knowledge creation, and because of that, they are putting forth different alternatives. Still, these theories on knowledge creation are not static themselves, and their development does not happen in a vacuum. The function of the knowledge creation metaphor is to point out emerging trends in theories on learning and human cognition that are important when approaches on knowledge creation are developed further.

One commonality in theories representing the knowledge creation metaphor is the societal need for a new approach on learning. The focus is not the same but the need for something new is quite similarly emphasized. It can be, of course, maintained that this is only rhetorics. Here we think, however that the rhetorics show a deep change in modern societies. According to Nonaka, the so-called knowledge society "calls for a shift in our thinking concerning innovation in large business organizations... It raises questions about how organizations process knowledge and, more importantly, how they create new knowledge" (Nonaka 1994, p. 14). According to Scardamalia and Bereiter (2010), knowledge building focuses on "the 21st century need to work creatively with knowledge." The basis for expansive learning is a broader societal need: "The ultimate test of any learning theory is how it helps us to generate learning that penetrates and grasps pressing issues the humankind is facing today and tomorrow" (Engeström and Sannino 2010, p. 21). Shortly, traditional epistemologies and learning theories are not enough especially if their focus is on processing existing information or solving existing problems. It is crucial to achieve a deeper understanding on collaborative processes and practices and create novelty and innovation (how new things emerge and are developed collaboratively). Toward that end, it is essential to examine human learning from a more developmental perspective that will address creation of novelty in conjunction with growth of the participants and transformation of their practices.

These theories transcend many traditional dichotomies concerning learning and human cognition (Paavola et al. 2004, pp. 562–566). That is, if the focus is on collaborative creativity, both individuals and social processes must be taken into account, and both conceptual knowledge and social practices must be emphasized. The knowledge creation approaches emphasize *mediating elements* between subjective and objective worlds to avoid Cartesian dualisms, and they aim at describing how activities are organized around *shared objects*. The focus is on "real" problems, that is, problems and issues that have meaning outside a specific educational setting. Generally speaking, the focus is on problem solving but not just on solving existing problems but being able to create and define focal problems by the participants. All these theories highlight diversity, variety, and multivoicedness as a requisite for innovation (e.g., Engeström and Sannino 2010; Nonaka 1994; Scardamalia and Bereiter 2010). This requires that traditional hierarchical structures be changed so that all complementary and relevant voices are involved. Knowledge creation processes are not linear but entail surprises and messiness, which are directed at expansive and improvable processes and toward novel syntheses. One focus is the new kinds of an agency needed. Scardamalia and Bereiter have highlighted that knowledge building is *not* something that comes naturally but requires specific efforts and epistemic agency of participants. Overcoming the creative participation gap (Jenkins et al. 2009) mentioned above requires intentional facilitation, guidance of collaborative building, and creation of knowledge from educational institutions. Expansive learning is usually connected to deliberate efforts and interventions to solve pressing contradictions of existing practices. Nonaka (1994, pp. 17–18) has highlighted intentionality and autonomy as a basis for converting meaningless information into targeted knowledge creation.

The trialogical approach has been influenced by theories representing the knowledge creation metaphor of learning, but it has a theoretical and practical focus of its own. Like knowledge building, it has its background on technology-enhanced collaborative learning in educational settings. It aims at helping students to create knowledge artifacts together. But unlike knowledge building, it also highlights material and pragmatic aspects of collaborative knowledge creation. The focus is not just on ideas and idea improvement, but also on practical criteria and material aspects directing collaboration. That is why in the trialogical approach, the focus is not just on epistemic mediation but also on pragmatic, social, and reflective mediation. This is why we think that Popper's "World 3" emphasized in knowledge building ends up being too distinct from practices and material issues and Peircean and Vygotskyan approach to human-mediated activity provides a better theoretical grounding for theories on knowledge creation (Paavola and Hakkarainen 2009).

The trialogical approach has taken many influences from expansive learning and cultural-historical activity theory. The focus is on artifact-mediated activities and on practices and object-orientedness of human activity. But in distinction to expansive learning, the trialogical approach is not a theory on transformations of human activity systems. The trialogical approach focuses more narrowly on questions concerning how to organize students' or participants' work on developing shared knowledge artifacts together and how technology supports this collaboration.

The trialogical approach has much less direct influences from the theory of organizational knowledge creation, but the use of different forms of knowledge and their conversions is seen as important. The trialogical approach has originally been developed within the context of technology-enhanced collaborative learning.

Affordances provided by technology-mediated learning environments for creating, discussing, elaborating, and building on shared knowledge artifacts have affected the emergence of the trialogical framework (Hakkarainen 2009a; Paavola and Hakkarainen 2009). The role of knowledge artifacts and their iterations are emphasized which bring in mediating elements that are not prominent in the theory by Nonaka and Takeuchi. The trialogical approach is an educationally oriented approach; it aims at giving guidelines and design principles for collaborative learning.

Conclusions

In this chapter, we have delineated the elements of the trialogical approach to learning and how it relates to broader perspectives on knowledge creation. The trialogical approach is a result of quite a long evolution. It has started with comparisons on different theories on processes of knowledge creation. The trialogical approach is not a well-specified pedagogical model, but it has guided further cultivation of pedagogical approaches such as the *progressive-inquiry* model and *learning through collaborative design* framework or technological environments like Knowledge Practices Environments (KPE). It is more like a framework that assists investigators and practitioners to examine and develop those technology-mediated processes and practices that involve collaborative efforts of building and creating knowledge artifacts and practices together. It is a weakness in that there are no clear guidelines for students and teachers for implementing it. It is a strength as it gives hints and ideas for changing existing practices to have more object-oriented activities and trialogues. The idea of trialogical approach has given impetus for advancing both research and development of technology-mediated collaborative learning (see Paavola et al. 2011).

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Chapter 5
Harnessing Emerging Technologies to Build the Next Generation of Knowledge Creation Platform for School Students

Pei-Shan Tsai, Ching Sing Chai, and Kah Eng Hoe

Introduction

Since the 1990s, the rapid development of information and communication technology (ICT) has facilitated the integration of technology into classroom teaching and learning activities and afforded learners opportunities to construct digital artifacts that represent their knowledge. In particular, ICT has been deployed to enhance collaborative learning and knowledge co-construction among learners (Solimeno et al. 2008). This kind of online learning environments is currently known as computer-supported collaborative learning (CSCL), which is designed to enable and promote social interaction between teacher and learners and among peers (Molinari 2004). Most CSCL environments are based on the theoretical foundation of sociocultural learning theories. They leverage on the notion of zone of proximal development (Vygotsky 1978), assuming that the multiple perspectives brought forth in a community create multiple zones of proximal development for the learners to be supported (Oshima 1998) and that the diversity of ideas could lead to the emergence of new ideas. As such, the integral feature of CSCL is the promotion and cultivation of group learning besides independent learning (Solimeno et al. 2008).

Within the CSCL literature, knowledge creation, rather than learning, is much emphasized especially among researchers associated with the knowledge building fraternity. Paavola and Hakkarainen (2005) argue that learning in the knowledge age needs to go beyond information given (i.e., acquisition of existing knowledge) by advancing current knowledge through collective improvement of shared understanding/ideas mediated through technology. In other words, they are arguing that knowledge creation should be the underlying thrust of today's classroom.

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Knowledge creation in a community involves “more than the creation of a new idea, it requires discourse (talk, writing, and other actions) to determine the limits of knowledge in the community, set goals, investigate problems, promote the impact of new ideas, and evaluate whether the state of knowledge in the community is advancing” (van Aalst 2009, p. 260). From the perspective of social constructivism, it emphasizes social interactions (i.e., active participation and peer discussion) among learners for constructing knowledge (Pena-Shaff and Nicholls 2004). Research undertaken in this field explores how social practices promote and facilitate knowledge creation. Many studies have investigated the influence of the presage factors (i.e., participation levels, interaction, reflection, literacy skills, scaffolding, etc.) on the quality of knowledge building (Cacciamani et al. 2012; So et al. 2010). There is a body of research investigating learners’ knowledge creation processes using online platforms (e.g., Chai and Tan 2009; Hong 2011; Zhang et al. 2009). In addition, there is also an emerging trend in the application of technological innovations (e.g., Web 2.0) in knowledge creation. In general, these studies in knowledge creation are evolving along the interactive and constructivist perspectives.

Furthermore, in response to the need to transform education, knowledge creation that focuses on engaging learners to work directly on knowledge construction has received much attention (see Chai et al. 2011). Three of the more mature and well-researched knowledge creation models are the model of knowledge spiral (i.e., the SECI model, Nonaka and Takeuchi 1995), the expansive learning framework (Engeström 1999a), and the knowledge building approach (Scardamalia and Bereiter 1994). Paavola et al. (2004) and Tsai et al. (2013) indicated that these models highlighted the importance of innovative knowledge creation. While these models are derived from and associated with different disciplines of study, two common features of these models are (1) a focus on improving knowledge objects/conceptual artifacts that the knowledge creators have explicated and (2) an emphasis on the community as the social mechanism for the knowledge objects to be culturally accepted. Hence, the creation of technological platform in support of knowledge creation effort has to be anchored in the dual foci of the cognitive and social dimensions of knowledge creation.

In the following section, we will first review the three knowledge creation models. This will be followed by a brief discussion of the three main knowledge creation models and our attempt to synthesize them as a coherent framework to guide knowledge creation in classrooms. We will also review existing platforms for knowledge creation that incorporate the two aforementioned anchoring features and identify both strengths and limitations of these platforms. After reviewing from the perspectives of the underlying theories and existing platforms, we will provide a synthesis that brings together the theoretical and technological considerations to support the proposed new platform.

The Related Theories of Knowledge Creation

Paavola et al. (2004) and Tsai et al. (2013) indicated that three of the more mature and well-researched knowledge creation models are the model of knowledge spiral (i.e., the SECI model, Nonaka and Takeuchi 1995), the expansive learning framework (Engeström 1999a), and the knowledge building approach (Scardamalia 2002). The concise descriptions of these models are presented below.

The Model of Knowledge Spiral (the SECI Model)

Nonaka and Takeuchi's (1995) SECI model, a well-known framework for exploring knowledge spiral process, was proposed to explain the interaction between two kinds of knowledge: tacit knowledge (the knowledge regarding personal experience, beliefs, and perspectives) and explicit knowledge (the knowledge that is articulated through clear and effective expression). The interaction between tacit and explicit knowledge takes shape through four types of knowledge conversion: (a) socialization (from tacit to tacit knowledge), (b) externalization (from tacit to explicit knowledge), (c) combination (from explicit to explicit knowledge), and (d) internalization (from explicit to tacit knowledge). These processes are aimed at helping the organizations to explicate the workers' tacit knowledge that they obtain from their working experience so as to improve the organizations' products and performances (Chai et al. 2011).

The Theory of Expansive Learning

The theory of expansive learning, which is based on activity theory, focused on the sociocultural context and collectives in learning processes; that is, learners' behaviors cannot be comprehended independently of the social cultural contexts (Engeström and Sannino 2010). A collective activity system involved six elements: tools, subject, object, community, division of labor, and rules. Simply put, an activity system is constituted through a subject (a person) who uses tools to work on an object (a problem) to achieve an outcome. The work is situated within a sociocultural system in a community (the organization), which comprises other people who assume associated roles/duties, and the community is shaped by implicit and explicit rules. For example, a teacher (subject) uses computer-based drill and practices (tools) to improve students' mastery of mathematical operations (the object) in a school (community) to achieve good examination (the outcome). The teacher is supervised and supported by other associated school personnel (roles/division of labor), and the teacher has to follow certain code of conducts and even pedagogical practices (rules). Many studies utilized the expansive learning to analyze existing activity systems and identify contradictions among elements (Ahonen et al. 2000; Engeström 1999b; Nummijoki and Engeström 2009). Through changing and redefining the elements and the relationships among the elements, expansive learning activity creates new practices and the associated new knowledge (Engeström 1999a). The activity theory has been used to create new knowledge in designing instructional or teaching and learning environments (e.g., Lim and Chai 2008) and human and computer interaction (e.g., Nardi 1996).

The Knowledge Building Approach

The knowledge building approach is undergirded by a focus towards learners' collective creation and improvement of ideas (Bereiter 2002). In practice, knowledge building is a process where learners identify problems of understanding that interest them; articulate their ideas about the problems in a community; build on, argue, criticize, discuss, and refine the ideas; and also organize, relate, and synthesize the ideas. These interactive and dynamic processes are supported by the Knowledge Forum reviewed below. Bereiter views such endeavor of working on ideas as the essence of knowledge creation work. Much research has been conducted on the knowledge building approach, and they generally indicate that the approach is conducive for the cultivation of knowledge creation practices among learners (see, e.g., Scardamalia and Bereiter 2006).

Scardamalia (2002) proposed 12 principles encompassing the socio-cognitive and technological dynamics involved in community-based knowledge creation process. These principles underlie the emergence of knowledge building practices among learners. These 12 principles are (a) real ideas and authentic problems, (b) improvable ideas, (c) idea diversity, (d) rise above, (e) epistemic agency, (f) community knowledge and collective cognitive responsibility, (g) democratizing knowledge, (h) symmetric knowledge advancement, (i) pervasive knowledge building, (j) constructive uses of authoritative sources, (k) knowledge building discourse, and (l) embedded and transformative assessment. In the socio-cognitive dimension, the principles can be institutionalized through pedagogical approaches, and in technological dimension, the principles can be substantiated through the use of Knowledge Forum. These principles were widely utilized as indicators for designing knowledge building activity (Zhang et al. 2011).

Synthesizing the Three Models of Knowledge Creation

This chapter synthesizes the three models of knowledge creation together, as shown in Fig. 5.1. The model of knowledge spiral provided the foundation for the phasing of knowledge creation activities. Building on the SECI model, we propose that

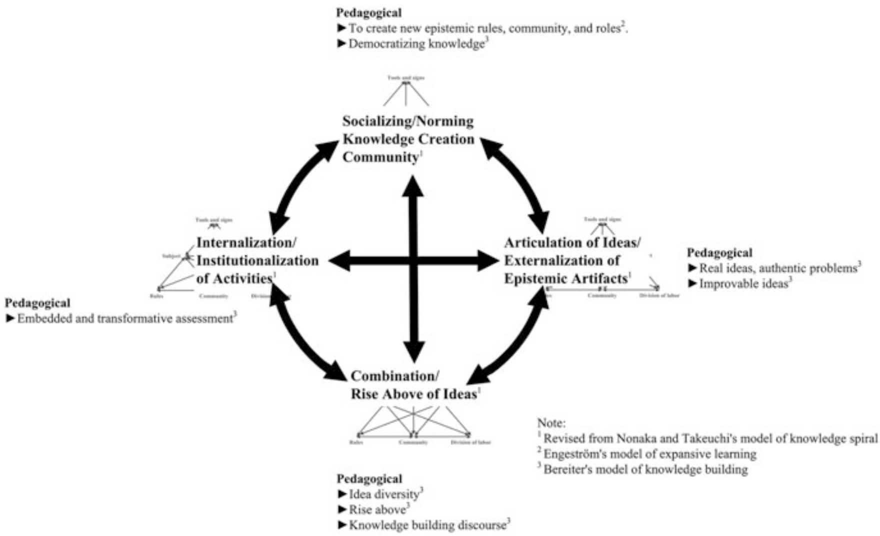

Fig. 5.1 The framework of synthesizing the three models of knowledge creation

fostering knowledge creation involves socializing/norming knowledge creation community, articulation of ideas/externalization of epistemic artifacts, combination/rise above of ideas, and internalization/institutionalization of the knowledge created. Depending on the history of the knowledge creation communities, the phases could be more or less dynamic. A mature knowledge creation is likely to be able to start and traverse the various phases of knowledge creation, but a beginning community may be better off in undertaking a more linear phase-by-phase progression.

In addition, each phase of the knowledge creation activities can be examined through the expansive learning framework. For example, during the *socializing/norming knowledge creation community* phase, the object of interest is the formation of the sociocultural ethos that promotes epistemic agency among the learners. This would involve creating new epistemic rules through pedagogical events, support by others in the immediate and associated contexts (e.g., leadership and parent support), and also changes in the roles of teachers and students (Lim and Chai 2008).

The knowledge building approaches provided the epistemic frameworks and valuable principles in shaping knowledge creation practices. Building on Scardamalia's (2002) articulation of the socio-cognitive and technological dynamics, these principles are viewed as a pedagogical focus in knowledge creation practices. For example, during the *internalization/institutionalization of activities* phase, the objective is the enhancement of learner's tacit knowledge. This would include each learner's internal assessment during the knowledge creation processes that is similar to the principles of embedded and transformative assessment (Scardamalia 2002). While the new synthesized framework did not include all the 12 principles, we believe that the most important pedagogical principles have been incorporated. Hence, the new synthesized framework only includes seven principles, that is, socializing/norming knowledge creation community phase reflecting the principles of *democratizing knowledge*; articulation of idea/externalization of epistemic artifacts phase reflecting the principles of *real ideas, authentic problems*, and *improvable ideas*; combination/rise above of ideas phase reflecting the principles of *idea diversity, rise above*, and *knowledge building discourse*; and internalization/institutionalization of activities phase reflecting the principles of *embedded and transformative assessment*, as shown in Fig. 5.1. Detailed descriptions of the synthesized framework of related theories of knowledge creation are presented below.

Socializing/Norming Knowledge Creation Community

In this phase, drawing from the socialization stage in Nonaka and Takeuchi's (1995) SECI model, the emphasis is on establishing trust and understanding among the learners and providing initial explanation and discussion of why and how knowledge creation is likely to happen. The process of developing a community at this stage is often enacted in face-to-face learning environments. Face-to-face meeting affords much subtle communication richness such as that of verbal intonations and body language. Hence, this chapter proposes that the teacher assumes the main role of forming the community with technology support geared towards building social bonding. One of the important roles of teachers in knowledge creation is to construct and negotiate the rules and the roles (division of labor) in the community, which are the basic elements of expansive learning theory; that is, teachers could propose some regulations and norms for conducting knowledge creation and helping students to understand individuals' roles in knowledge creation community.

Articulation of Ideas/Externalization of Epistemic Artifacts

This stage, closely associated with the externalization stage in Nonaka and Takeuchi's (1995) SECI model, focuses on the articulation and development of epistemic artifacts, which are World 3 objects in Popper's (1978) three worlds. Popper delineates World 3 as the world of immaterial objects created by the human mind. Bereiter (2002) drew upon Popper's three worlds as the foundation of knowledge building work. As each individual views the world (the physical World 1) that they encounter in unique ways, the ideas they formed about the world are more or less different. These ideas (intramental private World 2 objects) are raw materials that could be shaped to form many epistemic artifacts. Theories, explanations, proposals, and hypotheses created by epistemic agents through the articulation of World 2 objects are examples of World 3 objects. The World 3 objects are thus man-made cognitive objects, and it needs to be made accessible to the community. Once created and shared, the World 3 objects are epistemic artifacts that can be further manipulated, improved, and transformed by the epistemic agent and other people. To work directly on epistemic artifacts with the intention of advancing its utility is, in essence, the knowledge creation works.

Combination/Rise Above of Ideas

In the combination/rise above of ideas stage, drawing from the combination stage in Nonaka and Takeuchi's (1995) SECI model, the stress is on interrelating and combining learners' ideas and thinking to attain deeper understanding. This stage is the main process in knowledge creation (Paavola et al. 2004). However, this stage is not easily achievable. For instance, Chan (2011) pointed out that the major behaviors of learners are in knowledge sharing rather than knowledge creation. Students often view their online postings as notes to share knowledge, rather than ideas to create knowledge. The format of a thread-based discussion forum may limit the interactions among ideas. Pedagogically, this stage highlights a higher-level combinative process of ideas. It is similar to the concept of "rise above" in that related knowledge can be systematically integrated and new insights could be derived. Scardamalia (2004, p.189) indicated that "the idea (rise above), based on the philosophical concept of dialectic, is that the most constructive way of dealing with divergent or opposing ideas is not to decide on a winner or a compromise position but rather to create a new idea that preserves the value of the competing ideas while rising above their incompatibilities." Several studies pointed out that the "rise above" process plays an important role in improving ideas during knowledge creation activity (Howland et al. 2012). For example, Zhang et al. (2007) found that the "rise above" process helped Grade 4 students to create more sophisticated conceptualization. That is, the "rise above" allows a learner to subsume some online posts that are created by peers and explore the content deeper.

Internalization/Institutionalization of Activities

Finally, in this phase, based on the internalization stage in Nonaka and Takeuchi's (1995) SECI model, the focus is on transforming the existing explicit knowledge in the group or organization level into individual's tacit knowledge. The concept of internalization process is akin to working on World 2 objects in the Popper's (1978) postulation of the three worlds. Working on World 2 has been a prevalent school practice, and it has been criticized as essentially transmission oriented and noncreative (Bereiter 2002). However, we argue that working on World 2 after one has devoted substantial work on World 3 is different from the prevalent school practice. It is a process of consolidating epistemic artifacts and processes in creating the artifacts, which could serve as epistemic resources for the subsequent World 3 works (see Tsai et al. 2013). Therefore, in the design of a knowledge creation platform, working on World 2 should also be addressed with equal importance as working on World 3.

The Current Platforms of Knowledge Creation

To date, researchers have created several platforms to support knowledge creation activities among learners. Among these platforms, the Computer-Supported Intentional Learning Environments (CSILE), Knowledge Forum, Synergeia, Future Learning Environment (Fle3), and wiki have been identified as important environments in the literature. The detailed descriptions, strengths, and limitations of these platforms are as follows.

Computer-Supported Intentional Learning Environments (CSILE) and Knowledge Forum

Computer-Supported Intentional Learning Environments (CSILE) is a pioneering knowledge building environment that supports learners' intentional learning and co-construction of an online knowledge repository of learners' ideas (Scardamalia et al. 1989). CSILE supports a process of knowledge building by asking a problem; collecting information; collaborating with experts (scientists and scholars), teachers, and learners; and providing scaffolding. For example, learners can type text, draw diagrams, and insert graphs to represent their ideas in the form of an online post which is called "a note." They can also search, comment, and revise existing notes for knowledge integration. CSILE aims to support learners in actively sharing their knowledge, finding their knowledge gaps, and improving their knowledge (Scardamalia et al. 1994). Some studies conducted on CSILE have revealed positive findings on learners' learning and knowledge building (Cuthbert and Hoadley 1998; Oshima and Oshima 1999). For instance, Cuthbert and Hoadley (1998) studied how the design of problem structure can scaffold middle school students' thinking and encourage them to integrate knowledge using CSILE. These studies provide some evidence that CSILE supports knowledge building and promotes interactions between the learners and their teacher and among group members.

Knowledge Forum, the second-generation CSILE, supports the process of collaborative knowledge building and idea improvement. Similar to CSILE, Knowledge Forum is a collaborative platform that supports students in working with ideas and developing deeper understanding about the topics. It mainly uses a threaded discussion forum in supporting the process of collaborative knowledge creation, as shown in Fig. 5.2.

The design of Knowledge Forum focuses on the process of idea improvement and knowledge building. One of the key characteristics of Knowledge Forum is the "rise above," which plays an important role in improving ideas (Howland et al. 2012). In addition, central to the idea of knowledge building, learners are expected to be contributors of knowledge. Hence, in Knowledge Forum, several analysis tools are provided for teachers to explore learners' contributions, such as

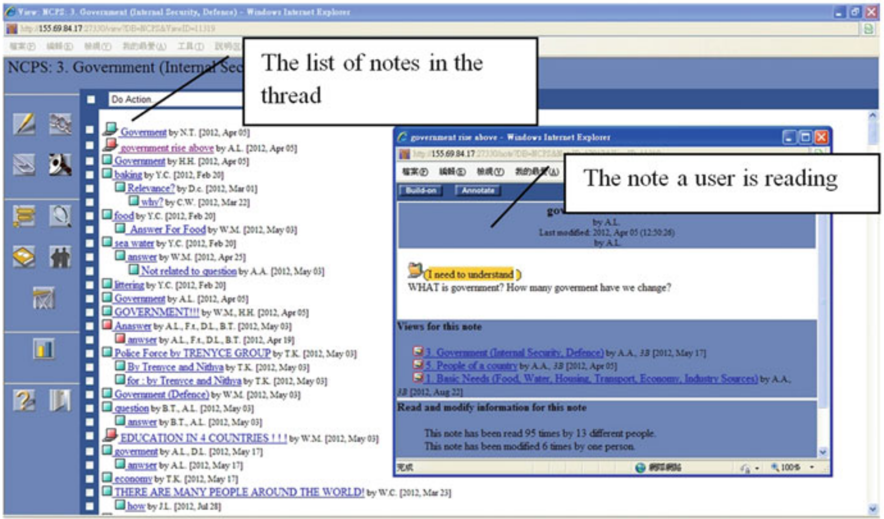

Fig. 5.2 Example of using knowledge forum in social studies

indicators (e.g., notes created, note revision, percentage of notes read, and percentage of notes with links) (van Aalst 2009), and Social Network Analysis (SNA) indices (Zhang et al. 2009). Zhang et al. (2011) revealed that providing feedback to learners such as analysis of dormancy in online discourse could encourage them to participate in knowledge building with more considerable and elaborative contributions. In sum, these studies demonstrated that Knowledge Forum provides a shared collaborative space for teachers and learners to be engaged in knowledge-creating practices.

Although previous research has revealed the advantages of utilizing the CSILE and Knowledge Forum in enhancing the knowledge creation process, problems with these learning environments have also been identified. Van Aalst and Truong (2011) suggested that Knowledge Forum is not easy to use for both teachers and learners. In fact, our experience shows that the interface design of Knowledge Forum at times militates against deepening cocreation of knowledge and often confuses learners by their complicated buttons and multiple cascading windows (Chai et al. 2012). In particular, the "rise above" function in the Knowledge Forum is only designed to copy selected notes into a new file, necessitating users to write a new note to explain what or why he/she is rising above. Similarly, for teachers and researchers using analysis tools in Knowledge Forum, understanding of learners' behaviors is handicapped by the somewhat unintuitive presentation modality (Chai et al. 2012). Moreover, learners may experience futility in a knowledge building activity; that is, they can be engaged in knowledge sharing predominantly rather than knowledge cocreation (Chan 2011). These problems may be due to learners' cultural backgrounds and technical aspects of using discussion forums which influence learners' learning processes.

Synergeia and Future Learning Environment (Fle3)

Synergeia and Future Learning Environment (Fle3) are two web-based platforms for supporting collaborative knowledge creation in classrooms and the development of knowledge artifacts (Leinonen et al. 2003), which were developed in a European project called ITCOLE, which stands for Innovative Technologies for Collaborative Learning (Rubens et al. 2005). Both platforms consist of four spaces, including three spaces for students to engage in knowledge creation practices and one space for teacher to manage the functions of platform. The three spaces for students include a *personal space*, a *collaborative knowledge building space*, and a *knowledge artifacts space*. The *personal space* aims to develop individual's ideas. Each learner can collect various resources (e.g., texts, links, documents, images, and multimedia) that are related to the topics, organize them for enhancing his/her understanding about the topics, and also decide whether or not to share them with group members. In the *collaborative knowledge building space*, similar to the threaded discussion forum in Knowledge Forum, learners can share documents with peers, initiate a discourse, or build on peers' contributions based on predefined knowledge types to attain deeper understanding of a topic, as shown in Fig. 5.3. In the *knowledge artifacts space*, learners can construct, externalize, and subsequently reconstruct and improve the knowledge artifacts through the groups' knowledge building process (Applet et al. 2002; Cacciamani et al. 2012). Moreover, a management space is created for teachers to select and adjust the functions to fit in with their courses; hence, teachers can adopt the platform to meet different course goals and different pedagogical approaches (Applet et al. 2002).

Research on knowledge building with Synergeia or Fle3 has also revealed the advantages and disadvantages of these two platforms. For example, Rubens et al. (2005) explored teachers' perspectives of user-friendliness and satisfaction with respect to the collaborative and pedagogical functions of Synergeia and Fle3 and found that teachers are satisfied with these systems. However, Chen (2006) indicated that although Fle3 provides managing functions to teachers, teachers could not regulate their courses by themselves. These findings may also bring forth the influence of teachers' pedagogical background and cultural context in the teaching.

Wikis

Recently, wikis, a Web 2.0 technology, has been proposed as a useful tool for building knowledge (Joubert and Wishart 2012; Kimmerle et al. 2011; Moskaliuk et al. 2009). For example, Joubert and Wishart (2012) indicated that discussion forums with wikis could be useful tools for collecting knowledge. Wikis can be a knowledge creation environment that supports the collaborative process as web

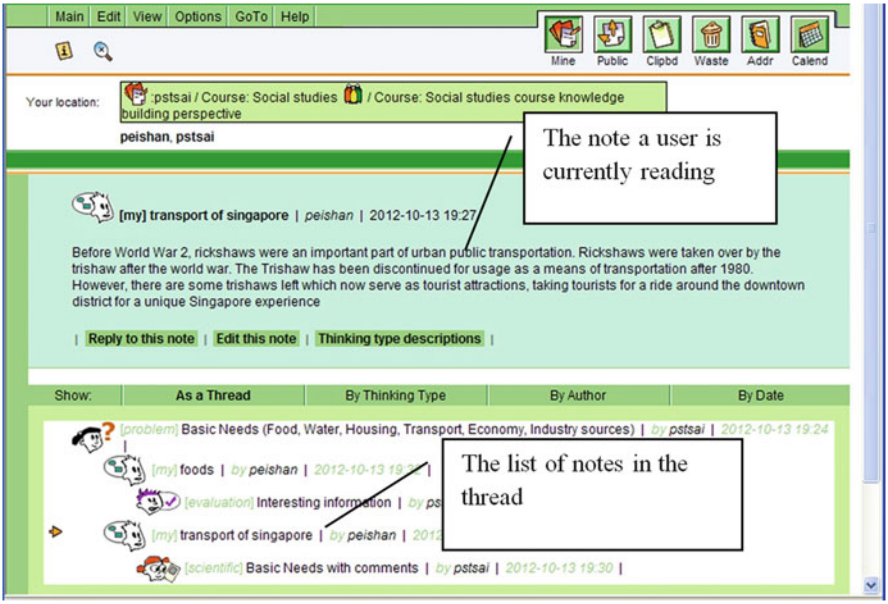

Fig. 5.3 The interface of knowledge building area in Synergeia

users cocreate, coedit, and comodify any parts of knowledge. It has potential for supporting the co-construction of knowledge.

The results of using wikis in knowledge creation revealed similar cultural, pedagogical, and technological findings. For example, review had shown that the functional characteristics of wikis were highly supportive of knowledge creation in both personal and group collective learning scenarios (Cress and Kimmerle 2008). Other researches, however, addressed the handicaps of using wikis, such as students arguing over the delays between buildings on contributions and receiving responses, some students reporting that their postings were difficult to see, and not all teachers were willing to support their students in contributing to the discussions in wikis (Joubert and Wishart 2012). Scardamalia and Bereiter (2010) had also warned that although the emergence of technologies (e.g., wiki) could be utilized to support knowledge building, the learners' behaviors (i.e., knowledge telling and knowledge transforming) depended on their purposes and contexts.

Implications

Juxtaposing the existing knowledge creation platforms reveals technological differences among them. Though not so prominent in Knowledge Forum and wikis, with Synergeia and Fle3 being the most inclusive, it is helpful to group the design characteristics into the following four categories of functionality to further guide our discussion: (a) teacher's management space, (b) knowledge construction space for epistemic artifacts, (c) collaborative knowledge creation space, and (d) personal space for the building of individual e-portfolio. These functionalities are of course interdependent on one another. *Teacher's management space* caters to teachers' pedagogical design and the management of functions in the platforms. Teachers' ability to be engaged in innovating instructional practices and contributing to knowledge advancement is a key aspect factor in enhancing their instruction and student learning (Chai and Lim 2011). *Knowledge construction space for epistemic artifacts* focuses on the creation and refinement of the epistemic artifacts that learners work on in the knowledge building activity. Epistemic artifacts are defined as tools for thinking, that is, the central part for the explanation of human culture and intelligence (Sterelny 2004). This space needs to cater efficient tools to prompt and support individual's effort in explicating the tacit World 2 objects.

The premise of knowledge creation is that learners collaboratively work on their epistemic artifacts. For example, in Synergeia and Fle3, a learner can collaborate with his/her peers to create their artifacts as the products of knowledge creation activity. *Collaborative knowledge creation space* caters for learners' co-construction of knowledge through ICT or knowledge building discourse. It is the major socially oriented activity in knowledge creation. In Knowledge Forum, Synergeia, Fle3, and wiki, the focal point of these systems is the provision of a threaded discussion forum for students to share their knowledge. Finally, *personal space for the building of individual e-portfolio* focuses on learner's individual effort in advancing personal knowledge and building personal epistemic repertoire (Tsai et al. 2013). The concept of building individual e-portfolio in personal space is similar to the concept of a personal space in Synergeia and Fle3. Learners actively collect various types of resources (involving texts, images, links, and multimedia) to develop their ideas and make the decisions whether they want to make public and share these resources with peers. In addition, the teachers can provide individual feedback to students in their personal space.

Many researchers utilized these platforms to explore learners' knowledge building processes and pointed out that exploring the quality of interactions and behaviors made by students in a knowledge building platform is helpful to the researchers and teachers in understanding students' problems and learning patterns (Joubert and Wishart 2012). These studies have revealed the importance of analyzing the behaviors of students in knowledge creation activities. However, there is a limitation in the usefulness of the knowledge building indicators afforded by current learning analytic frameworks. That is, the outcomes of these analyses are currently not provided to the students and teachers in real time when they are engaged in knowledge building activity. Teachers and students have to activate certain analytic tool to obtain the information and it requires dedicated time for the analysis to be run. Such arrangement may impede the flow of the lesson. Caswell and Bielaczyc (2001), Shell et al. (2005), and So et al. (2010) pointed out that teacher guidance plays an important role to encourage students to engage in knowledge building processes. It is therefore important that the teachers and the students are provided with timely feedback to address emerging issues during the knowledge building processes.

Other problems in the current available platforms may arise from the learners' diverse cultural, pedagogical, and technical backgrounds that influence their knowledge creation practice. Some general problems in using knowledge building platforms have been reported. For example, Zhang et al. (2011) revealed that students at lower grade might need help for writing and using the platform, such as saving the notes. Particularly, forgetting password, for online system access, is another common problem faced by young learners, some of whom have faint idea of self-responsibility. When school children are involved, it is important to provide adequate support for their effort in knowledge creation. Building on emerging technologies (technical aspect), this chapter hopes to further develop the technological and pedagogical capacities of knowledge creation platforms to alleviate some of these problems.

From the perspective of technological affordances, this chapter proposes that the new knowledge creation platform should provide relevant information for tracing and analyzing the learners' interactive activities to assist teachers in leading learners in knowledge creation. In the previous studies, the analysis of the learners' behaviors and interactions for knowledge creation is often conducted through participatory indicators (e.g., number of notes created per learner, number of posts, and rise-above notes) (Joubert and Wishart 2012; van Aalst and Truong 2011; Zhang et al. 2011), content analysis (Hong 2011; van Aalst and Truong 2011), semantic cloud (Cress et al. 2013), and Social Network Analysis (SNA) (Erkunt 2010; Hong 2011; Zhang et al. 2009). In the aspect of providing analytic feedbacks, the Knowledge Forum platform is one of the pioneering platforms. However, several potential improvements can still be made. For example, the outcomes of these analyses are currently not provided to the learners in real time when they are engaged in knowledge building activity. Java applets designed to provide the feedbacks have to be run before the learners can obtain the feedback. Also, the current analytics required the students to interpret the results, which is not easy for young children.

From the perspective of pedagogical affordances, this chapter provides some suggestions based on the new synthesized framework (describe above), which draws from the basic elements of expansive learning (i.e., rules, community, and division of labor) (Engeström 1999a) and the principles of knowledge building (Scardamalia 2002). These suggestions can be incorporated in the four major spaces identified from current knowledge creation platforms (i.e., teachers' management space, epistemological artifacts construction space, collaborative knowledge creation space, and individual e-portfolio space) to further engage students in knowledge creation practices. Therefore, the next section integrates the concept of new synthesized framework from both technical and pedagogical standpoints, and the four major spaces identified from current knowledge creation platforms, to propose a new knowledge creation platform.

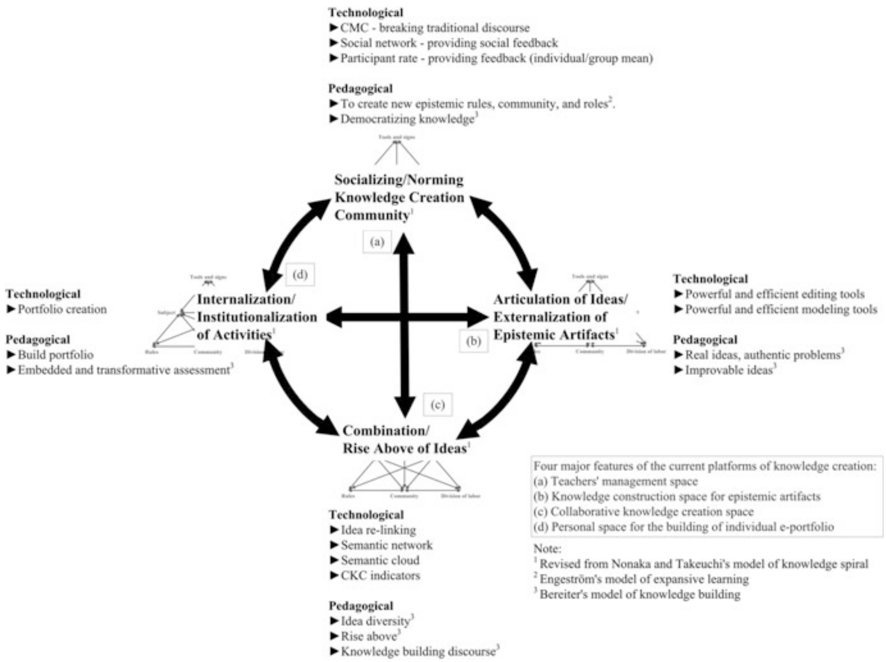

Fig. 5.4 The theoretical and technological considerations to support the new knowledge creation platform

The Theoretical and Technological Considerations to Support the Proposed New Knowledge Creation Platform

This chapter further provides a synthesis that brings together the concept of new synthesized framework from both technical and pedagogical standpoints, and the four major spaces identified from current knowledge creation platforms to support the proposed platform, as shown in Fig. 5.4. The detailed descriptions of the proposed platform are presented below.

Socializing/Norming Knowledge Creation Community

A community is formed by the accumulation of social interactions and relations among learners (Frank 1998). This aspect is often enacted in face-to-face learning environments. Online platforms break the limitations of classroom time and space, and turn-taking structure to extend the discourse, which is essential for idea development. However, the platform by itself would not engender the sociocultural environment conducive for knowledge creation. As explained earlier, a teacher has to lead in this aspect to construct a knowledge creation community. The teacher should be an active agent to help learners to assume their individual roles in the knowledge creation activity and facilitate deeper knowledge creation. As these are demanding tasks, supporting teachers in tracking and analyzing learning behaviors, and outlining strategies in facilitation of the knowledge creation processes, becomes one of the important issues in knowledge creation.

This chapter further proposes that the use of learning analytics in the new knowledge creation platform may help in fostering the sociocultural environment through providing appropriate indicators. Previous studies utilized s*ocial network* to explore the learners' social interactions among peers in the knowledge creation activities and further identify the learners as belonging to one of these categories: asking, sharing, and doing inquiry (Erkunt 2010; Hong 2011). In other words, the use of *social network* diagrams can help to inform the teachers whether the community is taking shape. Through simple graphical visualization, active and inactive learners are highlighted. Moreover, providing *social network* diagrams during the knowledge creation processes can create awareness among learners about personal and peers' social presence, for example, period of dormancy or active contribution. In sum, the new knowledge creation platform should provide adaptable assistance (i.e., learning analytics) for teachers in tracking and analyzing learners' learning behaviors, and strategies in the facilitation of knowledge creation processes, as well as in supporting learners in co-constructing knowledge.

Articulation of Ideas/Externalization of Epistemic Artifacts

The new knowledge creation platform is, in general, an amalgamation of the previous platforms with added features. It is, therefore, an online platform that allows users to build epistemic artifacts and interact based on those artifacts. From a pedagogical perspective, this stage emphasizes the formation of authentic problems and real ideas to be the anchors for subsequent idea improvements, which occurs through the collaborative space where ideas are shared as community-owned epistemic artifacts. In addition, from a technological view, the essential technological support could be a good multimedia editor that allows the epistemic agent to articulate and create the ideas either through text and drawings or even through dynamic models. Ease in writing, drawing, indexing, prototyping, and using multimedia elements is crucial consideration for this space, and the process of creating the epistemic artifacts should not impede the learners' flow of ideation. Therefore, providing powerful and efficient editing/modeling tools to support students in articulating their ideas, and later improve and organize their ideas in authentic problem solving, should be addressed in the new knowledge creation platform.

Combination/Rise Above of Ideas

This stage is one of the main processes in knowledge creation (Paavola et al. 2004), and it highlights a higher-level combinative process of ideas. As mentioned above, the "rise above" in the Knowledge Forum was only designed to copy selected notes into a new file. Our experience shows that students may not understand the purpose of the "rise above" nor utilize the "rise above" to link their ideas (Chai et al. 2012). The design of new knowledge creation platform should provide a more efficient way of combining learners' explicit knowledge to help learners to work on improving ideas and synthesizing the ideas at increasingly higher levels. For example, after the users selected a series of notes that they believe should rise above, the content of the selected notes would be included into a new note for the users to edit. In addition, Howland et al. (2012) indicated that building visual models enable people to externalize the mental models that they construct and encourage the process of conceptual change. This chapter proposes that the edited rise above or any set of selected notes can be exported to commonly used format such as PowerPoint slides or web pages for easy sharing and further collective refinement. In other words, learners can put the edited rise above or any set of selected notes into one editable artifact and share with their group members. Hence, learners can easily make sense of the relations between their ideas and then make deeper explorations and understanding.

Various technology-based modeling tools can be utilized to help learners to construct and externalize their thinking and ideas so as to make the theories public. This chapter also proposes some tools for supporting the development of ideas, making the relationships among ideas explicit, and visualizing learners' knowledge creation behaviors, such as idea relinking, semantic network, semantic cloud, and collaborative knowledge creation (CKC) indicators. *Idea relinking* allows students to relink the ideas posted after extended discussion. Students' active organization of association between ideas may help in idea improvement, which is an essential part of knowledge creation. *Semantic network* highlights the relationship between learners' ideas by presenting the flow of ideas in a semantic web with edges annotated by common keywords. *Semantic cloud* extracts popular keywords from the discussion based on semantic references inherent in the main topic. By selecting a particular keyword, which is hyperlinked to the associated notes, the learner can efficiently deepen its inquiry into a particular topic of interest and further build on the discourse, rather than having to browse through many notes to find what one is interested in. In other words, we suggest that some succinct forms of highlighting idea evolvement may help to reduce cognitive load and facilitate rapid idea improvement. CKC indicators, as an extension of the concept of participatory indicators (Joubert and Wishart 2012; van Aalst and Truong 2011; Zhang et al. 2011), aim to provide data to understand learners' behaviors and their interactions with notes. The participatory indicators, which are provided in Knowledge Forum, are mainly idiosyncratic, providing teachers and researchers an insight into a learner's personal behaviors reckoned by the number of notes, responses, and rise-above notes created. The collaborative aspect, which means the interactions with their peers' notes was ignored, such as number of response notes posted by group members, number of response notes created by learner, number of group members' notes, etc. Hence, the new knowledge creation platform is expected to provide personal and collaborative CKC indicators for teachers and learners to gain a better understanding in the note management economics of a learner. In particular, these CKC indicators can be utilized to explore learners' strategies during the knowledge creation activity. Such CKC indicators that are updated real time can promote active collaboration among students.

Internalization/Institutionalization of Activities

This chapter proposes that the learner himself/herself plays a critical role working on his/her intramental world that resides inside the human mind (World 2). One of the important roles of learners in knowledge creation is to build their e-portfolio, which is a valuable method to help each student to organize, develop, and reflect ideas individually and explore the topic deeper in knowledge creation activity. That is, in the process of building e-portfolio, each learner can reflect and thus create metacognitive awareness of his/her actions and strategies in the knowledge creation processes. The creation of e-portfolio is a reflection of one's enhanced World 2. It should be noted that the concept of e-portfolio extends the framework of personal space that Synergeia and fle3 provide. That is, the learner can create, organize, and record his/her ideas about the inquiry at hand and also record his/her reflections of the ideas during the process of knowledge creation. In addition, teachers may be allowed to give their comments or feedback to encourage learners to make reflections in knowledge creation activity. In other words, a space for learners to reflect and build on their tacit knowledge can serve as an important step for personal consolidation. It can also serve as a precursor before the next externalization occurs. Hence, the provision of an individual space for each learner to improve and reflect on his/her ideas, as well as collect various resources, should be addressed in the knowledge creation activity.

Conclusion

In this chapter, we argue that the design of the new knowledge creation platform should not only help learners engage in the activity but also assist teachers in understanding learners' behaviors in knowledge creation. This will enhance teachers' pedagogical competencies in fostering instructional practices and enhancing learners' activity in knowledge creation (Chai et al. 2011; Joubert and Wishart 2012). Hence, we elaborated the theoretical models and analyzed the current platforms in supporting knowledge creation activities, such as the Computer-

Supported Intentional Learning Environments (CSILE), Knowledge Forum, Synergeia, Future Learning Environment (Fle3), and wiki, to provide some suggestions for the development of a new knowledge creation platform. The integration of the theories of knowledge spiral, the expansive learning framework, and the knowledge building approach provided the fundamental ideologies for suggesting a new synthesized framework for knowledge creation. The results of reviewing the current knowledge creation platforms revealed that the major design characteristics of the platforms can be grouped into four categories of functionality, including teacher's creation of social climate, constructing epistemic artifacts, collaborative knowledge creation, and building individual e-portfolio. Associated technological affordances, that could support knowledge creation by students in a community setting, were introduced within the four phases of knowledge creation.

Furthermore, emerging ICT tools can play important roles in empowering learners to engage in idea work. Mobile technologies such as smartphones can be utilized to collect associated in situ data that students encounter when working with ideas (e.g., fieldtrips, interviewing key personnel). Video clips and simulated environments can act as epistemic anchors for the encounter when the "real world" is not accessible. As such, the new knowledge creation environment should allow many forms of web-based objects to be easily integrated into the online platform in support of learners' knowledge work. Currently, the platforms of knowledge creation are lacking in this aspect. The environment therefore needs to be more open.

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Chapter 6
Statistical Discourse Analysis of Online Discussions: Informal Cognition, Social Metacognition, and Knowledge Creation

Ming Ming Chiu and Nobuko Fujita

Introduction

The benefits of online discussions have increased both their uses and records of their uses, which allow detailed analyses to inform design and to improve their productivity. Unlike face-to-face talk, students on asynchronous, online forums can participate at different places and times and have more time to gather information, contemplate ideas, and evaluate claims before responding, resulting in superior decision-making, problem solving, writing, and *knowledge creation* (KC; Luppicini 2007; Tallent-Runnels et al. 2006; Glassner et al. 2005). For example, studies using aggregate counts from online forum data showed how specific actions (e.g., "why" or "how" questions, explanations, evidence, summaries) are related to KC (Lee et al. 2006; Lin and Lehman 1999; Wise and Chiu 2011).

While aggregate counts provide descriptive summaries, they do not fully utilize the information relating to the time and order of collaboration and learning processes (Reimann 2009) or capture the sequential data needed to test KC hypotheses about how group members' actions/posts/messages are related to one another (Chiu 2008a). Aggregate counts cannot illuminate the relationships among processes that contribute to knowledge creation. In contrast, analyses of sequences of messages can test whether some types of messages (e.g., asking for an explanation) or sequences of messages (different opinion followed by asking for explanation) often precede target types of messages (e.g., theorizing). These results can help us understand the temporal and causal relationships among different types of

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messages or message sequences that aid or hinder knowledge creation. We show how statistical discourse analysis (SDA, Chiu 2008b) can model these sequences to test these KC hypotheses. To explicate SDA, we introduce a specific set of data (Fujita 2009) and hypotheses to contextualize the methodological issues.

Data

In this study, we examine asynchronous, online forum messages written by students in a 13-week online graduate educational technology course delivered using Web-Knowledge Forum. These data are the second iteration of a larger design-based research study (Fujita 2009). Data sources included questionnaire responses, learning journals, and discourse in Knowledge Forum. One of the authors participated in the course both as a design researcher collaborating closely with the instructor and as a teaching assistant interacting in course discussions with students. The goals for this study were twofold: to improve the quality of online graduate education in this particular instance and to contribute to the theoretical understanding of how students collaborate to learn deeply and create knowledge through progressive discourse (Bereiter 1994, 2002).

Participants

Participants were 17 students (12 females, 5 males) (see Table 6.2). They ranged in age from mid-20s to mid-40s. Five were students in academic programs (4 M.A., 1 Ph.D.); 12 were students in professional programs (9 M.Ed., 3 Ed.D.). See Table 6.A1 in Appendix for details.

Procedure

Students were encouraged to engage in progressive discourse through three intervention activities: a reading by Bereiter (2002), classroom materials called Discourse for Inquiry (DFI) cards, and the scaffold supports feature built into Knowledge Forum. The DFI cards were adapted from classroom materials developed by Woodruff and Brett (1999) to help elementary school teachers and preservice teachers improve their face-to-face collaborative discussion. These adapted activities can model thinking processes and discourse structures in the online Knowledge Forum environment, which help online graduate students engage in progressive discourse. There were three DFI cards: *Managing Problem Solving* outlined commitments to progressive discourse (Bereiter 2002), *Managing Group Discourse* suggested guidelines for supporting or opposing a view, and *Managing*

Table 6.1 Knowledge Forum scaffolds and scaffold supports used in iteration 2

Scaffolds		
Cognition	Social metacognition	Dependent variables
Opinion	*Ask for explanation*	*Theorize/explain*
(I think knowledge building takes a long time)	(I need to understand why knowledge building has to take a long time)	(My theory of the time needed for knowledge building is based on its sequence of parts)
Elaboration	*Ask about use*	*New information*
(I think knowledge building takes a lot of smaller steps)	(Why do we need to understand how much time knowledge building takes?)	(Scardamalia and Bereiter's (1994) study showed that computer supports can support knowledge building in classroom learning communities)
Anecdotal evidence	*Different opinion*	
(Last week, our class took over an hour to come up with a good theory)	(I don't think knowledge building has to take a long time. It might depend on the people)	

Meetings provided two strategies to help students deal with anxiety. The cards were in a portable document file (.pdf) that students could download, print out, or see as they worked online.

Knowledge Forum, an extension of the CSILE (Computer Supported Intentional Learning Environment), is specially designed to support knowledge building. Students work in virtual spaces to develop their ideas, represented as "notes," which we will refer to in this chapter as "messages." It offers sophisticated features not available in other conferencing technologies, such as "scaffold supports" (labels of thinking types), "rise above" (a higher-level integrative note, such as a summary or synthesis of facts into a theory), and a capacity to connect ideas through links between messages in different views. Students select a scaffold support and typically use it as a sentence opener while composing messages; hence, they self-code their messages by placing yellow highlights of thinking types in the text that bracket segments of body text in the messages. At the beginning of the course, only the Theory Building and Opinion scaffolds built into Knowledge Forum were available. Later, in week 9, two students designed the "Idea Improvement" scaffolds (e.g., What do we need this idea for?) as part of their discussion leadership (see Table 6.1). The Idea Improvement scaffolds were intended by the student designers of the scaffolds to emphasize the socio-cognitive dynamics of "improvable ideas," one of the 12 knowledge building principles (Scardamalia 2002) for progressive discourse. In this study, we focus our analysis on tracing messages with scaffold supports that build on or reply to one another. Types of scaffold supports relevant to our hypotheses are organized and renamed (*italicized*) in terms of cognition, social metacognition, and dependent variables.

Table 6.2 Hypotheses regarding the effects of classroom problem solving processes on the outcome variables *new information* and *theorizing*

Explanatory variable	→ dependent variable	
Cognition	New information	Theorizing
Opinion	+	+
Elaboration		+
Anecdotal evidence		+
Social metacognition		
Ask about use	+	+
Ask for explanation		+
Different opinion		+

Symbols in *brackets* indicate expected relationship with the outcome variables: positive and supported [+], hypothesized but not supported

Hypotheses

We test whether recent cognition or social metacognition facilitate new information or theoretical explanations (Chiu 2000; Lu et al. 2011). Introducing new information and creating theoretical explanations are both key processes that contribute to knowledge building discourse. New information provides grist that theoretical explanations can integrate during discourse to yield knowledge creation. As students propose integrative theories that explain more facts, they create knowledge through a process of explanatory coherence (Thagard 1989). Hence, new information and theoretical explanations are suitable target processes to serve as dependent variables in our statistical model.

Researchers have shown that many online discussions begin with sharing of opinions (Gunawardena et al. 1997). Students often activate familiar, informal concepts before less familiar, formal concepts (Chiu 1996). During a discussion, comments by one student (e.g., a key word) might spark another student to activate related concepts in his or her semantic network and propose a new idea (Nijstad et al. 2003). When students do not clearly understand these ideas, they can ask questions to elicit new information, elaborations, or explanations (Hakkarainen 2003). Also, students may disagree (different opinions) and address their differences by introducing evidence or explaining their ideas (Howe 2009). Whereas individual metacognition is monitoring and regulating one's own knowledge, emotions, and actions (Hacker and Bol 2004), *social metacognition* is defined as group members' monitoring and controlling one another's knowledge, emotions, and actions (Chiu and Kuo 2009). Specifically, we test whether three types of cognition (informal opinion, elaboration, and evidence) and three types of social metacognition (ask for explanation, ask about use and different opinion) increase the likelihoods of new information or theoretical explanations in subsequent messages (see Table 6.2). To reduce omitted variable bias, additional individual and time explanatory variables were added. For example, earlier studies showed that males were more likely than females to make claims, argue, elaborate, explain, and critique others (Lu et al. 2011).

Table 6.3 Statistical discourse analysis strategies to address each analytic difficulty

Analytic difficulty	Statistical discourse analysis strategy
Data set	
Missing data (0110??10)	Markov Chain Monte Carlo multiple imputation (Peugh and Enders 2004)
Nested data (messages within topics)	Multilevel analysis (hierarchical linear modeling, Bryk and Raudenbush 1992; Goldstein 1995)
Tree structure of messages (Λ)	Store preceding message to capture tree structure
Dependent variables	
Discrete variable (yes/no)	Logit/probit
Infrequent variable	Logit bias estimator (King and Zeng 2001)
Similar adjacent messages ($m_3 \sim m_4$)	I^2 index of Q-statistics (Huedo-Medina et al. 2006)
Multiple dependent variables (Y_1, Y_2, . . .)	Multivariate outcome models (Goldstein 1995)
Explanatory variables	
Sequences of messages (X_{t-2} or $X_{t-1} \rightarrow Y_t$)	Vector auto-regression (VAR, Kennedy, 2004)
Indirect, multilevel mediation effects ($X \rightarrow M \rightarrow Y$)	Multilevel M-tests (MacKinnon et al. 2004)
False-positives (type I errors)	Two-stage linear step-up procedure (Benjamini et al. 2006)
Robustness	Single outcome, multilevel models for each outcome
	Testing on subsets of the data
	Testing on original data

Analysis

To test the above hypotheses, we must address analytic difficulties involving the data, the dependent variables, and the explanatory variables (see Table 6.3). Data issues include missing data, nested data, and the tree structure of online messages. Difficulties involving dependent variables include discrete outcomes, infrequent outcomes, similar adjacent messages, and multiple outcomes. Explanatory variable issues include sequences, indirect effects, false-positives, and robustness of results. SDA addresses each of these analytic difficulties, as described below.

SDA addresses the data issues (missing data, nested data, and tree structure of online messages) with Markov Chain Monte Carlo multiple imputation (MCMC-MI), multilevel analysis, and identification of the previous message. Missing data can reduce estimation efficiency, complicate data analyses, and bias results. By estimating the missing data, MCMC-MI addresses this issue more effectively than deletion, mean substitution, or simple imputation, according to computer simulations (Peugh and Enders 2004).

Messages are nested within different topic folders in the online forum, and failure to account for similarities in messages within the same topic folder (vs. different topic folders) can underestimate the standard errors (Goldstein

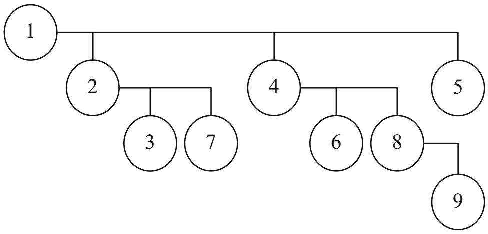

Fig. 6.1 Tree structure showing how nine messages are related to one another

1995). To address this issue, SDA models nested data with a multilevel analysis (Goldstein 1995; cf. hierarchical linear modeling, Bryk and Raudenbush 1992).

Unlike a linear, face-to-face conversation in which one turn of talk often follows the one before it, an asynchronous message in an online forum might follow a message written much earlier. Still, each message in a topic folder and its replies are linked to one another by multiple threads and single connections in a tree structure. See Fig. 6.1, for an example, of a topic message (1) and its 8 responses (2, 3, . . ., 9).

These nine messages occur along three discussion threads: (a) $1 \rightarrow 2$ ($\rightarrow 3$; $\rightarrow 7$), (b) $1 \rightarrow 4$ ($\rightarrow 6$; $\rightarrow 8 \rightarrow 9$), and (c) $1 \rightarrow 5$. Messages in each thread are ordered by time, but they are not necessarily consecutive. In thread (b), for example, message #6 followed message #4 (not #5). To capture the tree structure of the messages, we identify the immediate predecessor of each message. Then, we can reconstruct the entire tree to identify any ordinal predecessor of any message.

SDA addresses the dependent variable difficulties (discrete, infrequent, serial correlation, and multiple) with logit regressions, a logit bias estimator, I^2 index of Q-statistics, and multivariate outcome analyses. The dependent variables are often discrete (a justification occurs in a conversation or it does not) rather than continuous (e.g., test scores), so standard regressions such as ordinary least squares can bias the standard errors. To model discrete dependent variables, we use a logit regression (Kennedy 2008). As infrequent dependent variables can bias the results of a logit regression, we estimate the logit bias and remove it (King and Zeng 2001).

As adjacent messages often resemble one another more than messages that are far apart, failure to model this similarity (serial correlation of errors) can bias the results (Kennedy 2008). An I^2 index of Q-statistics tested all topics simultaneously for serial correlation of residuals in adjacent messages (Huedo-Medina et al. 2006). If the I^2 index shows significant serial correlation, adding the dependent variable of the previous message as an *explanatory* variable often eliminates the serial correlation (e.g., when modeling the outcome variable *theory*, add whether it occurs in the previous message [*theory* (-1)], Chiu and Khoo 2005; see paragraph below on vector auto-regression, Kennedy 2008).

Multiple outcomes (*new information*, *theorizing*) can have correlated residuals that can underestimate standard errors (Goldstein 1995). If the outcomes are from different levels, separate analyses must be done at each level, as analyzing them in the same model overcounts the sample size of the higher-level outcome(s) and biases standard errors. To model multiple outcomes properly at the same level of analysis, we use a multivariate outcome, multilevel analysis (Goldstein 1995).

Furthermore, SDA addresses the explanatory variable issues (sequences, indirect effects, false-positives, robustness) with vector auto-regression, multilevel M-tests, the two-stage linear step-up procedure, and robustness tests. A vector auto-regression (VAR, Kennedy 2008) combines attributes of sequences of recent messages into a local context (*micro-time context*) to model how they influence the subsequent messages. For example, the likelihood of *new information* in a message might be influenced by attributes of earlier messages (e.g., *different opinion* in the previous message) or earlier authors (e.g., *gender* of the author of the previous message).

Multiple explanatory variables can yield indirect, mediation effects or false-positives. As single-level mediation tests on nested data can bias results downward, multilevel M-tests are used for multilevel data – in this case, messages within topics (MacKinnon et al. 2004). Testing many hypotheses of potential explanatory variables also increases the likelihood of a false-positive (type I error). To control for the false discovery rate (FDR), the two-stage linear step-up procedure was used, as it outperformed 13 other methods in computer simulations (Benjamini et al. 2006).

To test the robustness of the results, three variations of the core model can be used. First, a single outcome, multilevel model can be run for each dependent variable. Second, subsets of the data (e.g., halves) can be run separately to test the consistency of the results for each subset. Third, the analyses can be repeated for the original data set (without the estimated data).

Analysis Procedure

After MCMC-MI of the missing data to yield a complete data set, each online message's preceding message was identified and stored to capture the tree structure of the messages. Then, we simultaneously modeled two process variables in students' messages (*new information* and *theorizing*) with SDA (Chiu 2001).

$$\mathbf{Process}_{ymt} = \beta_y + \mathbf{e}_{ymt} + \mathbf{f}_{yt} \tag{6.1}$$

For $\mathbf{Process}_{ymt}$ (the process variable y [e.g., new information] for message m in topic t), β_y is the grand mean intercept. The message- and topic-level residuals are $\mathbf{e}_{mt}$ and $\mathbf{f}_t$, respectively. As analyzing rare events (target processes occurred in less than 10 % of all messages) with logit/probit regressions can bias regression coefficient estimates, King and Zeng's (2001) bias estimator was used to adjust them.

First, a vector of student demographic variables was entered: *male* and *young* (**Demographics**). Each set of predictors was tested for significance with a nested hypothesis test (χ^2 log likelihood, Kennedy 2008).

$$\begin{aligned}\textbf{Process}_{ymt} = \beta_y + \mathbf{e}_{ymt} + \mathbf{f}_{yt} + \beta_{ydt}\textbf{Demographics}_{ymt} \\ +\beta_{yst}\textbf{Schooling}_{ymt} + \beta_{yjt}\textbf{Job}_{ymt} \\ +\beta_{yxt}\textbf{Experience}_{ymt} + \beta_{ypt}\textbf{Previous}_{ymt}\end{aligned} \tag{6.2}$$

Next, schooling variables were entered: *doctoral* student, *Masters of Education* student, *Masters of Arts* student, and *part-time* student (**Schooling**). Then, students' job variables were entered: *teacher*, *postsecondary teacher*, and *technology* (**Job**). Next, students' experience variables were entered: *KF experience* and *number of past online courses* (**Experience**).

Then, attributes of the previous message were entered: *opinion* (−1), *elaboration* (−1), *anecdote* (−1), *ask about use* (−1), *ask for explanation* (−1), *different opinion* (−1), *new information* (−1), *theory* (−1), and *any of these processes* (−1) (**Previous**). The attributes of the message two responses ago along the same thread (−2) were entered, then, those of the message three responses ago along the same thread (−3), and so on until none of the attributes in a message were significant.

Structural variables (**Demographics**, **Schooling**, **Job**, **Experience**) might show moderation effects, so a random effects model was used. If the regression coefficients of an explanatory variable in the **Previous** message (e.g., evidence; $\beta_{ypt} = \beta_{yt} + f_{yj}$) differed significantly ($f_{yj} \neq 0$?), then a moderation effect might exist, and their interactions with processes were included.

The multilevel M-test (MacKinnon et al. 2004) identified multilevel mediation effects (within and across levels). For significant mediators, the percentage change is $1 - (b'/b)$, where b' and b are the regression coefficients of the explanatory variable, with and without the mediator in the model, respectively. The odds ratio of each variable's total effect (TE = direct effect plus indirect effect) was reported as the increase or decrease (+TE % or –TE %) in the outcome variable (Kennedy 2008). As percent increase is not linearly related to standard deviation, scaling is not warranted.

An alpha level of .05 was used. To control for the false discovery rate, the two-stage linear step-up procedure was used (Benjamini et al. 2006). An I^2 index of Q-statistics tested messages across all topics simultaneously for serial correlation, which was modeled if needed (Goldstein et al. 1994; Huedo-Medina et al. 2006; Ljung and Box 1979).

Conditions of Use

SDA relies on two primary assumptions and requires a minimum sample size. Like other regressions, SDA assumes a linear combination of explanatory variables. (Nonlinear aspects can be modeled as nonlinear functions of variables [e.g., age^2] or interactions among variables [*anecdote* × *ask about use*].) SDA also requires independent residuals (no serial correlation as discussed above). In addition, SDA has modest sample size requirements. Green (1991) proposed the following heuristic sample size, N, for a multiple regression with M explanatory variables and an expected explained variance R^2 of the outcome variable:

$$N > \left(\left\{ 8 \times \left[\frac{(1 - R^2)}{R^2} \right] \right\} + M \right) - 1 \quad (6.3)$$

For a large model of 20 explanatory variables with a small expected R^2 of 0.10, the required sample size is 91 messages: $= 8 \times (1 - 0.10)/0.10 + 20 - 1$. Less data are needed for a larger expected R^2 or smaller models. Note that statistical power must be computed at each level of analysis (message, topic, class, school ... country). With 1,330 messages, statistical power exceeded 0.95 for an effect size of 0.1 at the message level. The sample sizes at the topic level (13) and the individual level (17) were very small, so any results at these units must be interpreted cautiously.

Results

Summary Statistics

In this study, 17 students wrote 1,330 messages on 13 topics, organized into folders in the forum. Students who posted more messages on average than other students had the following profile: older, enrolled in Masters of Arts (M.A.) programs, part-time students, not teachers, worked in technology fields, or had Knowledge Forum (KF) experience (*older*: m = 47 vs. other m = 37 messages; M.A.: 64 vs. 36; part-time: 47 vs. 27; *not teachers*: 55 vs. 36; *technology*: 54 vs. 39; *KF*: 44 vs. 32). Students posted few messages with the following attributes (see Table 6.4, panel B): new information (1 %), theory (4 %), opinion (5 %), elaboration (2 %), anecdotal evidence (1 %), ask for explanation (9 %), ask about use (2 %), and different opinion (1 %). Most messages were none of the above (83 %). (As some messages included more than one of these attributes, these percentages do not sum up to 100 %.)

Explanatory Model

As none of the second-level (topic) variance components were significant, a single-level analysis was sufficient. All results discussed below describe first entry into the regression, controlling for all previously included variables. Ancillary regressions and statistical tests are available upon request.

New Information

The attributes of previous messages were linked to new information in the current message. After an opinion, new information was 7 % more likely in the next message. After a question about use three messages before, new information was 10 % more likely. Together, these explanatory variables accounted for about 26 % of the variance of new information. See Fig. 6.2.

Table 6.4 Summary statistics at the individual level (panel A) and message level (panel B)

A. Individual variable ($N = 17$)	Mean	Description
Man	0.28	28 % of participants were men. 72 % were women
Young (under 35 years of age)	0.50	Half of the participants were under 35 years of age
Doctorate	0.22	22 % were enrolled in a Ph.D. or an Ed.D. program
Masters of Art	0.22	22 % were enrolled in M.A. program
Masters of Education	0.50	50 % were enrolled in M.Ed. program
Part-time student	0.78	78 % were part-time students. 22 % were full-time students
Teacher	0.67	67 % worked as teachers
Postsecondary teacher	0.28	28 % taught at the postsecondary level
Technology	0.22	22 % worked in the technology industry
Knowledge Forum (KF)	0.83	83 % had used Knowledge Forum previously
Past online courses	2.89	Participants had taken an average of 2.89 online courses. SD = 2.74; min = 0; max = 8
B. Message variable ($N = 1330$)	**Mean**	**Description**
Man	0.26	Men posted 26 % of all messages. Women posted 74 %
Young (under 35)	0.44	Young participants posted 44 % of all messages
Doctorate	0.20	Ph.D. students posted 20 % of all messages
Masters of Art	0.33	M.A. students posted 33 % of all messages
Masters of Education	0.47	M.Ed. students posted 47 % of all messages
Part-time	0.86	Part-time students posted 86 % of all messages
Teacher	0.57	Teachers posted 57 % of all messages
Postsecondary teacher	0.23	Postsecondary teachers posted 23 % of all messages
Technology	0.28	Those working in technology posted 28 % of all messages
Knowledge Forum (KF)	0.87	Those who used KF before posted 87 % of all messages
Past online courses	3.35	SD = 2.21; min = 0; max = 8. The average number of author's online courses, weighted by number of messages
New information	0.01	1 % of the messages had at least one new information
Theorize	0.04	4 % of the messages had theorizing
Opinion	0.05	5 % of the messages gave a new opinion
Elaboration	0.02	2 % of the messages had an elaboration of another's idea
Anecdotal evidence	0.01	1 % of the messages gave evidence to support an idea
Ask for explanation	0.09	9 % of the messages had a request for explanation
Ask about use	0.02	2 % of the messages had a request for a use
Different opinion	0.01	1 % of the messages had a different opinion than others
Any of the above processes	0.17	17 % of the messages had at least one of the above features

Note: Except for past online courses, all variables have possible values of 0 or 1

Theorize

Gender and attributes of previous messages were significantly linked to theorizing. Men were 22 % more likely than women to theorize. Demographics accounted for 5 % of the variance in theorizing.

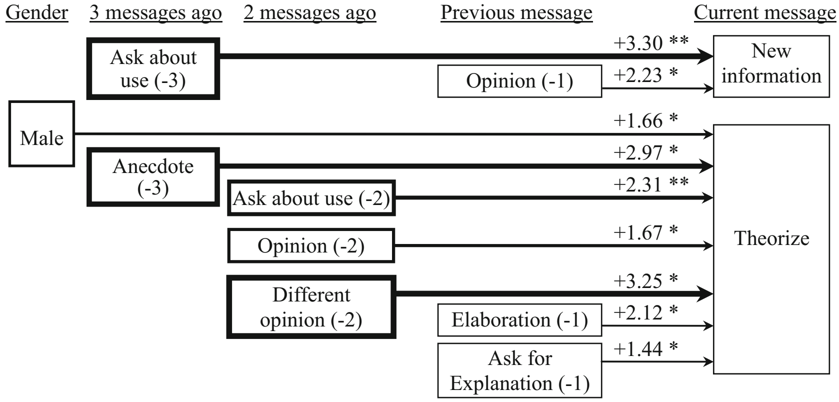

Fig. 6.2 Path diagram for new information and theorize. *Thicker lines* indicate stronger links. *$p < .05$, **$p < .01$, ***$p < .001$

Attributes of earlier messages up to three messages before were linked to theorizing. After an explanation or an elaboration, theorizing was 21 % or 39 % more likely, respectively. If someone asked about the use of an idea, gave an opinion, or gave a different opinion two messages before, theorizing was 21 %, 54 %, or 12 % more likely, respectively. After anecdotal evidence three messages before, theorizing was 34 % more likely. Altogether, these explanatory variables accounted for 38 % of the variance of theorizing.

Other variables were not significant. As the I^2 index of Q-statistics for each dependent variable was not significant, serial correlation was unlikely.

Discussion

During asynchronous, online discussions, students have more time to gather information, contemplate ideas, and evaluate claims, so they often display higher levels of knowledge creation than during face-to-face discussions (Hara et al. 2000; Luppicini 2007; Tallent-Runnels et al. 2006). Extending this research beyond aggregate attributes of *separate messages,* this study examined the *relationships among messages* with a new method, statistical discourse analysis. Both individual characteristics and the micro-time context of recent messages' cognition and social metacognition affected the likelihoods of subsequent new information and theorizing.

Demographics and Job

Past studies of primary and secondary school students had shown that individual differences in gender accounted for little of the variance in discussion behaviors

(Chen and Chiu 2008), but this study showed that these men were more likely than these women to theorize. Gender accounted for five percent of the variance. This result is consistent with the research that boys are more active than girls during online discussions in high school (e.g., Lu et al. 2011).

Micro-time Context of Recent Messages

Beyond the effects of individual characteristics, both cognitive and social metacognitive aspects of recent messages showed micro-time context effects on subsequent messages. These results showed that asynchronous messages are more than simply lists of individual cognition (Thomas 2002); instead, these messages influence and respond to one another.

Informal cognition (opinions, elaborations, anecdotes) often preceded formal cognition (new information, theorizing). After a message containing an opinion, messages containing new information and theorizing were more likely to follow. Anecdotes and elaborations were also more likely to be followed by theorizing. Together, these results are consistent with the views that familiar, informal cognition is often activated before more formal cognition (Chiu 1996) and that the former can facilitate the latter through spreading activation of related semantic networks both in the individual and among group members (Nijstad et al. 2003). This order of informal cognition before formal cognition also reflects the social nature of knowledge building discourse; individuals share their informal experiences, which group members consider, reshape, and integrate into formal, public, structured knowledge. For educators, these results suggest that students often share their ideas informally and teachers should encourage students to use one another's ideas to create formal knowledge.

Social metacognition, in the form of questions and different opinions, also affected the likelihoods of new information and theorizing. Reflecting students' knowledge interests, their questions identify key goals and motivate knowledge building. Questions about use of a particular idea had the largest effect on inducing more new information, showing their power to influence other's behaviors, which is consistent with Bereiter and Scardamalia's (2006) conceptions of "design mode" teaching and earlier research (e.g., Chen et al. 2012). Furthermore, both types of questions elicited more theorizing, which is also consistent with earlier studies (e.g., Lu et al. 2011). These results suggest that educators can design instruction to give students autonomy or "collective cognitive responsibility" (Scardamalia 2002; Zhang et al. 2009) so that students can create their own learning goals (or at least subgoals) and ask questions to motivate themselves and their classmates to build knowledge that is meaningful to them. Lastly, a different opinion had the largest effect on a subsequent theory, consistent with past disequilibrium research showing that disagreements provoke explanations (e.g., Chiu and Khoo 2003). Together, these results suggest useful prompts that a teacher might encourage students to use during online discussions, for example, through brief cue cards or direct teacher questioning.

Statistical Discourse Analysis

This study showcases a new methodology for analyzing relationships among individual characteristics and nonlinear, asynchronous messages during an online discussion. Such analyses must address analytic difficulties involving the data, the dependent variables, and the explanatory variables. First, data issues include missing data, nested data, and the tree structure of online messages. Second, difficulties involving dependent variables include discrete outcomes, infrequent outcomes, similar adjacent messages, and multiple outcomes. Lastly, explanatory variable issues include sequences, indirect effects, false-positives, and robustness of results.

SDA addresses each of these analytic difficulties as follows (see Table 6.3). First, SDA addresses the data issues (missing data, nested data, tree structure of online messages) with Markov Chain Monte Carlo multiple imputation (MCMC-MI), multilevel analysis, and identification of the previous message. Second, SDA addresses the dependent variable difficulties (discrete, infrequent, serial correlation, and multiple) with logit regressions, a logit bias estimator, I^2 index of Q-statistics, and multivariate outcome analyses. Lastly, SDA addresses the explanatory variable issues (sequences, indirect effects, false-positives, robustness) with vector auto-regression, multilevel M-tests, the two-stage linear step-up procedure, and robustness tests.

Conclusion

This study extends the online discussion research beyond aggregated attributes of *separate messages* to *relationships among messages* by showcasing a new methodology, statistical discourse analysis. The results showed that both individual characteristics and the micro-time context of recent messages' cognition and social metacognition affected the likelihoods of subsequent new information and theorizing. Unlike past studies of students, this exploratory study with a few students suggests that gender in adults might account for substantial differences in online behaviors. Specifically, men were more likely than women to theorize. Rather than simply being lists of individual cognition, asynchronous messages create a micro-time context that affects subsequent messages. Informal cognition (opinions, anecdotes, elaborations) facilitates more formal cognition (new information and theoretical explanations). Meanwhile, social metacognition, in the form of questions and different opinions, had the strongest effects on subsequent new information and theoretical explanations.

Appendix: Ancillary Data

Table 6.A1 Student demographics

Name	Gender	Age	Degree	Reg	Job	Residence	Familiar with KF	Previous online courses
Adam	M	26–35	M.A.	P/T	Graduate student	Toronto, ON	Yes	5
Anne	F		M.Ed.	P/T	Secondary teacher	Newmarket, ON	No	0
Belinda	F	36–45	M.Ed.	P/T	Postsecondary instructor	Kelowna, BC	Yes	5
Chloe	F	36–45	M.Ed.	P/T	Software trainer	Toronto, ON	Yes	4
Christine	F	26–35	M.A.	P/T	Postsecondary instructor	Taiwan	Yes	5
Dylan	M	36–45	M.Ed.	P/T	Postsecondary instructor	Toronto, ON	Yes	0
Evelyn	F	<25	M.Ed.	F/T	Graduate student	Toronto, ON	Yes	0
Gail	F	36–45	Ed.D.	P/T	Elementary school principal	Simcoe County, ON	Yes	3
Ian	M	26–35	M.Ed.	P/T	Secondary teacher	Toronto, ON	Yes	0
Jeff	M	26–35	M.Ed.	P/T	Elementary teacher	Toronto, ON	Yes	3
Kelly	F	26–35	M.Ed.	P/T	Teacher	Toronto, ON	No	0
Laurel	F	26–35	Ed.D.	P/T	Educational technology consultant	Markham, ON	Yes	6
Maria	F		MA	F/T	Postsecondary instructor	Toronto, ON	No	0
Megan	F	36–45	Ph.D.	F/T	Postsecondary instructor	Millbrook, ON	Yes	8
Sharon	F	26–35	M.A.	P/T	Elementary teacher	Toronto, ON	Yes	2
Paul	M	36–45	Ed.D.	F/T	Information and planning analyst	Peterborough, ON	Yes	7
Yvonne	F	36–45	M.Ed.	P/T	Educational technology consultant	Ottawa, ON	Yes	4

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Chapter 7
Creating Knowledge

Timothy Koschmann

Introduction

The five chapters that comprise this section are quite diverse. The first three are fundamentally think pieces, exploring different models and theories related to the volume's unifying concept, knowledge creation in education. The latter two have a more methodological bent, but orient to methodology in somewhat different ways. The Tsai, Chai, and Hoe chapter (Chap. 5) focuses on designing tools to support knowledge creation in classrooms. Its orientation, therefore, is to advancing *pedagogical* method. The final chapter, by Chiu and Fujita (Chap. 6), demonstrates one way to study knowledge creation in instruction. Its orientation, then, is to *research* method. In this commentary, I will delve into the phenomenon of knowledge itself, focusing on the kinds of things (e.g., acquiring, creating, using) that we can do with it. I end with some thoughts about where research on knowledge creation might go in the future.

Addressed in various ways in all five of the chapters in this section is the topic of knowledge building (KB). KB, of course, refers to the educational philosophy developed and espoused over the past two-dozen years by Carl Bereiter and Marlene Scardamalia. It has its roots in child reading research and includes recommendations for technology design that have strongly shaped subsequent research and design in computer-supported collaborative learning (CSCL). In its earliest incarnations, KB entailed a special kind of interaction in which learners take control of their learning (Scardamalia and Bereiter 1991). They observed that this kind of interaction is descriptive of adult learners, but is rare in schools. They argued that schools ought to be restructured to foster more "knowledge-building discourse," that is, discourse in which "ideas are conceived, responded to, reframed and set in historical context" (Scardamalia and Bereiter 1994, p. 266). Over the intervening

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years, they have reiterated and systematically refined this position (Bereiter and Scardamalia 1993, 2003; Scardamalia and Bereiter 1991, 1994; Bereiter 2002, 2014).

Related in some ways to KB is Engeström's (1999) notion of learning by expansion. Two of the chapters, those by Tan and Tan (Chap. 2) and Paavola and Hakkarainen (Chap. 4), seek to develop these connections. Learning by expansion has its roots in Marxist socioeconomic theory. It involves transforming activity systems as a means of resolving recognized contradictions within them. Like KB, learning by expansion aspires to a model of learning that goes beyond mere reproduction of established knowledge. Just as a distinguished form of discourse is foundational to KB, Engeström also envisioned a form of dialogue at the heart of learning by expansion. He wrote:

> An activity system is by definition a multivoiced formation. An expansive cycle is a reorchestration of those voices, of the different viewpoints and approaches of the various participants. (Engeström 1999, p. 35)

Exploring how this "reorchestration" of voices occurs might be a good way of better understanding how knowledge creation is done. The idea of expansive learning cycles has mostly been applied in organizational contexts. Paavola and Hakkarainen present their "trialogical approach" as an attempt to apply this idea to instructional reform.

Bereiter (2002) makes the argument that education needs to be restructured to be more attuned to the needs of the "knowledge age." This resonates with Nonaka and Takeuchi's (1995) conception of the "knowledge-creating company." Here, the proposal is advanced that forward-looking organizations should recognize the importance of knowledge creation to their successful operation. An implication of these two suggestions is that schools must do more than impart factual knowledge; they must also foster the development of knowledge-creation skills. The problem, however, is that before we can undertake wide-scale reform of the educational system, we need to have a better grasp of just what these knowledge-creating practices might be. As it stands, knowledge creation (KC) is more of a prescriptive notion than an empirically developed principle. Nonetheless, it is an idea very much in the air these days and, so, in this volume it becomes the supervening concept, encompassing both KB and learning by expansion.

One workplace in which knowledge creation would presumably be de rigueur is the scientific laboratory. Scardamalia and Bereiter (1994) cited research communities, particularly their practices for evaluating and disseminating findings, as a primary source of inspiration for their notion of KB. As Tan and Tan suggest in their chapter, scientists are members of a community for which the creation of knowledge is the cardinal objective. For scientists, knowledge creation would seem to be closely tied to discovery, discovery being pretty much what makes science science. Indeed, scientific discovery would seem to represent the epitome of knowledge creation. But what do we actually know about the "knowledge-building discourses" through which discoveries are made?

Discovery: An Interactional Account

Though the scientific literature is replete with retrospective accounts of discovery, we have little firsthand knowledge of the attested interaction that leads up to and eventually results in a discovery. One exception was a discovery in astronomy made, quite by chance, while a tape recorder was running. Because of the availability of this recording, the detection of the first optical pulsar has drawn considerable interest from social scientists studying the practices of scientific discovery (e.g., Garfinkel, Lynch and Livingston 1981).

The discovery occurred at the Steward Observatory on Kitt Peak in the Arizona desert on the night of January 16, 1969. Present on the telescope platform that night were John Cocke and Michael Disney, astrophysicists, and Robert McCallister, the "night assistant." Over the course of the night, they did a series of "runs," that is, they collected a series of samples of emitted light from different sectors of the sky. These samples were displayed on an oscilloscope screen (Cocke et al. 1969). Garfinkel et al. (1981) report that "the pulsar was in hand between the 21st and 23rd runs" (p. 136). During Run #18, however, the following exchange takes place:

(Excerpt 2 from Koschmann and Zemel 2009)[1]

```
Disney:     We've got a bleeding ↑pulse here.
            (2.0)
Cocke:      ↑He::y.
            (4.5)
Cocke:      Wo::w!
            (1.2)
Cocke:  →   You don't suppose that's really it do you?
            (1.8)
Cocke:      It ca:n't be.
Disney:     (Sure) it's right bang in the middle of the
            period. (Look), I mean right bang in the middle
            of the sca::le. It really looks something to me
            at the moment.
            (0.8)
Cocke:      Hmmm.
```

Within this excerpt, we can see that a certain kind of noticing has already taken place. Cocke's "You don't suppose that's really it do you?" (l. 19) is the earliest moment at which the possibility of a pending discovery is first entertained.

The question that needs to be considered here is how do you talk about something before you know what it is that you are talking about? The answer is that you talk about it in "evidently-vague" (Garfinkel et al. 1981, p. 135) ways. I draw your attention to the use of *it* in line 19. Cocke's use of the indefinite pronoun has a retrospective/prospective character—its sense drawing on a shared understanding of what they are doing together (i.e., looking for pulsars) yet pulling back from

[1] The transcription conventions are described in Appendix A of Koschmann and Zemel (2009).

indexing it as a named thing. The status of the "bleeding pulse," then, is provisional pending further evaluation. What we see here is knowledge in the very process of being born.

By Run #22, Disney proposes, "We'll have to figure out what this means now." This proposal reflects a shift in their orientation to the thing at hand, previously an "object of sorts" with "neither demonstrable sense nor reference" (Garfinkel et al. 1981, p. 135), to something that now holds consequences for subsequent action. This subtle shift in how the principals discuss the object in question illuminates a discovery in progress. Indeed, we might say that it *is* the discovery or, at the very least, the "discovering work" (Koschmann and Zemel 2011). It is a work of "reorchestrating the participants' viewpoints," to recall Engeström's felicitous phrase, of recalibrating the local referential resources. These referential resources (and the practices that incorporate them) are built up in the moment, they are "radically local" (Engeström 1999, p. 36). They also provide us a means of studying discovery, not as an epiphenomenon or occult event, but rather as a form of observable action.

But how does this apply to discovery in the classroom?

"Cold" Discovery

Atkinson and Delamont (1977) made a distinction between "hot discovery," the outcome of inquiry into questions for which no answer is currently available, and "cold discovery," the result of inquiry into settled matters reenacted for pedagogical purposes. Can we study "cold" discovery by analyzing the participants' "referential practices" in the same way that we did in the case of the "hot" discovery described earlier? Like the optical pulsar episode, we happen to have a recorded example of a discovery being made under pedagogically arranged circumstances.

Roschelle (1992) reports a study in which two high school students, "Dana" and "Carol," worked together at a computer running simulations in Newtonian mechanics. He videotaped them as they worked, as well as in periodic interviews in which they were asked to explain what they were doing. The software they were using was designed to simulate aspects of displacement, velocity, and acceleration, but in a graphic representation consisting of balls, dotted trails, and arrows (Koschmann and Zemel 2009). By directly manipulating these elements and conducting various experiments, the students came to notice some regularities in the behavior of the objects on the screen. To call their work a rediscovery is a bit of a misnomer—it is a new discovery for them and it is a "radically local" one. Our task as analysts is to discover within Roschelle's collected materials just what their discovery might be.

Over the course of several experiments conducted with the simulator, both students make observations. Carol says at one point, "OU:H, you know what I think it is? It's like the li::ne, (0.3) that arrow it's the li::ne, of where it pu:lls that down like see how that makes this dotted line, that was the black arrow (.) it pu::lls it." She uses several 'evidently-vague' *its* here, the first apparently referencing the thing they are seeking—an explanation for the behavior of the objects on the screen. (Note the similarity to Cocke's use of "it" discussed earlier.) A bit later, Dana reports an epiphany of her own, "OH: I got it!" and, then, "When you add on this arrow (.) it's the length of the total (.) that it it assumes." Both had articulated partial understandings of what they had seen, but it was not clear that they were attending to the same features of the display. When doing a later experiment, however, they were able to integrate their proposals and make a prediction that proved to be correct and the following exchange occurs:

(Clip #8 from Koschmann and Zemel 2009)

```
Carol: Ri⌈ght it does.
Dana:    ⌊That's per⌈fect!
Carol:                ⌊It travels right along that edg:e.
       (0.5) So we want it to travel along that edg:e
       until (0.4) there. (0.6) Cuzz that will make it
       come (.) down straight.  See it will travel along
       that edge =
Dana:  = yeah =
Carol: = Until it's straight there =
Dana:  = So, but what we didn't realize before.
Carol: Might have to make it a little shorter though.
Dana:  Can't believe we didn't like think of this at
       all yesterday.
Carol: I know. Makes me feel quite stupid.
```

Dana's "Can't believe we didn't think of this at all yesterday" references a newly developed understanding and related set of practices for manipulating the objects on the screen. So what one sees here, and this is a much abbreviated account of their unfolding deliberations, is a gradual progression from evidently vague reference to something that indexes their newly acquired understanding as a thing in hand. By analyzing how they recalibrate their referential practices, we can unpack the processes by which their discovery occurred.

This is all well and good provided we have a recording (preferably video) and a transcript, but what if we lack such resources? Indeed, what if there is no face-to-face interaction to record at all, as is common in many modern learning environments? That is, what if the interaction is entirely computer mediated? Finally, what if the learning does not involve a classical scientific experiment?

I have one additional instance of a kind of knowledge creation that matches these characteristics. When interaction occurs through networked computers, there is no embodied conduct to analyze, but the interactants' referential practices can still be studied, though the pragmatics of the interaction may be somewhat different. Zemel and Koschmann (2013), for example, reported on two student teams doing mathematics problem solving within the Virtual Math Teams Project. Members of the teams were geographically distributed and their sole means of communicating was through a screen-based interface. The interface affords two ways of interacting: participants can communicate through a chat window or they can create objects on a shared, electronic white board (Stahl 2009). A log is created of their interaction over time and, by running this log through a "player," it is possible to sequentially reconstruct the students' interaction from moment to moment.

One of the two teams, Team B, consisted of three students who had chosen the tags, Bwang8, Aznx, and Quicksilver. They had been assigned a sticks-and-squares combinatorics problem. It involved generating a progression of patterns in a series and, for each iteration, predicting how many sticks would be required and how many squares would be produced. Bwang8 started off the session by typing, "you can divide the thing into two parts." His proposal is a cryptic one. Moving to the whiteboard he then drew 9 vertical lines, followed by 9 horizontal (see Zemel and Koschmann 2013). Just as he was completing his figure, Quicksilver, who had just returned to the group, inquired, "What are the lines for?" and Aznx directed him to the problem statement. Bwang8 then returned to the chat exchange and typed, "so you can see we only need to figure one out to get the total stick." His closing statement, prefaced with "so you can see," was produced as if his presentation on the whiteboard self-evidently represented a completed solution.

Unlike a traditional mathematician at the board, Bwang8 is not able to talk/type while drawing, so he must undertake these activities in sequence. His original proposal creates a context for understanding his representations on the whiteboard and the specific way in which he constructs this representation reveals the logic of the solution he is presenting. His two sets of sticks can be seen as a decomposition of one of the stick patterns that had been supplied in the problem statement. What he is able to show, in effect, is that the problem can be broken in half and that if they can develop a formula for the number of sticks in each half, they will have solved that part of the problem. Despite initially posing some problems of intelligibility for his audience, the team was eventually able to build on Bwang8's solution. His demonstration was built up in stages, and just like the two discoveries mentioned earlier, it can be analyzed in terms of the referential resources utilized. It represents yet another example of how the creation of knowledge can be studied in practical terms and speaks to the generalizability of the method.

Creating Knowledge

Bereiter and Scardamalia posit in Chap. 3 that when "dialogue succeeds in advancing from one shared knowledge state to a more advanced knowledge state, knowledge has been created" (see Chap. 3). By substituting "recalibration of referential resources" for "advancing knowledge state," however, we are able to translate their criterion into observable conduct. The knowledge created becomes translated into new ways of referencing a world held in common. As mentioned earlier, this kind of knowledge is "radically local," that is, it is lodged within the situation at hand for the purposes of the situation at hand. Seen in this way, the situatedness of knowledge is not something that needs to be overcome (pace Bereiter 1997), but rather an inescapable aspect of knowledge itself.

In choosing a title for this commentary, I opted to invert *knowledge* and *creation* to emphasize the active and processual nature of the phenomenon we are exploring. *Creating knowledge* still does not quite get it either, however. When knowledge becomes the direct object of the verb, we are misled by our grammar into thinking of it as a commodity, as something that has a reality separate from the situations in which it is made relevant and brought to bear on practical concerns. It would be good if we had a better way of talking about such things.[2] More to the point, however, is that we need to find a new way of *thinking* about knowledge that treats it not as a thing, but rather as a form of action or, even better, as a property of *all* action. We have methods by which we create knowledge and these methods are foundational to how we build a world in common. In the three examples presented here, I attempted to show how these methods could be studied by examining the referential resources actors utilize in accomplishing practical tasks.

In closing, I wish to thank the editors of this volume for their invitation to weigh in on the topics being considered here. As should be apparent from my remarks, these are matters that have been occupying my thoughts for some time now. It is my hope that the space opened up for discussion here will foster new inquiry into in the myriad ways in which knowledge and knowing are manifested in our everyday lives.

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[2] Dewey and Bentley (1991/1949) proposed replacing the word *knowledge* with the duplex, "knowing and known." For some reason this never really caught on.

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Section II
Knowledge Creation Pedagogies in Practice

Chapter 8
Designing the Situation for Pervasive Knowledge Building: Future School Experiences

Hyo-Jeong So and Esther Tan

Introduction

For the past decade, we have witnessed several initiatives that aim to design future learning environments. Such initiatives often reflect our dissatisfaction with current educational systems and an urgent need to reconsider ways of educating students to be well prepared for demands in the knowledge society. The current discourse about designing future learning environments, however, seems obscure due to uncertainty about economic, societal, and technological changes, coupled with the general perception of the limited function of school learning in a rapidly changing society (Bereiter 2002). While each initiative toward future education may adopt a different focus or understanding of what future teaching and learning should embody, there seems to be some agreement on core skills and competencies that are believed to be necessary for students. For instance, *learning how to learn* and *adaptive expertise* have been advocated by several researchers as important competency that helps students deal with high levels of complexity in real-world situations (Bransford and Schwartz 1999; Hatano and Inagaki 1986). Great levels for *collaboration* are also considered as a critical disposition and skill that students need to possess for construction, sharing, and spread of knowledge in the information age (Thomas and Brown 2011).

How schools and classrooms need to transform to successfully develop such core competencies is a challenging task that necessitates fundamental shift in our thinking toward the nature of knowledge and knowing. Indeed, knowledge creation

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has become the central topic for reconceptualizing schools from multiple perspectives, which encompasses pedagogical, cultural, and institutional changes. For instance, Hargreaves (1999) argues for the *knowledge-creating school* where the process of knowledge creation becomes a core mechanism for educational innovation and change. He hypothesizes that knowledge-creating schools are likely to display similar characteristics found in high-technology firms in terms of audits, management, validation, and dissemination of creating professional knowledge. Hargreaves suggests that a culture for continual improvement, coherent and flexible institutional structure, social relationships among people, and a readiness to tinker and experiment with ideas form the defining characteristics and conditions found in both knowledge-creating schools and high-technology firms that are successful in the process of creating knowledge.

The criticality for knowledge creation is also argued by Scardamalia and Bereiter (1999) in their discussion about *schools as knowledge building organizations*. They suggest that for schools to function as learning organizations, it would require that the schools be transformed "from that of service provider to that of a productive enterprise to which the students are contributors" (p. 275). Further, Scardamalia and Bereiter (1999) position a *knowledge building approach* found in professional communities as a productive enterprise that schools could adopt to help students construct a *deep understanding* about the world through a collaborative mechanism. An explicit focus on deep understanding and collective effort is also found in the claim by Bereiter (2002) for the significance of *enculturation into World 3*, that is, the world of conceptual artifacts such as theories and conceptual statements (Popper 1972) as the core role and purpose of formal school education. He contends that in current educational planning reacting to the future, we need to refocus our discourse toward the fundamental question, which is to identify and articulate the type of functions schools are better suited to provide than other organizations. Bereiter (2002) articulates that the core purpose of formal school education should be to produce high-level knowledge workers through enculturation into World 3, which means "joining the ranks of those who are familiar with, understand, create, and work with the conceptual artifacts of their culture" (p. 237). In sum, school should educate students for a sustainable future and equip them for the marketplace.

It may appear that knowledge-creating schools or schools as knowledge building organizations seem to advocate different ways of reconceptualizing schools. For instance, Hargreaves (1999) focuses at the macro-level perspective on school management and teachers' professional knowledge creation whereas a knowledge building approach focuses more on classroom learning and students' creation of knowledge for deep understanding. However, what stands in common in both conceptualizations is the emphasis on the criticality of involving both teachers and students in the continual and pervasive process of *knowledge-creating practices and discourse*, which is the focus of the current chapter.

This chapter foregrounds a knowledge-centered pedagogy as an overarching framework to design future learning environments. Specifically, we present our research work in a particular future school in Singapore that aims to make *pervasive knowledge building* a core practice of student learning. Scardamalia (2002) considers pervasive knowledge as one of the core principles of a knowledge building pedagogy and contends that "knowledge building is not confined to particular occasions or subjects but pervades mental life – in and out of school" (p. 81). By pervasive knowledge building in the context of our research study, we advocate the continuous improvement and the progressive advancement of knowledge (Scardamalia and Bereiter 2006) beyond the four walls of the classroom to embrace both formal learning situation in the classroom and informal learning. According to Sharples et al. (2005), *learning context* is constructed by the learners interacting with the environment and by reason that context does not and cannot remain constant: "learning also creates context through continual interaction as learners move from one location to another" (Lonsdale et al. 2003, as cited in Sharples et al. 2007, p. 9). As such, apart from the pedagogical intent to initiate students into a knowledge-creating culture which lies at the core of knowledge building pedagogy (Scardamalia and Bereiter 2006, p. 97), we give emphasis to the notion of pervasive knowledge building across formal and informal learning contexts, especially with the mediation of mobile technologies and applications.

Employing design-based research as a methodological tool, we trace how the design of knowledge building activities has evolved over a 3-year period toward our research goal for promoting pervasive knowledge building among students. As an attempt to make our tacit design ideas explicit, we pay particular attention to unpack and elaborate the complexity of design features that guided the overall design of knowledge building activities. It should be noted that the purpose of this chapter is not to present the design and enactment of a particular intervention, but, rather, to reflect on the opportunities and challenges arising from our research trajectory. Thus, we conclude the chapter with discussions that highlight tensions and issues related to the design of future learning environments from knowledge creation perspectives.

Designing the Situation for Pervasive Knowledge Building

We adopt Dillenbourg's (1999) notion of "design the situation" as the primary approach to promote the type of interaction and practices we desire to see. Here, designing a learning situation that promotes pervasive knowledge building points to two critical constructs: context and cognitive scaffolds. First, as aforementioned, learning creates context as learners move from one learning environment to another. In the context of our research study on mobile learning activities to foster in situ knowledge building, we position field trip as an integral and concrete part of the entire curriculum rather than a stand-alone event (Orion and Hofstein 1994), thereby encouraging pervasive knowledge building. Second, *designing the situation* suggests a more encompassing framework and a holistic pedagogical approach that fosters the learning conditions necessary to support and sustain such a pervasive learning space. Learners would thus need to be equipped and empowered to be agents of their own learning in such a learning space. It also suggests the significance of the pedagogical design and the discrete appropriation of cognitive support (e.g., technology-mediated cognitive tools) as critical determinants for framing such a learning situation to bring about pervasive knowledge building practices in and out of the physical constraints of the classroom.

This segment will surface two key principles and their theoretical underpinnings in designing a learning situation to move learners toward pervasive knowledge building with the mediation of mobile technologies, which is the main goal of the research project described in this chapter. First, the constructivist orientation toward teaching and learning foregrounds the essence of knowledge building pedagogy and practices, for it refocuses knowledge and knowing at the community level, giving focus to the collective learning gains in the advancement of knowledge (Brown and Campione 1990; Scardamalia and Bereiter 1992; Wenger 1998). Scardamalia and Bereiter (2006, pp. 97–98) further explicated that knowledge building is "a coherent effort to initiate students into a knowledge creating culture" and knowledge building pedagogy presupposes that "authentic creative knowledge work" can occur in the day-to-day classroom context. Constructivist practices, according to Lebow and Wager (1994, as cited in Gilbert and Driscoll 2002, p. 59), place significance on "a learner's ability to use and manipulate information in authentic situations." Therefore, to create an authentic learning situation that can sustain knowledge building, "a collective and authentic community goal" becomes the first necessary design principle to bring about genuine engagement and collaborative efforts at the community level (Gilbert and Driscoll 2002, p. 59). Undergirding the presence of a common community goal is the development and continual improvement of "epistemic artifacts" (Scardamalia and Bereiter 2006, p. 98), such as theories, abstract models, knowledge objects, and databases for they function as tools to bring about further advancement of community knowledge. This inadvertently surfaces the second most important design principle in sustaining pervasive knowledge building practices among the community of learners, that is, incorporating technological tools and integrating various technological devices and applications to effectively support the documentation, archiving, improvement of these epistemic artifacts, and, more significantly, facilitation of discourse and collaborative efforts (Jonassen 1995; Scardamalia and Bereiter 2006). Our research efforts on pervasive knowledge building give preeminence to the design of learning activities that fosters collaborative knowledge building and confers technology a mediatory role in promoting collective cognition and discourse.

Design-Based Research: Context and Trajectory

Research Context

We discuss a 3-year design-based research in a local secondary school, which is a member of the FutureSchools@Singapore project, an initiative of the Ministry of

Education, Singapore. Future schools in Singapore served as the test-beds for innovative pedagogy and technology to transform current learning environments. From the educational reform stance, future schools are positioned as a change agent for adopting and spreading innovative ideas to the rest of schools. The research school is one of the eight future schools in Singapore, and the research team has worked with teachers and students in this future school since the opening of this new school in 2010.

New goals for education require changes in the design of learning environments, and obviously there are multiple ways to conceptualize necessary design elements. In the case of this particular future school, the overall educational goal is to create pervasive learning environments that foster student competencies in critical thinking, collaboration, and communication, which are regarded as core skills in a knowledge society. With this overarching goal, we conceive the school as a knowledge creation space, which is fundamentally different from a "knowledge transmission" metaphor of a school dominating the current school culture and practices. When a school is conceptualized as a knowledge creation space, the main function for school learning is not to dispense knowledge but to create conditions and situations where students can be assimilated into the authentic process of working with knowledge or conceptual artifacts. Thus, the goal of education becomes an enculturation into World 3 as aforementioned (Bereiter 2002).

Adopting knowledge building as a central pedagogy, our specific goal in the research project is to promote pervasive knowledge building practices in and out of school contexts, harnessing the affordances of mobile technologies and related technological applications. This overarching research goal stems from our belief that the skills and dispositions to work with knowledge would become a critical high-level competency for students in the future learning spaces of the twenty-first century, marked by the growing importance of collaborative learning and knowledge community.

While we had a clear overarching goal for education conceptualized above, our research work carried a broader responsibility under a social and educational agenda to "building a socially responsive design with the goal for supporting change" (Barab et al. 2004, p. 265). We envisioned to design and to develop a sustainable and scalable model of knowledge building pedagogy and technology integration, which could be translated, disseminated, and adopted in other school contexts, beyond local significance. Further, our research undertaking involved *designing for change,* which was to change and transform the current school learning environment into what we conceptualized as a knowledge creation space.

It is apparent that designing for change involves the reconfiguration of multiple aspects of design from the physical learning environment to the pedagogical framework. The design of learning spaces can be considered from the architectural, technological, and pedagogical design dimensions (So 2012). First, the architectural design dimension refers to the spatial and material arrangement of objects and resources in the physical environment. Schratzenstaller (2010) surfaces the importance of architectural spatial design in schools: "even the best technological or pedagogical ideas cannot be used to their full effect if they are not architecturally integrated into the classroom" (p. 35). Second, the technological design dimension refers to the arrangement and utilization of technological tools and artifacts in both physical and virtual forms. The challenge in technological design is to establish a high level of compatibility between technological tools and core practices of teaching and learning in schools. Lastly, the pedagogical design dimension includes the planning and enactment of teaching and learning activities, involving changing roles, agency, and identity of teachers and students toward future learning environments. Although presented separately, the three dimensions of design are interdependent and influencing each other. This interdependency of the design dimensions is best explicated in Bielaczyc's (2006) exposition on creating an effective socio-techno infrastructure for teaching and learning by orchestrating multiple critical dimensions of classroom structures and learning culture. The integration of technological tools into the classroom social structures and the physical organization and arrangement of classroom have a definitive impact on successful learning environments.

When the three dimensions of design are considered, the socio-techno infrastructure of the future school that we worked with is considerably different from many local schools in Singapore. In terms of the architectural design, the school buildings were designed to provide ample spaces for open and flexible learning where students could freely discuss their ideas in a small-group setting. The technological design aspect was conducive for collaborative learning, leveraging flexibility and connectivity of 1:1 computing and small class size of 20–25 students to create a technology-rich environment. The pedagogical design was what we believed to be the most critical aspect of designing for change in that it involved a fundamental rethinking of how and what should be taught and assessed. In the rest of this chapter, we focus mainly on the pedagogical design dimension to illustrate the point that our design research goes beyond integrating new technology or improvising creative activities into curriculum. It necessitates a "fundamental cultural transformation" (van Aalst and Truong 2011, p. 493) to transform prevalent traditional views of student agency, teacher's role, and the nature of knowledge and knowing.

Overview of Research Trajectory

Under the overarching research goal to promote pervasive knowledge building practices with mobile technologies, the lower secondary integrated humanities (History and Geography) and the science curriculum were redesigned to integrate knowledge, skills, and attitudes to solve real-world problems in authentic places via mobile learning activities. In particular, we focused on *mobile learning trails* as a main platform of designing for change to anchor and promote pervasive knowledge building. In the context of our research study, mobile learning trails are defined as learning activities in and out of school mediated by mobile devices and applications. These mobile learning trails set the stage for contextualized learning and collaborative meaning-making among students in the course of interaction with and within context. The on-site activities sought to maximize the presence of a *real-world* platform, engaging students in meaningful knowledge creation and production where "the process of learning is informed by sense of place" (Lim and Calabrese-Barton 2006, p. 107). We believe that learning trails mediated by mobile technologies afford continuous and authentic learning experiences that can promote pervasive knowledge building practices and discourse we desire to see. Hence, in these mobile learning trails, students engaged in collaborative learning activities integrating classroom learning and field trips to develop deep understanding in both typological (i.e., language-based, categorical) and topological (i.e., space-based, continuous) representations (Lemke 2000; Roschelle and Pea 2002).

With explicit considerations to "design the situation" where pervasive knowledge building with mobile technologies becomes core practices of learning, we developed and designed various learning activities in and out of school contexts. As shown in Fig. 8.1, four mobile learning trails were implemented at a variety of places in Singapore from January 2010 to August 2012. Premised upon design-based research methodology, each trail adopted a different emphasis and focus, reflecting a progressive continuous research effort to improve the design configurations leading to desired learning experiences and outcomes. In the first implementation of the Geography learning trail in Sentosa, we sought to enculturate students into the practices of small-group collaborative learning to accommodate the general lack of collaborative mind-sets and skills among the students. This is consistent with previous research that emphasizes the criticality of enculturation process in knowledge building (Bielaczyc and Ow 2007; Kolodner et al. 2003; van Aalst and Truong 2011). From the second mobile learning trail, we gradually moved the students to engage in more comprehensive and complex types of knowledge building activities promoting a learning continuum leveraging on various technological tools and platforms. For instance, the second trail on the fall of Singapore focused on engaging students in pervasive knowledge building practices in multiple World War II battle sites for conceptual understanding about the various reasons for the fall of Singapore to Japan. In the third trail on the British defense strategy at Fort Siloso, there was a rich integration of History and Geography topics so that students could engage in higher-level thinking questions and discourse. Trail tasks not only enabled students to see connections of ideas and knowledge in History and Geography but also enhanced students' interaction with the rich physical resources and information to synthesize their findings on British defense strategies and related issues. In the fourth learning trail at the Singapore River, we continued to foster interdisciplinary thinking by integrating Biology, History, and Geography in the design of the trail activities. We sought to bring the students to a higher platform of critical thinking and in situ knowledge building with the Big Question on why civilization started at river mouth. Here, students had to leverage the conceptual knowledge and understanding of all the three subject areas on civilization, systems, and change to answer the Big Question.

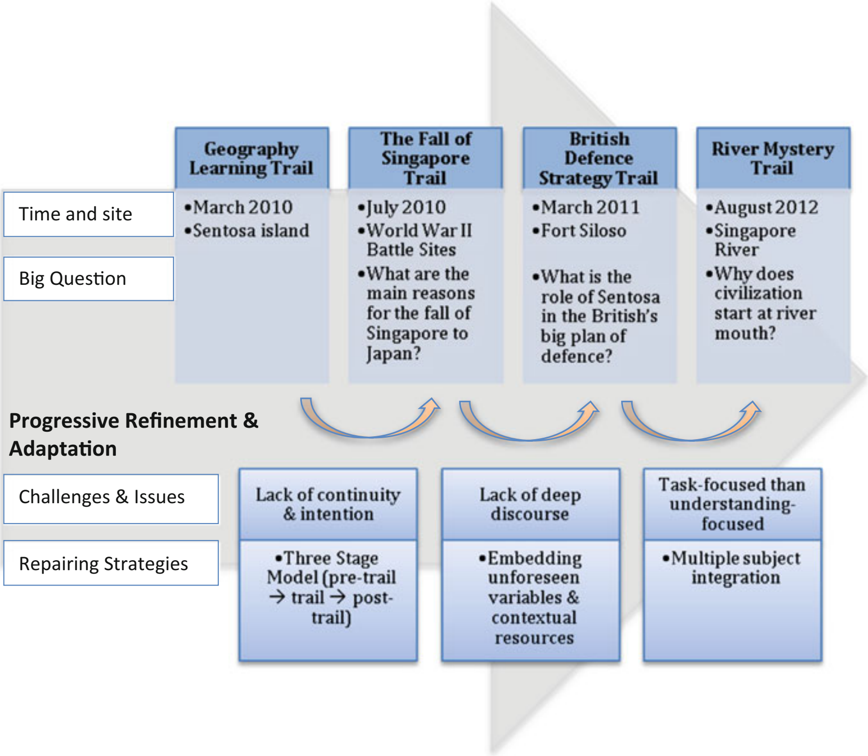

Fig. 8.1 Design progression of the mobile learning trails

While we adopted a broader framework – the FAT approach (Tan and So 2011) – that encompasses the design of *facilitation*, *activity*, and *technology* elements, through the continuous review and critique process, we increasingly realized more complexity in pedagogical aspects of design than we had expected. It was necessary to amend and fine-tune design elements in various aspects of activity design, participation structure, and scaffolding strategies. The lower part of Fig. 8.1 shows a set of challenges and issues that emerged in each intervention of all the mobile learning trails and how we addressed such issues with "repairing strategies" (Bielaczyc and Collins 2006) that were fed into the next iteration of design. On the whole, our implementation path was driven by the continuous review and redesign process through a repairing mechanism, which eventually led us to unpack and articulate the core design considerations explained in the following section.

Core Considerations for Pedagogical Design

Under the overarching goal for "design the situation" for pervasive knowledge building, each design consideration is explained with challenges and issues found in our research implementation, together with repairing strategies.

Designing Intentional Learning Experiences Across Time and Spaces

The Geography learning trail at the Sentosa Island provided students with an authentic learning platform to gain deeper understanding in Geography and History and to advance the conceptual knowledge in real-world settings with rich social and physical features. Premised on the idea of the enculturation of World 3, we designed learning activities that allowed students to immerse themselves in the process of learning-by-doing, in this case, what geographers do in their real life. This enabled students not only to experience authentic cognitive practices such as data collection and analysis but also to put into actual practice and authentic tools used by practitioners of the field to improve their conceptual understandings.

Overall, the first mobile learning trail was successful for engaging students in the process of knowledge building in situ leveraging on the rich affordances of the physical environment. However, we found that the students were still inclined to perceive outdoor learning trails as a one-off excursion and failed to see the connection between classroom and outdoor learning experiences, which was a deterrence to pervasive knowledge building. We attribute this prevailing perception to the students' lack of agency and awareness of learning intentions in the knowledge building process. Students often perceive learning as a completion of a series of cognitive activities and procedures for attaining certain goals. The importance of intentional learning is found in several studies on knowledge building. Hewitt (2001) reports that in the initial stage of knowledge building, students tend to show a task-based mentality in which learning goals are perceived to be completion of tasks rather on development of deep understanding. Bereiter and Scardamalia (1989) argue that intentional learning that premised on student agency should be a fundamental goal for education, and students need to "direct mental efforts to goals over and above those implicit in the school activities. Without such intentional learning, education degenerates into doing of school work and other activities" (p. 385).

Our repairing strategy to address this issue of the lack of student agency and intention in the process of knowledge building was to engage them in more continuously interrelated experiences of learning activities driven by own inquiries and ideas. To design the situation where students made explicit connections between their classroom learning and mobile learning trail experiences, we employed a three-stage model from pre-trail to post-trail to foster continuous and intentional learning in the following design of the mobile learning trail, the Fall of Singapore trail. The three-stage model was enacted as follows. First, in the pre-trail lessons, teachers scaffolded students' cognitive understanding through the introduction of a Big Question that encompassed core ideas and concepts required in a chosen topic. Then, students in small groups generated their own inquiry questions and ideas about the Big Question. During the outdoor learning trail, small groups engaged in pursuing their group inquiry questions, as well as, the set of activities/tasks given by the teachers at various learning stations on the trail. Back in the classroom, post-trail lessons helped students consolidate their whole learning experience and collate the ideas and findings from the mobile learning trail to rise above their existing ideas related to the Big Question. The three-stage model from pre-trail to post-trail helped both teachers and students see the connection of various activities under the big theme and engaged students in more continuous and intentional learning experiences.

Figure 8.2 shows an example of students' idea generation (during pre-trail lesson) in Knowledge Forum on the Big Question, "Why does civilization start at the river mouth?" The nature of the Big Question was open-ended and ill-structured to give flexible room for various ideas to be generated and advanced. The Big Question played an important role to make the community discourse divergent yet focused to collectively advance the community's knowledge about the given question. The Knowledge Forum postings illustrated that students discussed various topics such as river economy, physical conditions and changes of the river, tourism, and wind directions in the pursuit of the Big Question. At the mobile learning trail, students in small groups, undertook various activities at each of the three learning stations to carry out their own investigation with the aim to improve the ideas generated prior to the trail.

Designing Activity/Task Types Leading to Collaborative Meaning-Making

Aligned with the theoretical framework on constructivist learning environment (Brown and Campione 1990; Scardamalia and Bereiter 1992; Wenger 1998) and knowledge building principles (Scardamalia 2002), the mobile learning trail tasks were designed to enable learners to leverage on the rich affordances of the real-world platform to collectively generate ideas, share, and affirm findings and solutions in inquiry-oriented activities. More significantly, all trail task questions pointed to an ultimate problem statement where learners needed to see relationships across the findings to the various task questions and eventually to evaluate and synthesize shared knowledge and understanding.

Across the implementation of the four mobile learning trails, we found that some interventions were more successful than others in terms of the emergence of collaborative meaning-making discourse. For instance, the observed level of student engagement and interaction seemed lower in the Fall of Singapore trail as

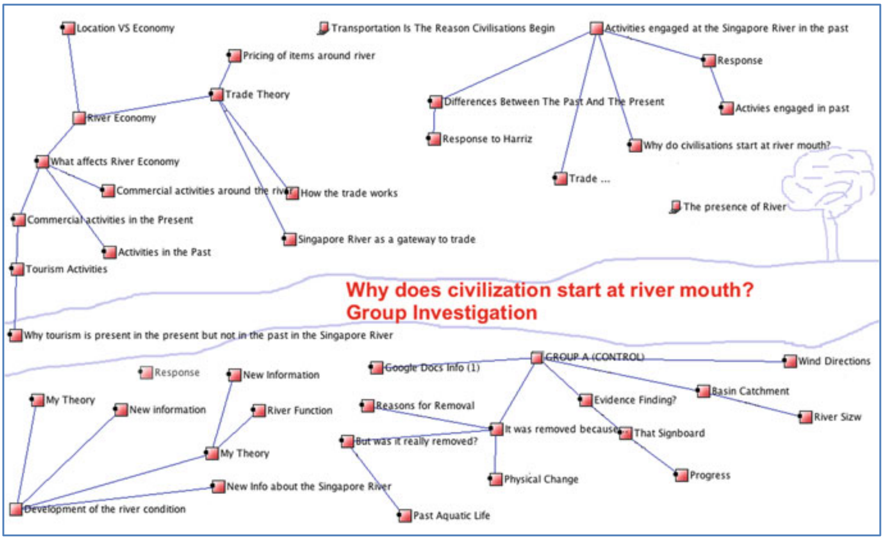

Fig. 8.2 Student-generated inquiry in Knowledge Forum. *Student names were removed for confidentiality

compared to the Geography learning trail at Sentosa Island. A detailed examination of discourse analysis (see Tan and So 2011) revealed that the nature of activity/task design was pivotal to bring about the emergence of deep discourse among students. More specifically, we found two elements critical for the design of learning tasks or activities leading to the deeper level of discourse and collaborative meaning-making we aimed to see: (a) *structuredness of problems* and (b) *integration of contextual resources and unforeseen variables*. Table 8.1 presents three variations of problem types in terms of activity or task structuredness incorporated into the design of mobile learning activities.

First, the task types can be largely categorized into *performative* and *knowledge generative* tasks along the continuum of structuredness as presented. Performative tasks require rather fixed and procedural application of concepts and skills, whereas knowledge generative task types lead to multiple possible solutions and require students to generate, experiment, and justify their ideas. In general, knowledge generative types are likely to lead to a high level of interaction in the sharing and improvement of ideas among students to construct and advance knowledge. However, in the context of our research on the design of mobile learning trails, we found that another type of task could be factored in between the performative and knowledge generative task type. This is contingent on the level and extent of integrating complex situational resources and variables, which is also our second design element. Our analysis of student discourse in group settings indicated that even performative tasks could generate high levels of collective meaning-making if the tasks were designed to incorporate unforeseen variables in the physical environment (Tan and So 2011). That is, whether activities or tasks can lead to

Table 8.1 Design of activity/task structure

Types	Characteristics	Examples (from the British Defense Strategy Trail)
Performative	Procedural, close-ended, linear	Calculate tower height using trigonometry
Complex performative	Procedural but can be nonlinear and complex with incorporation of unforeseen variables	Measure and calculate the gradient of the slope at three different sections of the beach and rank the slope from the gentlest to the steepest
Knowledge generative	Ill-structured, open-ended, design problems, nonlinear	Design thinking with a focus on the beachfront area of the Sentosa Island in terms of its attractions, accessibility, and amenities. Identify a problem area and propose a solution

collaborative meaning-making depends on the level of embedding unexpected complex variables and contextual resources as the integral part of a certain activity or task. We call these tasks *complex performative* to refer to such a type of tasks or activities that incorporate unforeseen complex variables and resources.

The examples in Table 8.1 illustrate the differences between performative and complex performative types. The examples given were part of "British Defense Strategy Trail" in 2011, which was designed to promote student's critical thinking about the Big Question, "What is the role of Sentosa in the British's big plan of defense?" During the mobile learning trail at the Fort Siloso, the students performed several types of subtasks designed under this Big Question. For instance, both tasks – "calculating tower height" and "calculating the gradient of the slope" – could be considered chiefly as well-structured problems where students were expected to apply known formulas. However, calculating the gradient of different slopes at the beach areas presented some unforeseen variables such as changing conditions of steepness and inclination at the different slopes, which made the seemingly straightforward application task complex and ill-structured.

We found some evidence that the complexity of the problems arising from the interaction with the real-world platform required the students to negotiate changing elements and to collectively review their ideas and findings at the knowledge convergence phase (Tan and So 2011). We conducted discourse analysis of three groups of students who performed the various types of tasks during the mobile learning trail. The analysis revealed that there were higher occurrences of externalization and elicitation of ideas observed in the complex performative task type than in the performative task type. The frequency of consensus building discourse was also higher in the complex performative and the knowledge generative task types as compared to the performative task type (refer to more detailed analysis and findings in Tan and So 2011). Our subsequent design of mobile learning trails focused on contextualizing activities and tasks which required students to negotiate with unforeseen variables and to deploy situational resources in the rich physical affordances in the collective undertaking of trail tasks. We hoped to see students engage in deeper knowledge building discourse and exercise more critical thinking in making associations and connections across various subject areas in different learning contexts and situations.

Promoting Interdisciplinary Thinking and Discourse

The last design consideration is to promote interdisciplinary thinking and discourse through the design of learning problems and tasks that integrate concepts and skills in multiple subject areas. Our ultimate intention underlying this design consideration is an epistemic one, which is to change students' beliefs about the simplicity of knowledge as stand-alone and disconnected. This design consideration arose from the consistent findings of the analysis of student discourse in online and off-line contexts. It was apparent that students continued to show task-completion focused patterns of interaction rather than understanding-focused. We wanted students to see the intricate yet complex relations among several concepts and skills learned in multiple subject areas and to experience how the integration of conceptual understanding helped to bring about deeper knowledge and facilitate richer discourse. Akin to Scardamalia and Bereiter's (2006, p. 7) exposition on "knowledge of" in contrast to "knowledge about," implicit or intuitive knowledge would require the learner to make inferences. Tasks and activities that promote "knowledge of" learning outcomes were designed around problems, rather than topics, to enable learners to see the connections of knowledge and ideas. Further, Klein (2005) posits that in integrative interdisciplinary pedagogy, the "application of knowledge takes precedence over acquisition and mastery of facts" (p. 10) and that the learning outcome would be the learner's ability to display the relational and higher critical thinking skills to adapt knowledge across contexts and situations.

One way to address the issue of task-oriented practices is to intentionally embed problems and tasks/activities that are interdisciplinary and knowledge generation-centered in nature. Our design of the Big Questions aims to foster community inquiry culture (e.g., "What is the role of Sentosa in the British's big plan of defense?" "Why does civilization start at the river mouth?"). These Big Questions are broad enough to engage students to employ more interdisciplinary and integrated thinking for idea generation, connection, and idea advancement. For instance, when designing the recent mobile learning trail at the Singapore River trail, task design witnessed an unprecedented rich integration of History, Geography, and other related subject areas (e.g., Biology, Economics) with the intent to develop a holistic understanding of the body of cognitive and procedural knowledge and skills in the integrated humanities. The Big Question "Why does civilization start at the river mouth?" kindled a discussion of diverse topics and ideas crossing multiple subject areas and knowledge such as river economy, wind directions, tourism, etc., and students displayed the capacity to see connections

Table 8.2 The frequency of postings showing interdisciplinary ideas in Knowledge Forum

	Class A	Class B
Ideas containing one subject area	38 (45 %)	23 (47 %)
History-oriented ideas	4	1
Geography-oriented ideas	30	15
Biology-oriented ideas	4	7
Ideas containing more than one subject area	46 (55 %)	26 (53 %)

and relatedness across these various ideas to carry out their own investigation and to advance their knowledge.

Table 8.2 presents the frequency counts of student ideas generated in Knowledge Forum, analyzed in terms of evidences of interdisciplinary thinking. The two classes used Knowledge Forum to share and generate ideas about the Big Question "Why does civilization start at the river mouth?" The student postings were analyzed to see whether they contained ideas pertaining solely to one subject area or multiple content areas. The two classes showed a similar pattern in terms of the level of interdisciplinary ideas. As illustrated in Table 8.2, slightly more than half of the student postings in both classes contained ideas coming from more than one subject areas.

This design consideration implies that not only students' epistemic views need a reformation but also teachers' roles and practices. As the culture for co-construction of knowledge is gaining increasing significance for students, this means that teachers need to acquire new pedagogical content knowledge that will enable them to orchestrate much more complex forms of activities than the traditional methods of teaching and learning (Dillenbourg and Jermann 2010; Slotta 2010). However, the current school structure that practices a subject-based curriculum is not conducive for teachers to collaboratively work toward the creation of new approach for teaching knowledge across multiple disciplinary areas.

Tensions and Challenges

Zhang et al. (2011) contend that several conditions are necessary to sustain knowledge building as a school-based innovation. Those conditions include shared vision of learning and innovation, high expectations and trust in student agency, teacher professional community, collective responsibility, and committed leadership. We found several of these conditions in the future school that we worked with. The school has a strong socio-technical infrastructure, as compared to many other local schools, which helped the initial stage of the research design and implementation. The school leaders and teachers placed particular emphasis on the development of core twenty-first-century skills such as collaboration, critical thinking, and creativity, which were compatible with our main research goals. As a future school, the school provided facilities, tools, and resources where teachers and students could easily access and utilize for collaborative learning. The school also allocated fixed time slots, known as "white space," for teacher professional development where teachers and researchers could collaboratively design learning tasks for research implementation and discuss the core ideas and principles underlying the knowledge building pedagogy.

Under such school culture and infrastructure, we found that the teachers and students exhibited positive beliefs and disposition toward the importance of collaborative knowledge building and the role of technological support in the teaching and learning process. In addition, we observed positive impacts of the mobile learning trails and activities for students' critical thinking skills (So et al. 2012). Teachers' narratives revealed that they observed the differences in student discourse quality between the classrooms with and without the mobile learning trail experiences. Teachers also perceived that the early experiences of mobile learning trails helped students to better connect concrete and abstract ideas and ask questions that exhibited higher levels of critical interdisciplinary thinking.

While it was encouraging to see many possibilities for promoting pervasive knowledge building practices in this future school context, we also found several challenges and tensions in our research trajectory, which are summarized here in three aspects: (a) the enculturation process of the know-how of collaboration, (b) the appropriation and coupling of technological platforms and tools leveraging on the affordances of physical environments and resources, and (c) the conflicts in assessment methods and designed learning outcomes/experiences.

First, while students in general perceived positively about the role of collaborative knowledge building, concurrently, we noticed that students exhibited conflicts in their espoused beliefs and real practices (So et al. 2012). That is, students could articulate the meaning and importance of collaborative knowledge building based on their espoused beliefs, but in practice, they tended to lag behind in social practices for engaging in meaningful collaborative discourse. Competitive and task-oriented disposition often led to the division-labor approach where students employed an efficient method to complete given tasks rather than engaged in collaborative meaning-making process. Overall, the sense of "cognitive collective responsibility" (Scardamalia 2002, p. 68) was still lacking even among students with positive espoused beliefs about collaborative learning.

Consistent with the previous literature that highlighted the enculturation of a knowledge building pedagogy (van Aalst and Truong 2011), we argue that the enculturation process to transform both students' beliefs and their practices is critical from the initial stage of research implementation. For instance, we designed and implemented a collaborative knowledge building workshop where we made the core principles, terms, and practices of knowledge building more explicit to students (Zhang et al. 2012). During the hands-on sessions in the workshop, we noticed that the discursive terms of knowledge building practices such as "my theory is," "what I need to understand," and "my better idea is" appeared in their group discussion, which could be indicative of students' gradual metacognitive awareness of knowledge building principles and practices. We, of course, do not suggest that the enculturation process can be achieved through a short-term intervention and/or prescriptive approaches. Rather, we contend that such workshops can help students gain initial exposure to and clear understanding toward knowledge building pedagogical principles. Also, with continuous enculturation, the transformation from teacher-centered task-focused learning to student-centered understanding-focused learning can be better facilitated.

The second challenge lies in the appropriation and coupling of technological platforms and devices. Recently, we have witnessed the emergence of various technological platforms that claim to support collaborative knowledge building. However, we found that many of the existing platforms do not support the type of collaborative knowledge building practices for emergent nonlinear activities and discourse. In the implementation of the four mobile learning trails and the related activities in classroom and outdoor settings, we increasingly recognize the importance of intentional learning where students can engage in their own inquiry questions and ideas rather than following the linear sequence of designed tasks. Particularly in the context of mobile learning trails, it is important to design tasks that leverage on the rich resources and information available in the physical environment. Thus, the process of collaboration can be emergent and nonlinear with the learner's interaction with the situated resources, tools, and information. As more situational and complex variables are embedded into the design of collaborative knowledge building tasks in authentic situations, we believe that there is a critical need to design technological platforms that effectively accommodate and support nonlinear emergent types of learning at multiple levels (e.g., individual, cross-groups, community, etc.) and across timescales, events, and topics.

The last tension is related to rather macro issues in the educational system about the conflict between desired learning outcomes and assessment methods. As surfaced by several knowledge building researchers, assessment is a critical issue that makes the adoption and spread of knowledge building practices more challenging in schools (van Aalst and Chan 2007). While the research school was built and designed as a future school, the school assessment mode and measure remained conservative – chiefly adhering to the requirements of the existing traditional assessment methods and high-stake examination that merit individual performance over collective cognitive efforts. Knowledge building pedagogy places emphasis on collective progressive inquiry journey and continual advancement of knowledge, foregrounding "ideas as conceptual artifacts that can be examined and improved by means of public discourse" (Lee et al. 2006, p. 279). This evidently runs contrary to the semestral standardized high-stake examination format which models after Cambridge "O" and "A" Level Exam, testing individual cognition and content mastery. Albeit that the school recognizes the value of collaborative learning and knowledge building practices, it is highly complex and challenging to track and measure individual progress in discourse inquiry amid the corpus of collective knowledge advancement made in public discourse. One meaningful measure to address this long-standing issue is to develop and design assessments that are able to measure both the product and the process. Assessments that align with collaborative knowledge building pedagogy should be able to, one, monitor and measure both individual and group cognition and, two, undertake "the dual roles of scaffolding learning and measuring it" (Lee et al. 2006, p. 281). The latter serves as a critical channel to equip and empower learners to assess their own progressive knowledge growth and also how it shapes and in turn is being shaped by the community advancement of knowledge. Lee et al.'s (2006) work on knowledge building portfolios offers one possible solution to meaningful assessment for knowledge building practices. However, other issues of consideration would be the high level of involvement of teachers/facilitators in the design and execution of such an assessment mode. More research seems necessary to develop assessment modes that value and measure productive critique and collective undertakings.

Conclusion

In the discourse of future education, there have been calls for schools to invest more in new technologies and new ways of teaching and learning and to adopt the characteristics often found in innovative companies. There are also predictions that schools may disappear or be marginalized with the advancement of technological innovations, which enables learning to happen in any places beyond the physical boundary of schools. Our conceptualization of future schools or learning environments, however, differs from those technology-driven or sometimes utopian thinking of schools for the future. We concur with Facer (2011) that the role of schools as a physical, local organization would be more important than ever with socio-technological changes in the coming decades, and schools are important organizations for enabling and building the types of interaction and conversation that we desire to see in our students. Indeed, the history of education implies that the classroom of the present is "very much a genealogical object" (Schratzenstaller 2010, p. 19) that reflects societal and educational goals of its historical predecessors. Thus, transforming the current education and learning environment should start from reimaging and rethinking goals, values, and expectations sought for education in the new era.

Obviously, there are multiple ways to conceptualize how schools and learning environments should be redesigned and what the critical design elements are. In this chapter, we put forward our position that knowledge-centered pedagogy is a viable way to envision goals for education and to conceptualize schools as a knowledge creation space that provides conditions, situations, and resources enabling students to engage in high-level knowledge work. Our design-based research work in a particular future school in Singapore is presented to illustrate the viability of knowledge building as a pedagogical model for rethinking and redesigning school learning. In particular, we used the design of mobile learning trails as a main platform to designing for changes in student learning that we aim to develop, which are skills and disposition relevant to working with knowledge. Through the progressive refinement of research interventions, we unpack and discuss broad design considerations that guided our design decisions. Our design considerations are neither prescriptive nor rigid. The flexible nature of the design would allow reinterpretation and adaptation when transferred to other contexts of learning (Barab et al. 2004).

While we focus chiefly on the design of pervasive knowledge building environments and the complexity of design elements from the pedagogical stance, several macro issues such as economic forces, educational policies, assessment systems, and enculturation emerged in our research trajectory. This phenomenon itself is an indication of the critical need to consider the interplay of multiple factors in a learning ecology and, concurrently, the potential danger of a microscopic view for conceptualizing future education. In the face of increasing complexity in the future society, we believe that our discourse for knowledge creation in education will witness new heights in educational research with more concerted research effort undertaken in different contexts of schools to critically examine necessary conditions and design elements for transforming current learning environments.

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Chapter 9
From Problem-Based Learning to Knowledge Creation

Jennifer Yeo

Introduction

The fast-growing body of scientific knowledge, the rapid advancement of science and technology, and the influence of science and technology in our daily life have shifted the goals of K-12 science education from one that is focused on content acquisition to one that emphasizes creative and meaningful use of scientific knowledge. Problem-based learning (PBL), with its activity centered on problem solving through investigation, explanation, and resolution, is highly regarded as an effective inquiry model to bring about this integration of new knowledge in the context of its use (Greenwald 2000; Hmelo-Silver 2004; Sonmez and Lee 2003). Its emphases on student centeredness and collaborative learning were also aligned with the theories of constructivism regarded to be necessary conditions for developing deep understanding of disciplinary content knowledge (Savery 2006).

Yet, the implementation of PBL in high school learning was fraught with difficulties. One of the problems is the disparity between the nature of PBL and K-12 educational settings. First, their goals are different. While PBL aspires for lifelong skills, K-12 educational settings covet curriculum coverage and excellence in high-stakes examination (Hmelo-Silver 2004; Savery 2006). Thus, PBL's student-centered approach and strong focus on process skills may not be considered a superior approach to the tried-and-tested methods of "teaching to the test." Second, the highly structured classroom organization of K-12 schools and the compartmentalized subjects in the school curriculum would present a hurdle in accommodating the flexibility in time and subject organization needed in the implementation of a more fluid and multidisciplinary nature of PBL.

Besides the mentioned problems, another systemic problem, and perhaps a more significant one, would perhaps be the tension between the emphasis on content

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learning in K-12 science classrooms and the focus on the development of skills in PBL. For example, science teachers in Angeli's (2002) and Lee and Bae's (2008) study experienced pressure to cover the contents specified in the official syllabi in their implementation of PBL. Furthermore, the meta-analyses of the effectiveness of PBL for content mastery in school setting such as those conducted by Albanese and Mitchell (1993), Vernon and Blake (1993), and Hmelo-Silver (2004) were found to be inconclusive. A meta-analysis by Douchy et al. (2003) on the effect of PBL on knowledge and skills in higher education and high school in general showed a positive effect on the skills of students, but a similar conclusion could not be made about the content knowledge acquired. While there were a few studies that produced evidence of an increase in achievement in content knowledge (e.g., Liu et al. 2006), there were those that showed no significant difference in content acquisition between students schooled in PBL and the traditional approach (e.g., Gallagher and Stepien 1996; Mergendoller et al. 2000).

This study was undertaken in an attempt to address the anticipated problems with systemic factors faced by schools implementing PBL and uncertainty of its effectiveness in bringing about both content mastery and process development. The goal was to look into the implementation of PBL in a local high school and to identify the tensions that arose so that interventions can be introduced to achieve the goals of science education in Singapore. The aim of this study was thus to simultaneously test the theories of PBL that informed the interventions as well as improving the practice of PBL. The dual emphasis on theory and practice in this study justifies the use of design research as the intervention methodology in this study, in which learning is studied in context through systematic design and study of instructional strategies and tools (Brown 1992). This study was conducted in three different science classrooms, one for each research cycle, set in the natural setting of the participating school. It involved the active participation of the teachers teaching the classes in the theory-building process and practice refinement in each research cycle.

In the following sections, this chapter describes the transformation of PBL in a local high school through design research as it sought to implement PBL to foster deep science learning and problem-solving skills.

School Science Learning and PBL

What School Science Learning Entails

This study takes the view that science learning is a meaning-making process (Mortimer and Scott 2003). As the body of scientific knowledge is defined by the unique language it uses to make sense and to communicate its interpretation of the world, students learning science need to appropriate the ways in which different forms of language are used to construct meaning scientifically. In other words, students should be engaged in making sense of the meanings inscribed in different forms of languages, using them to communicate with one another meaningfully and producing creative solutions with them (Bereiter et al. 1997).

Drawing from the theories of situated learning (Lave and Wenger 1991), embodiment and social development of learning, students' meaning making of science should be supported by an environment that provides (1) an authentic context for students to participate in the meaning-making practices of science, (2) relevant experiences of similar phenomenon for uncovering the meaning inscribed in the language of science, and (3) a platform for interaction whereby students learn through a collaborative process. An authentic context in which the system of scientific knowledge is constructed allows connection between the real world and the abstract language of science to be made effectively. The coupling of our felt experiences with meaning in theory of embodiment (Varela et al. 1991) highlights the importance of engaging students in similar kinds of phenomena through which particular meaning patterns have been made. The inherent meaning in interaction (Vygotsky 1978) suggests science learning as a collaborative process of knowledge construction whereby students use a language to communicate with one another and to make sense of one another, thus helping them develop a meaningful and coherent understanding of the world.

How PBL Supports Science Learning

The conception of PBL was triggered by the realization that the traditional method of separating content from practice did not facilitate medical students' application of content to context (Savery 2006). PBL focuses on the application of newly found information in solving problems in real-life contexts (Savery and Duffy 1996; 2001). Its learning process, shaped and directed by students, is organized around investigation, explanation, and resolution, while the teacher acts as a metacognitive coach (Greenwald 2000; Hill and Smith 2005; Hmelo-Silver 2004). The features of PBL – (1) authentic problem, (2) students' active participation in the problem-solving process, and (3) collaborative and self-directed problem solving – are aligned with the conditions of school science learning described above. Table 9.1 shows the alignment between the features of PBL and conditions of school science learning.

While the features of PBL in respect to the conditions of science meaning making suggest that PBL is a suitable pedagogical approach, research findings did not seem evident. The goal of this study is hence to refine the pedagogical approach to support science meaning making more effectively. The following sections describe each of the research cycles in turn and explain how and why interventions were introduced to improve the meaning-making process in science learning.

Table 9.1 Alignment between features of PBL and conditions of school science learning

Conditions of school science learning	How PBL aligns with these conditions of school science learning
Context	Authentic problems in PBL provide a meaningful context for science learning through similar types of problems that scientists solve in their everyday practice
	Similarity between the problem-solving process of PBL (generating hypothesis, exploring possible solutions, investigating the problem, analyzing results, and generating solutions and recommendations) and the science inquiry process (hypothesis generation, hypothesis testing, and theory-building process that scientists use to construct scientific knowledge)
Experiential	The problem-solving process provides the platform for students to experience the phenomena and make use of language and other forms of representations to communicate their felt sensations and to think about the phenomenon studied
Interaction	The collaborative and self-directed nature of PBL allows students to work in small groups to construct knowledge. With the group collaboratively directing their own efforts in problem solving, they learn to own their learning and develop scientific practices such as argumentation, questioning, and reflection

Methodology

This study was a 2-year design research (Design Research Collective [DRC] 2003) aimed at refining the theory and processes of PBL for high school science learning. Three research cycles were carried out during this 2-year research project. The findings of each research cycle informed the interventions introduced to the next cycle. In each cycle, both the outcome of PBL and the process of learning (activity) were examined in order to understand how the interventions introduced supported science meaning making. The analyses focused on (a) the enactment of PBL and (b) the extent of science meaning making achieved. Using cultural-historical activity system as an analytical framework, the activity system of the enacted PBL was reconstructed for each research cycle.

The Field Site

This study, conducted in T Academy (pseudonym), was a partnership between the teachers in the school and researchers of this project to refine an instructional program that the school had embarked on. T Academy had developed the THINK cycle, a new pedagogy for science, to offer its students a broader learning experience. It was an instructional model based on the PBL approach that consisted of five stages of problem solving, namely, trigger (T), harness (H), investigation (I), network (N), and know (K). In this approach, students, working in small groups, were presented with simulated problems of the real world (T). They would identify questions that they need to investigate (H) before embarking on a series of investigations (I), which may include searching for information or conducting experimental investigation. In the process of solving the problem, they would network (N) with fellow team members and experts. Finally, they would present their solution to a panel of judges (teachers) to demonstrate their knowledge gained (K). Throughout the THINK cycle, each group was supported by a teacher facilitator who acted as a metacognitive coach. An online discussion platform was introduced in the second and third research cycles to facilitate collaboration.

The Research Cycles

Three research cycles were conducted over two academic years, one in the first and two in the second. The THINK cycles in this study were conducted with grade 9 students. In each cycle, one group of students working together on a given trigger problem was selected as the case study. The students in each case were similar in academic and cultural background as issues arising from differences in academic and cultural factors were beyond the scope of the study. Throughout the study, there was a strong partnership between researcher and three physics teachers to engineer changes in the classroom as well as to improve PBL theory based on empirical evidence. Two researchers worked with the teachers in refining the PBL process, attended almost all the lessons that the teacher conducted, and sometimes acted as a co-facilitator.

Data Collection

For each research cycle, interaction among the students was the key data for reconstructing the THINK cycle activity. Video recording was used to capture face-to-face interactions, and online interactions were recorded in the database of the online forum. Other sources of data included (a) interviews with teachers and students to understand their actions, motives, and goals and (b) the artifacts produced by the students which provided more information about their learning processes.

Analysis Method

School learning is a specific historical type of activity, with specific objects that drive classroom practices (Miettinen 1999). To make sense of the events taking place among the people and materials in the enacted PBL classrooms, *cultural-*

historical activity theory (CHAT) was adopted as a theoretical lens for analyzing the activity by connecting the activity enacted (actions and behavior of the teacher and students) to the motive that drives the enacted activity and instruments that afford the activity. It offers a three-level scheme for organizing an activity: activity, action, and operation (Engeström 1999). Activity refers to a conscious process that takes place, as opposed to the innate property of the activeness of animals and human beings (Engeström 1999; Kozulin 1986). In a science classroom, an activity refers to the classroom practice employed for science learning. What distinguishes one classroom activity from another is the motive that drives each activity and the object that the activity is oriented to. For instance, a traditional approach to science learning is often oriented toward mastery of knowledge, driven by the need to prepare students for examinations. On the other hand, PBL is oriented toward problem solving in order to prepare students to solve real-world problems (Savery 2006). An activity is translated into reality by chains of goal-directed actions. For instance, a didactic teaching approach may be made up of a series of events such as a motivational demonstration, individual seatwork, and presentation through different forms of media. Each learning event is considered a classroom action. An action, in turn, is made up of a series of operations. These operations refer to the specific behavior of students during learning events. For instance, the operations of doing a science experiment may include measurement, drawing graphs, calculating, and writing.

Expanding from this three-level framework is the expanded CHAT framework (Fig. 9.1) by Engeström (1987), who maintains that an activity is not an isolated activity system existing on its own. Instead, it is part of a larger social cultural system in which it is embedded in, including the norms of the activity (rules), community members (community), and their roles (division of labor). Thus, analysis cannot be taking place at the action level, but rather at the activity level. The expanded version of CHAT takes into consideration the influence of the social cultural context in which the classroom activity is taking place. The reconstruction of the enacted PBL thus involved identifying the cultural-historical factors influencing the classroom activity taking place.

Research Cycle 1

Participants

The first research cycle was carried out in Class 1E, with 23 (8 boys and 15 girls) high-achieving students. Prior to this research cycle, the students had completed five other THINK cycles – three on biology, one on chemistry, and one on physics – where they worked in groups of four or five. For this research cycle, a group of four students, three girls and a boy, was selected as this group was similar in their academic and cultural background. The teacher was Mr Chen, who was also the

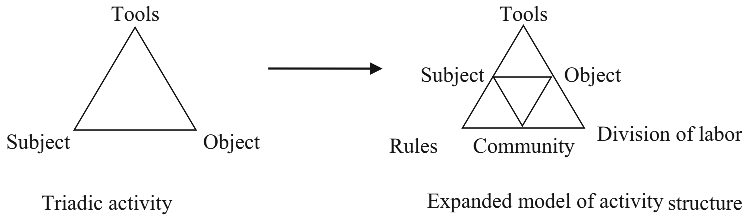

Fig. 9.1 Engeström's (1987) expanded activity structure

head of the technology department and had taught for 5 years in the school. He was one of the pioneering teachers involved in designing the THINK cycle framework. As an anchor in the physics program, he designed all the physics THINK cycles.

Design of the First THINK Cycle

The trigger problem was about a road accident between a Toyota Hilux lorry and a BMW car near a traffic junction, which caused the death of a passenger seated at the back of the lorry after being flung onto the road. Using the concepts of two-dimensional kinematics, students were asked to find out which driver was at fault. In order to simulate a real-life crime scene investigation, "evidences" such as scaled drawings of the accident scene, photographs showing the victim, and information about the vehicles involved in the accident were presented as important clues to the problem. As a final product, the students were to generate a group report and a 10-min presentation to a group of "judges," made up of four physics teachers in the school. The THINK Cycle 1 was carried out over five lessons (a total of 7.5 h).

The Activity System of THINK Cycle 1

The enacted THINK Cycle 1 can be described by five key episodes: (1) presentation of trigger problem, (2) discussion of hypotheses and identification of learning issues, (3) lecture of the concepts of projectile motion, (4) problem solving of practice questions and trigger question, and (5) presentation of solution to trigger problem. In each activity, the focus on mastery of the intended content knowledge as stipulated by the curriculum objectives was evident.

Right from the presentation of the trigger problem, the mastery of content knowledge was emphasized by Mr Chen who stressed on the need to master "physics principles and the math principles" in solving the problem and that "we will test you whether you are really good in physics" during the presentation. The concepts of kinematics were again highlighted when students proposed their hypotheses. Mr Chen gave more attention to ideas related to the intended topics, whereas responses related to traffic rules and road conditions received none other than a cursory acknowledgment. The focus on the content knowledge was most evident during the lecture and problem-solving episodes. Practice problems given to the students to solve closely resembled an earlier example given by Mr Chen. The students merely had to identify the correct numerical values to substitute into equations given to them. Explaining for his actions, Mr Chen said, "I give them a problem so by getting them to tackle the problem, the SIO will have been covered . . .." SIO refers to the specific instructional objectives specified in the GCE "A" level examination syllabus. In a similar vein, during the presentation episode, questions asked by Mr Chen were mainly used to test the students' understanding of two-dimensional kinematics. Evidently, disciplinary content knowledge was the key object of the THINK cycle. This inference was supported by the teacher and students, who rank content knowledge as their top priority during the interview. As echoed by Mr Chen, the objectives of this THINK cycle were primarily to learn "kinematics and projectile motion," all of which were content driven.

With the object of the activity focused on content mastery, the practice and trigger problems functioned as tools. They were used by Mr Chen (1) to direct students' attention to the topic of projectile motion during the generation of hypotheses and learning issues episode, (2) as a form of illustration of the concepts of projectile motion in the worked examples, and (3) to provide the context for applying the knowledge of projectile motion to ensure understanding. Just as the problems were given to ensure that "at least I equalize everyone in terms of the basic understanding of projectile motion," the trigger problem was given as he recognized that not everyone would be able to solve it, "which is why I had one problem a day at the start of the lesson . . . at least to give everyone a chance to think about the problem . . . which are very similar to the CSI." It seemed that the trigger problem was intended as an extended practice.

Mr Chen's actions seemed to be influenced by the importance he placed on the learning objectives for this THINK cycle. During the interview, Mr Chen had ranked the objectives listed in the official syllabus as his top priority. He had specifically emphasized that his main objective was "to get the kinematics projectile motion taught to them." Other objectives, such as "the understanding of the (Singapore's) laws . . . which is not deemed essential to the topic but something good to have," were given less emphasis.

Other mediating factors included the syllabus' objectives and assessment criteria as Mr Chen explained that the first practice question was to help students be "accustomed to resolving vectors, x component and y component, to solve problems" and the second question was "to get them to see that all they had to do is to look at the displacement rather than distance," as he made reference to the vertical displacement of the object in the equation of motion. Furthermore, it was observed that Mr Chen would instruct students on the assessment criteria such as "you will get the negative one penalty," and ". . . whether you know how to do, the first thing I want to see that will probably get you two marks straightaway is . . .." On these remarks, Chen explained that "ultimately the examination is 40 %. . . . in the marking scheme, . . . we mark them based on the steps they give." Therefore, he felt that "the assessment objectives are very important" and "PBL is not very strong in getting them (students) into structures" in terms of procedural steps. As a result, he had to "hammer them with the necessary structures because even in A levels, there is a certain right way of doing things." In other words, Mr Chen's decisions were influenced by the official national curriculum.

In terms of their roles in this THINK cycle, it was clear that Mr Chen was authoritative, while the students took on a more passive role of following the teacher's instructions. Students seldom worked collaboratively together although they were grouped. They seldom sat together, and when they did, it was mostly to help each other in working out the practice questions.

In a nutshell, the activity of the enacted THINK Cycle 1 was influenced by a community made up of a teacher, students, and curriculum planners. Sharing a common objective of mastery of two-dimensional kinematics, trigger and practice problems were used as tools to help students to achieve the learning goals. The subjects' behavior was influenced by the curriculum goals, objectives, and assessment criteria. What resulted from this THINK cycle was a shallow understanding of its concepts and its limited application to solve problems. Figure 9.2 represents the activity system of the enacted THINK Cycle 1.

Contradictions and Tensions in the THINK Cycle 1 Activity System

The enacted THINK Cycle 1 did not resemble the constructivist's features of PBL. Although a contemporary approach to learning was adopted by the teacher and the students, the traditions of a didactic classroom teaching did not seem to be broken. Instead of collaborative problem solving, traditional practices such as lecture and drill and practice remained the dominant forms of work in this classroom. This lack of transformation in the THINK cycle science classroom could possibly be due to the motive driving it.

According to Leont'ev (1978), every activity is driven by a motive; what distinguishes one activity from another is the object, which gives direction to the activity. All actions are hence in relation to this driving force. In Mr Chen's PBL unit, acquiring and mastering content knowledge seemed to be the primary object, and the problems were used merely as tools for reinforcing the content acquired. Engeström (1987) attributed this "strange reversal of object and instrument" in school learning to the historical isolation of school from other societal activities. Calling the school science content knowledge "'A' level peculiar content knowledge," Mr Chen acknowledged that "in 'A' levels, there is a certain right way in doing things." He also added that:

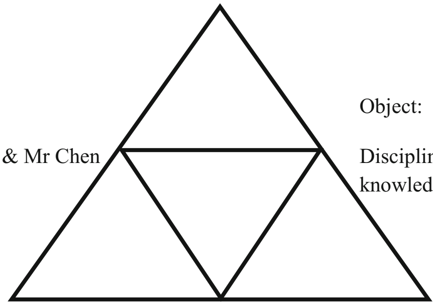

Fig. 9.2 Activity system of the enacted THINK Cycle 1

> certain structures are there in the 'A' level curriculum . . . if you don't show the steps, no matter how good you are and how much you understand . . . the problem or the concepts, you will not do as well as someone who don't know as much but know the structures well.

Therefore, he felt the need to address the importance of examination by "trying to find a system to get the best of both worlds." In other words, although Mr Chen may have the intention to embrace PBL, to him, the motive of schooling is primarily to learn well and succeed in examinations, rather than to seek far transfer to real-life applications.

The lack of transformation could perhaps be explained by the tension between the exchange value and the use value of the object. In the enacted THINK cycle, content mastery is considered essential for getting good examination results, which in turn determines a child's academic path (Lave and Wenger 1991). Problem-solving skills and metacognition are useful and are essential skills in dealing with everyday problems but may not be so crucial in doing well in high-stakes examinations that test mainly recall and procedural knowledge. As mentioned by student SX that while "relating to real world is interesting, it is worrying for exam." Mirroring this concern, Mr Chen said that "PBL will be able to role model better the skills that are required for working life . . . (but) PBL approach is not strong in getting them into structures . . . (which) are there in the 'A' level curriculum." He further commented that "ultimately assessment objectives are very important . . . with current 'A' level, PBL is very difficult to be successful in a big scale." Therefore, to overcome the perceived disadvantage of PBL, Mr Chen stressed that a certain amount of drilling would be necessary.

In a nutshell, the first research cycle identified challenges that teachers and students faced in implementing PBL in science education system, constrained by a national curriculum and an expectation to produce good examination results. Yet, for any true transformation in teaching and learning, PBL has to be the pedagogical base in the curriculum and not part of a didactic curriculum (Savery 2006). To overcome this "lethal mutation" (Brown and Campione 1996) of PBL in the enactment of THINK Cycle 1, considerations will be taken of the contradictions and tensions observed in this first research cycle in the design of THINK cycle, with the hope of bringing THINK cycle to a closer alignment to the PBL approach.

Research Cycle 2

Participants

This second research cycle was conducted with Class 1A in the following year. There were 25 high-ability local students, 9 boys and 16 girls. It was their first experience of THINK cycle since it was the beginning of a new academic year. A group of students, made up of five 14-year-old students, three females (EL, XM, CF) and two males (SH and YH), was identified for the study. The physics teacher of Class 1A was Ms Tam who joined the teaching profession for half a year when Research Cycle 2 was conducted. She had no prior experience in PBL.

Design of THINK Cycle 2

In the second research cycle, a concerted effort was made to align this THINK cycle (to be referred to as THINK Cycle 2 henceforth) to its constructivists' principles. Interventions in its design and implementation introduced include the following: (1) a real-life problem was designed and used as the anchor for all learning activities instead of functioning as a tool for additional practice; (2) learning activities were designed to center on real-life problem-solving practices, rather than a preamble for a lecture on related scientific concepts and principles; (3) collaboration mediated by a computer-supported collaborative learning system, Knowledge Constructor, was introduced instead of individual practice of procedural-based problem solving. A screenshot of Knowledge Constructor environment of one of the forum discussions is shown in Fig. 9.3. To address the teachers' concern about balancing content mastery and development of skills, instructions were specifically given to students to identify learning issues and to work on them as they solved the problem.

Guided by the principles of PBL, the design of THINK Cycle 2 was based on the topic of two-dimensional kinematics. The trigger problem involved a humanitarian

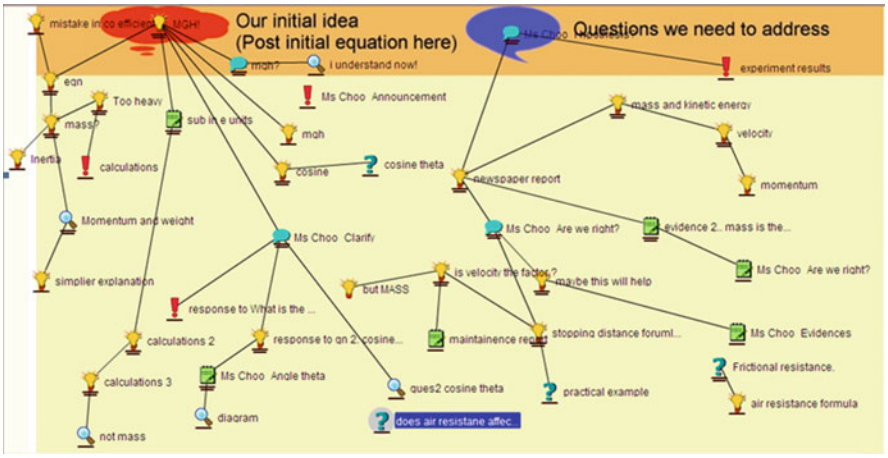

Fig. 9.3 Screenshot of the Knowledge Constructor environment

movement to deliver food items to civilians trapped in a war zone. Assuming the role of controllers of an airplane, the students were asked to find out the most appropriate time to release a package of the food items from the moving airplane. A simulated airplane in the form of a remote-controlled car moving on tracks placed above the ground was set up. A lump of plasticine representing the food parcel was placed in the car. This parcel would be released when a plastic door placed on the base of the car was pulled open by a string that had its other end tied to a fixed structure at the starting point of the car. The students' task was to find out the length of the string that held the "catch door" to the starting point. Figure 9.4 shows the setup of the simulated model plane. Table 9.2 summarizes the design of THINK Cycle 2 according to its five stages.

The Activity System of THINK Cycle 2

The analysis of the interaction data showed the group of five students sharing a common objective of seeking a solution to the given trigger problem throughout the THINK Cycle 2. This is evident from the students' talk on Knowledge Constructor that consisted mostly of proposed solutions. Few learning issues were identified or explored, even though students were specifically told to do so at the start of the activity. Even face-to-face sessions to discuss the ideas posted online consisted mostly of sharing procedural steps, but the students were unable to make use of scientific theories to support their proposed solution most of the time. For example, student YH proposed a seemingly sound solution:

Fig. 9.4 Setup of the simulated model plane

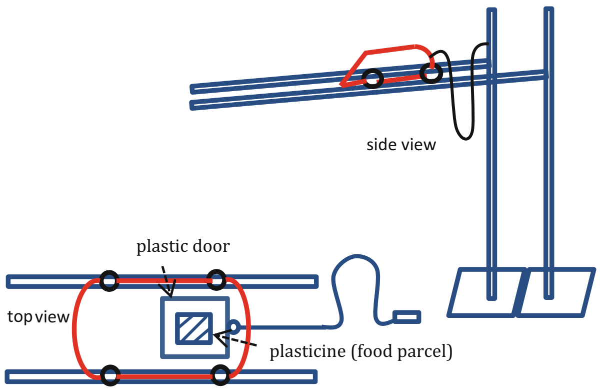

Table 9.2 Design of THINK Cycle 2

Stages	Activities
Trigger	Presentation of trigger problem
Harness	Generation of solution (individual and group), refinement of solution (individual and group), exploration of content knowledge in the context of problem solving
Investigation	Operationalization of group solution
Network	Communication through CSCL system, Knowledge Constructor
Know	Testing of solution through competition, writing of group report, and individual reflection log

Calculate time taken for parcel to drop from height of "plane" to ground
Calculate time taken for "plane" to reach the designated spot
Subtract answer of first question from second question
Find distance from car to starting point at the designated time (answer in third question)
Distance = required length of protruding string

But he was unable to explain his proposed procedure scientifically, other than reiterating that the parcel "will move forward with the same speed as the plane" as a matter of fact. Even though EL raised some content-related questions about the phenomenon, the students were keener to vote for a group solution instead of exploring reasons to explain their solutions.

The focus on solution seemed to compromise the students' learning of the intended content knowledge. Instead of exploring the learning issues to help inform the solution of the problem trigger, the students relied on "more knowledgeable" others for their solution. For example, YH sought the help of his school seniors, while EL's brother helped her solve the problem. While a majority was in favor of YH's solution initially, it was the coteacher's support for EL's solution that resulted in students gravitating toward EL's solution. However, in the actual solving of the problem, students made use of trial-and-error approach to find the length of the string. Ms Tam was eventually disappointed that not much physics was learnt at the end of the THINK cycle.

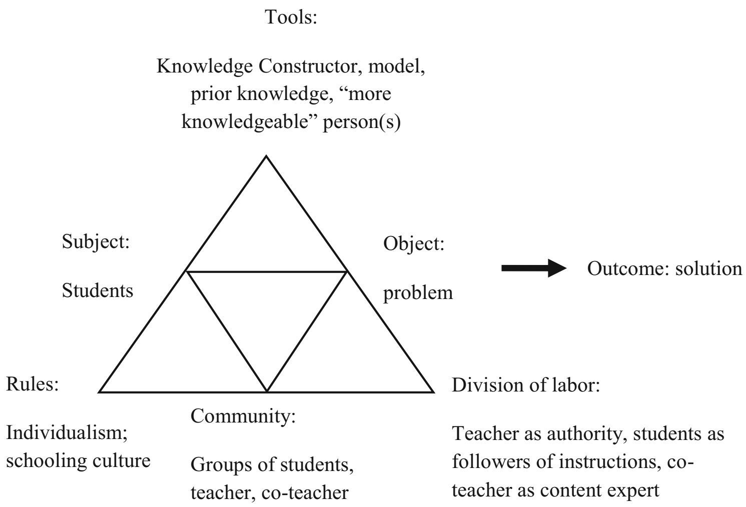

Fig. 9.5 Activity system in the PBL classroom – THINK Cycle 2

In terms of the mediating rules and division of labor, the THINK Cycle 2 was characterized by individualism and passivity instead of collaboration or self-directedness to deepen their understanding of the underlying learning issues. For example, questions raised about the phenomenon were mostly left unanswered. Instead of intersubjective relationship between teacher/coteacher and students, there were signs of power relationship between students and teacher/coteacher. In other words, the students remained as passive learners, while the teachers continued to retain their authoritative status. As a result of the activity, little content knowledge as stipulated by the syllabus was achieved. Figure 9.5 depicts the activity system of THINK Cycle 2.

Contradiction Between Knowledge of "Know-How" and "Know About"

The enactment of THINK Cycle 2 continued to show the contradiction between the kinds of knowledge generated by problem solving and that expected of science learning despite a closer adherence to the principles of PBL. In problem solving, the goal is to successfully resolve the problem. What matters is a kind of knowledge that is called "know-how," knowledge that emerges and manifests itself as part of an ongoing activity (Paavola and Hakkarainen 2005). This probably explained why the group of five students observed was no longer motivated to explore the learning issues further after they found out sufficient knowledge to solve their problem. What resulted was merely functional knowledge.

However, context-specific “know-how” knowledge may not be transferable to other contexts, especially in the context of examination. This is problematic, especially since generalizable and abstract knowledge is the goal of school science learning. This was one of the reasons contributing to Ms Tam’s apprehension when she realized that her students did not use the equations of motion to solve the trigger problem.

The observation in THINK Cycles 1 and 2 seems to resonate with the problems raised by Sfard (1998) about acquisition-based learning and participation-based learning. In the case of an acquisition-based PBL, its transmission approach to transfer knowledge from one mind to another does not provide adequate opportunities for students to participate in science meaning making. Instead, with most of the meaning making done by the teacher as he/she diligently transfers the knowledge he/she has constructed to the students, the only opportunity left for students to engage in meaning making is probably when they are trying to solve problems. Even then, findings in Research Cycle 1 show that the activity can be reduced to mechanical steps as heuristics of solving examination-like questions are explicitly taught to the students. Such acquisition-based approaches compromise on the opportunities for students to be engaged with systems of scientific semiotic resources that are necessary for constructing meaningful knowledge for the students.

The practitioner origin of PBL suggests that the design of PBL falls into the participatory paradigm. Described to be similar to the inquiry practices of scientists (Greenwald 2000), it is said to link students to the essential habits of mind and thought processes of scientific exploration and discovery. However, as shown in this study, its implementation in a high school context may pose a real challenge to teachers and students in trying to achieve the discrete knowledge goals in the science curriculum. In problem solving, it may not bring to the fore the depth of knowledge that underlies the practical knowledge that is eventually applied to solve the problem. Learning may thus be reduced to the functional aspect of know-how, thereby diminishing the opportunities for students to be deeply engaged in making sense of the scientific principles and concepts. The specificity of knowledge constructed as a result of solving problem in a specific context also runs contrary to the need to construct generalized knowledge that can be applied in new situations.

Instead of one or the other, Paavola and Hakkarainen (2005) suggested a third metaphor of learning, knowledge creation, to overcome the content-process divide. Knowledge creation refers to learning environments that emphasize on the continual advancement of the community’s knowledge. These learning environments extend the acquisitive notion of learning by emphasizing not only individual cognition but also the community’s collaboratively development of artifacts (Paavola and Hakkarainen 2005). Learning is, therefore, perceived as a kind of individual and collective activity that goes beyond the information given, focusing on the continual advancement of knowledge and understanding while highlighting the collaborative, systematic development of conceptual and material artifacts at the same time (Paavola and Hakkarainen 2005). Applied to PBL, the principle of idea improvement of community's knowledge could direct students' attention toward seeking continual refinement of the solution sought and collective advancement of the group's knowledge. This could involve students in working on interpreting and transforming the disciplinary knowledge in the context of the problem as they work toward a resolution. This dual emphasis on content and practice holds the promise of affording the construction of generalized knowledge, broadly indexed to the problem situation, thus averting the problem of inert knowledge or narrowly contextualized knowledge often associated with acquisition and participative-based learning environments, respectively (Scardamalia 2002). The principles of epistemic agency and collective advancement of the community's knowledge of a knowledge creation learning environment (Scardamalia and Bereiter 2004) could inform the necessary strategies to scaffold students in collaboration and self-directed learning during THINK cycle.

Research Cycle 3

Participants

The third research cycle involved one physics teacher and her students working on a trigger problem related to the law of conservation of energy. The teacher, Ms Cho, who is a physics graduate, had been one of the collaborating teachers in the research. A recent graduate (about 1 ½ years) from the teacher's teaching institution, she had volunteered to participate in the research. It was her second year teaching the THINK cycle. The group of students in this study consisted of four girls (D, J, XC, and K) and one boy (M) of 14 years of age.

Design of THINK Cycle 3

Conscious of the content-process tensions in the previous cycles, the design of this THINK cycle (which will be referred to as THINK Cycle 3) was guided by principles of knowledge creation that emphasized collective advancement of cognitive and material artifacts. With a trigger problem involving a fictitious roller-coaster accident in an offshore island in Singapore, students were tasked to investigate the cause of the accident in groups of five. Supporting the students in a more structured manner, students were directed to (1) construct a mathematical expression to explain how the roller coaster worked during the harness stage and (2) create and test their hypothesis during the investigation stage.

The construction of a generalized expression to explain the roller-coaster ride was to address the potential absence of generalizable theory in mediating problem solving that was observed in the second research cycle. The creating and testing of hypothesis support students' engagement in the meaningful use of theory in problem solving. A model of the last section of the ride where the accident happened and "evidence" gathered from the scene of the accident such as newspaper reports, police reports, and maintenance reports were also provided to mediate this problem-solving process. The structuredness of this THINK cycle was to support students with self-directed learning that was absent in the second research cycle.

In alignment with knowledge creation, students were encouraged to build on one another's ideas and make revisions to existing ideas. For example, they could return to the harness stage to refine their theory of the roller coaster's motion or refine their experimental design if their hypothesis was not supported. In this sense, the principle of idea improvement was built in. Throughout the process of THINK cycle, the students would network with one another via face-to-face and online platforms. Knowledge Constructor continued to provide the technological platform in this THINK cycle to mediate students' collaboration.

The Activity System of THINK Cycle 3

Two main activity systems were found in the enactment of THINK Cycle 3: knowledge building and problem solving. The two activity systems were found to be closely related to the other, with the outcome of each activity supporting the other, even though the object for each of the activity system was different.

The knowledge-building activity was enacted in the harness stage. It involved students building an expression to describe how the roller-coaster ride worked. Two instances of knowledge building were observed, with the first being orchestrated by the teacher. The first instance took place when the students were trying to explain "how friction affects the point in which the car stops?" A search on the Internet led to a large amount of information, albeit detached from the problem context, copied onto the Knowledge Constructor. To direct the students to apply the information to the problem context, Ms Cho prompted the students with three questions, "1. Why/how does the cart start to move down the slope?" "2. Why does it come to a stop?" "3. How do we find the stopping distance?" These three questions led the students to think about the information they found on the Internet and applied it to the problem context to derive an expression to describe how the roller coaster worked. This derivation eventually led them to hypothesize the cause of the accident.

A second instance of knowledge building took place when the students, in testing their hypothesis with the model setup, found that their results were contradictory to the theoretical results they expected to find. This time, they took their own initiative to examine at their interpretation of the problem context in the light of the scientific knowledge they found. The result was a refinement of their understanding of the problem context, in terms of the assumptions made. The social processes observed during this knowledge-building activity included sharing of information as each student posted the information they had found on the Internet,

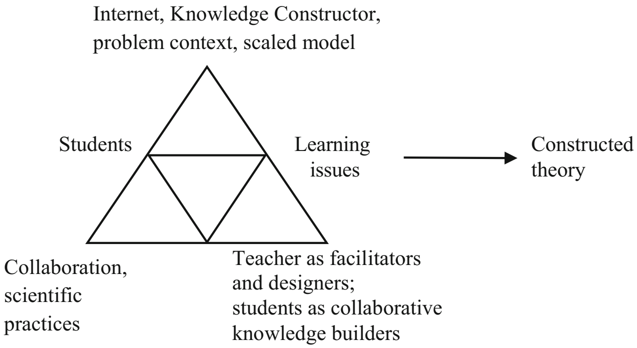

Fig. 9.6 Activity system for construction of expression for the roller coaster

negotiation of information found on the Internet, and interpretation of the work-energy theorem in the context of the problem. The participation structure observed from the interaction data also showed signs of collaboration among the students in the knowledge-building process as the students built on one another's ideas by elaboration or argumentation. This activity resembles the kind of theory-building activity that Scardamalia and Bereiter (2003) advocate, whereby continuous advancement of context-general knowledge distinguishes the activity from other content-focused learning activity. Figure 9.6 shows the activity system for this model construction activity.

The problem-solving activity was enacted during the investigation stage. When the students had derived an expression describing the motion of the roller coaster derived, they studied the "evidences" created by the teacher and research team to hypothesize the cause of the accident. In this case, the students hypothesized that the excessive weight of the roller-coaster ride was the cause of the accident. They then gathered evidences to support their hypothesis experimentally and theoretically. Experimentally, they made use of the model setup to test the stopping distances for different mass in an attempt to find out the relationship between stopping distance and mass. They tested their theory by making use of the data provided in the "evidences" and the derived expression to find out if the results concur with the empirical data. To their surprise, the two results contradicted. This led them to another round of knowledge building as described earlier.

In short, the problem-solving activity had the problem of the roller-coaster accident as its object. Mediating this activity were the derived expression constructed during the modeling activity, the evidence created by the teachers and researchers, and the model setup. In this process, the students played a significant role in solving the problem. Online discussion data showed the students sharing their interpretation of the evidences, negotiating possible factors that might have caused the accident, and interpreting the derived equation in the context of the problem. The outcome of the problem-solving activity was more puzzling questions that triggered another episode of knowledge building. In the second cycle, a

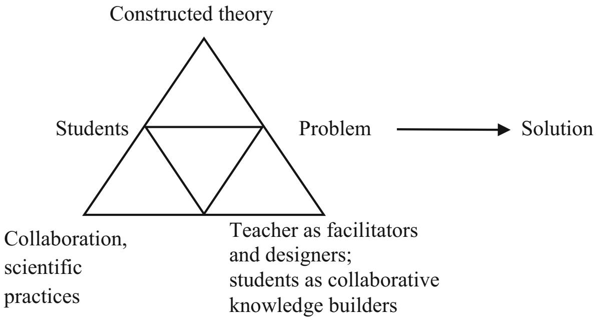

Fig. 9.7 Activity system for problem solving

solution was finally found. Figure 9.7 shows the activity system for problem solving.

While each activity could be associated with an activity system on its own, each serving different objects, the enactment of THINK cycle in this research cycle shows that they are closely connected. The derived expression constructed during the knowledge-building activity served as the mediating tool for problem solving. The process of problem solving, in turn, provided the impetus for further advancement of knowledge as students were puzzled by the discrepancy in their findings. In other words, the two processes were closely coupled despite the differences in their focus.

Therefore, to represent the activity of the enacted PBL, we used two activity systems, one to represent knowledge building and another to represent problem solving, to illustrate the different focus of each activity and their interdependence on each other. Figure 9.8 shows the components of each activity system and their interdependence in this THINK cycle.

Overcoming the Content-Process Divide with Knowledge Creation

In refining the PBL process, findings in the first two research cycles indicated a constant tension between the roles of content and problem. In an acquisition-based PBL, the strong emphasis on acquisition of content knowledge reduces the role of problem to that of a tool to ensure that the acquired knowledge can be transferred reliably to examination-like questions through a mechanical application of a set of rules and heuristics. On the other hand, a participation-based PBL foregrounds the problem-solving process so much that knowledge fades into the background. Appropriation of knowledge is assumed to happen through the embodied act of doing.

It is in this respect that the introduction of the notion of knowledge creation seemed to resolve the tension between content and process. The third research cycle shows that problem-solving activity could trigger puzzling problems for knowledge

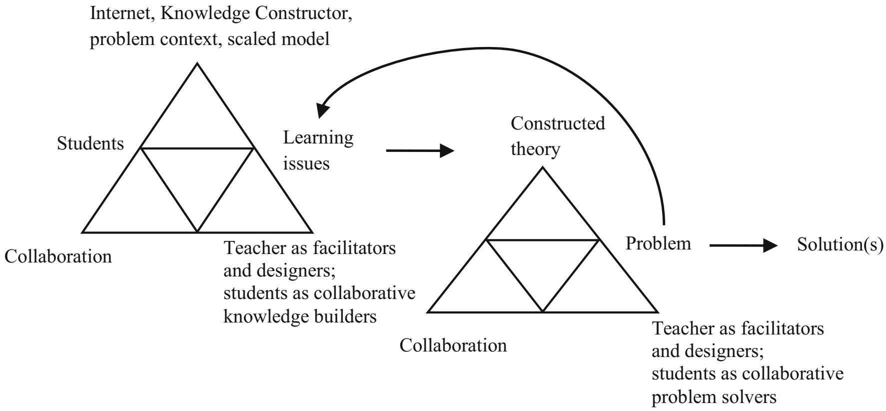

Fig. 9.8 Interdependence between theory-building activity system and problem-solving activity system

building, while the outcome of knowledge building provides the tools needed for meaningful problem solving. In other words, the findings of this study show that the problem-solving and knowledge-building processes are codependent as the absence of any one of the processes will restrict the goal to either content mastery or problem solving. The interdependence between the two processes implies that each functions as a tool for the other and also as a focus of attention in its own activity. Without problem solving, the knowledge constructed in the knowledge-building activity has no functional use, therefore rendering the activity to lose its use value. With the absence of knowledge building, problem solving may be reduced to haphazard trial and error or mere functional know-how, which may not be generalizable to other situations, thereby reducing the usefulness that a problem-solving activity may provide. While this study has not shown that the knowledge resulting from THINK Cycle 3 may be generalizable to other problems, the kinds of knowledge constructed make application more probable than in THINK Cycles 1 and 2. Therefore, the integration of the two activity systems in PBL situated in the knowledge creation paradigm provides an effective bridge between the tension observed between content and problem.

Discussion and Conclusion

The purpose of this study is to refine the pedagogical approach of PBL to support science meaning making more effectively through three cycles of design research. Through the three research cycles, three designs of THINK cycles were observed. THINK Cycle 1 was a linear enactment of the five stages of presentation of trigger, lectures of intended disciplinary content knowledge, practicing on given problems and trigger problem, and, finally, presentation of solution. The enactment did not

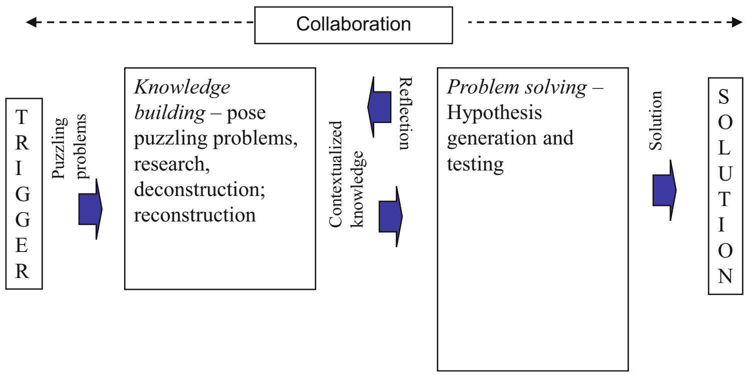

Fig. 9.9 Knowledge creation-based PBL framework

result in deep understanding of the knowledge, development of skills, or any significant transformation in pedagogical approach. The reason was traced to the contradiction between content and process as the teacher and students were torn between a focus on mastery of disciplinary content knowledge for examination purpose and development of problem-solving and learning skills. The design of THINK Cycle 2 was intended to return to the constructivist's roots of PBL. The problem trigger formed the center of the activity. The result was a strong focus solving the problem, with exploration of learning issues observed during the harness stage. Students also did not seem to collaborate effectively with one another. In the THINK Cycle 3, the principles of knowledge building were introduced; in particular, the advancement of knowledge was introduced as its motive. Instead of a linear enactment of the five stages of PBL, the knowledge creation framework integrates the processes of knowledge building and problem solving to orchestrate science meaning making, with an iteration between knowledge building during the harness stage and problem solving during the investigation stage. Figure 9.9 describes the framework of this knowledge creation-based PBL.

Supporting this knowledge creation activity are a collaborative setting, authoritative sources, and the problem context. It was found that students were able to develop a deeper understanding of the intended disciplinary content knowledge and were able to work collaboratively with one another in the problem solving. Table 9.3 summarizes the design and contradictions observed in each research cycle.

The three research cycles revealed how science meaning making could be supported. The first two research cycles showed that neither focusing on knowledge nor social processes in PBL seemed to support science meaning making in high school adequately. Rather, a focus on the transformation of knowledge through social processes of learning provides the structure needed for science meaning making to take place. In this respect, the principles of knowledge building provided the mediating structures to support students developing meaningful and creative use of knowledge in the service of problem solving. The principle of advancement of knowledge helped to direct students' attention toward developing a deeper

Table 9.3 A summary of the design and contradictions of each research cycle

	Cycle 1	Cycle 2	Cycle 3
Key design features of the instructional approach	Lecture and drill and practice of intended content knowledge	Trigger problem as the center of activity	Emphasis is placed on advancement of cognitive artifacts – content and solution
	Problem trigger provided as additional practice for the intended content knowledge	Exploration of learning issues was encouraged through problem solving	Structuredness in theory building and problem solving to support students' self-directed learning
		Collaboration was mediated through the use of Knowledge Constructor	Collaboration was mediated through the use of Knowledge Constructor
Contradictions identified	Content-process divide: pedagogical approach remained didactic despite that a constructivist approach was adopted. This was due to a strong focus on content mastery over the development of problem-solving skills	Content-process divide: a stronger adherence to the principles of PBL resulted in students focusing excessively on arriving on the solution without much exploration into the intended content knowledge to learn. Students were unable to direct their attention on pertinent learning issues and lacked the skills to collaborate effectively	
Interventions to be introduced to the next THINK cycle	Returning to the roots of PBL by engaging teachers and researchers to work jointly in understanding and designing PBL activities	Introduction of KB principles – collective knowledge advancement and epistemic agency	

understanding and use of the intended disciplinary content knowledge in the context of problem solving. In addition, the focus on theory building during the harness stage and problem solving during the investigation stage seemed to provide the structure for students to overcome the difficulties of directing their attention on learning issues and problem solving during the THINK cycle activity.

Besides showcasing the principles of knowledge creation in the design of THINK cycle, this study also aimed to construct and refine the theory of PBL. Through design research, the model of PBL for school science learning was constructed and refined through the three research cycles. The analytical lens of

CHAT provided the framework for this expansive learning (Engeström 1987) of PBL.

Finally, as a case study within a design research, further studies need to be conducted to better understand the necessary supports needed to mediate students' learning in science better. Further theorizing and empirical research are needed to refine the proposed framework of PBL and to deepen our understanding of how PBL supports science meaning making.

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Chapter 10
Knowledge Creation in the Mangle of Practice: Implications for Educators

Yew-Jin Lee

Introduction

Educational improvement research is a persistent worldwide problem that uses all manner of resources to understand and enhance student learning. Under most circumstances, solutions derived from the research community (from efficacy studies) are disseminated into schools for their implementation under real-world conditions (during effectiveness studies). These interventions have been equally diverse and myriad although at their heart, they are united in increasing the frequency and intensity of quality learning. And because of the widespread appeal of educating learners in twenty-first-century competencies, policy discourses about knowledge reproduction (KR) modes in education have fallen out of favor, and in its place, knowledge creation (KC) philosophies are on the ascendant. The former speaks about the memorization and correct recall of knowledge that some have dismissed as inert knowledge, whereas the latter is believed to better prepare youth to learn as well as to relearn and to be ready for the many unanticipated problems in the future.

Knowledge creation is also said to be undergirded by expansive learning, a form of acting in the world that generates qualitatively new knowledge by individuals or institutions. This desirable form of knowledge simultaneously changes the collective when it returns and transforms the community, thereby enabling yet more radical learning to occur (Engeström 2011; Lee and Roth 2007). Despite the promise of KC to enact societal-level transformations as mentioned, its track record has been rather limited and we have yet to witness widespread implementation of KC in school settings.

In this chapter, it is claimed that one reason why classroom success using KC has been so elusive is because social practices in complex systems such as schools

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operate squarely within Pickering's (1995) mangle—a complex interplay of human and nonhuman agency—and are therefore often resistant to large-scale transformation. Accordingly, I describe four case studies where epistemic projects or objects were a focus of collective activity and the associated challenges during these processes of change. While it is impossible and indeed undesirable to suggest any single solution to unlock KC barriers in schools, my findings affirm that the formation of new or enlarged epistemic objects as well as the co-transformation of learner/institutional agencies are emergent, fragile, and unpredictable. This therefore calls for stakeholders to gain a deeper understanding of the production, circulation, and exchange of sociomaterial resources during (epistemic) object-centered activity. By so doing, one can perhaps free up its back-and-forth movements, to complexify its links/relations with other sociomaterial resources to build even richer epistemic objects although I do not suggest that the ability to control these resources is necessarily coextensive.

In what follows, I describe the transition from understanding knowing as discrete properties of individuals toward more holistic accounts that involve people eternally acting with artifacts/representations in sociocultural (i.e., sometimes called sociomaterial) contexts. Attention is then devoted toward cultural-historical activity theory (CHAT), which is a framework that foregrounds a sociomaterial perspective of knowing. The strong interrelationships between activity theory and knowledge creation are then unpacked, especially in terms of their focus on objects and creative human agency during transformation.

Knowledgeable Practices: People Acting in Contexts

Human consciousness is believed by learning theorists to be woven into seemingly mundane tasks like writing a letter, cooking, shopping for groceries, or using a spreadsheet, which past psychological analyses had either relied upon social or cognitive factors to explain behavior. Understood this way, psychology had often dualistically opposed the two or made one the causal effect of the other. In fact, much of the explanatory power in accounting for mastery was lost when researchers were forced to choose between "smart people" or "smart contexts" to explain skillful actions, ability, and talent (Barab and Plucker 2002). In contrast, some of those in the sociocultural camp recognize that cognition arises neither solely from the environment nor from within an individual; instead, intelligent behavior is co-constituted during the transactions between the historically constituted settings of activity and persons. This position that dismisses the possibility of Robinson Crusoes operating as self-sufficient cognitive monads underscores the importance placed on sociocultural factors over one's genetic heritage or unseen psychological phenomena.

The Soviet psychologist Lev Vygotsky built upon these ideas and proposed that the origins of higher mental functioning proceeded from the inter- to the intra-psychological plane. By way of example, a child begins by learning (i.e., acquiring preexisting cultural knowledge) with the assistance of an experienced peer or adult. In time, the child is able to perform the same tasks without guidance once this knowledge or more precisely the tools of that culture (e.g., language, norms, traditions, rituals) are internalized (see Lave and Wenger 1991, pp. 47–52). In this theory of semiotic mediation, competency is especially marked by the concept of the *sign* (e.g., language that Vygotsky regarded as the "tool of tools"), which is a psychological device that is used in regulating internal mental behavior from the outside so to speak.

Some researchers however deny that there is an "interior" or "exterior" for learning to traverse and that human thought and behavior always contain both elements, dialectically. For instance, actions such as classroom discussions involve the use of language, which is fundamentally a social tool (*langue*), and at the same time a unique and concrete realization by a student of the myriad possibilities of speech that are open in that culture (*parole*). And since actions relate both to collective activities while being realized by chains of embodied operations by a person, this further makes it impossible to partition what is interior or exterior or, for that matter, individual or collective. This holistic view means that it seems preferable to describe those learning situations such as found in classrooms as joint participation in a common activity (i.e., being educated) using historically situated tools and artifacts with the chief outcome being to increase subject-matter literacy. Learning and expertise, which are better defined as knowledgeable practices or knowledgeability, are now seen as stretched over people, artifacts, practices, events, and generations (Hutchins 1995; Lave 1988). This recent perspective flies against conventional views of intelligence that are housed within human minds, which privilege the transmission of information from those that know to those that do not. Moreover, this sociomaterial viewpoint of learning gives equal priority to human and nonhuman agency to which we elaborate in the next section.

The Missing Artifacts in the Landscape of Knowledgeability

It was not long ago that Yrjö Engeström (1999, p. 29) invited researchers to make a "serious study of artifacts as integral and inseparable components of human functioning" insofar as Cobb et al. (2003, p. 14) reported that "the use of tools and artifacts is a relatively inconspicuous, recurrent, and taken-for-granted aspect of school life." This is not to deny the importance of examining knowledgeability as a holistic unity of people acting in contexts; it simply foregrounds how these "things" and "matter" that I cluster under what I call sociomaterial resources or artifacts are ever present in what we have labeled human cognition. These coextensive resources are manifold and can range from something as routine as a well-designed hammer that already in its construction affords the best swing to that as technically sophisticated as a smartphone with its arsenal of apps. Simple albeit universal social norms such as queuing in line or raising a hand to signal a question in class can be regarded as sociomaterial resources too as they help organize human behavior in patterned and recognizable ways. In other words, these resources or artifacts already contain within them accumulated human wisdom, which flattens the distinction between human and nonhuman intelligence as we know it. Sociomaterial resources can visibly impact learning in communities when (a) they are assembled in collaborative retooling (Miettinen and Virkkunen 2006), (b) both the individual and the community mutually experience expansive learning (Engeström 1987), and (c) these resources demand and control human behavior, affect, and cognition (McDonald et al. 2006; Wenger 1998).

Another clear indication that these sociomaterial resources are indispensable for much of human cognition is when they "break down" with resultant paralysis and chaos (Koschmann et al. 1998). Precisely because these beliefs, representations, artifacts, and other products of human life are so mundane that they have become unproblematic or "black boxed." Hence, these "missing masses"—nonhuman actors that participate in the functioning of human cognition and societal life (Latour 1992)—are so easily overlooked, even in school, which many regard as a center of learning. New research has shown that learning in communities is furthermore indeterminate and contingent; who is the expert in the classroom can quickly change because of subtle variations in accessing these resources through individual and collective actions (Boyer and Roth 2006; Tobin et al. 2005). Thus, as classroom settings are continuously changing due to the local production of resources, it similarly opens (and closes) up the possibilities for learning and identity for some participants. These results demonstrate that more research is certainly needed with this new post-humanist lens to identify what and who is learning moment by moment, day by day.

From a KC stance, this close attending to sociomaterial resources and artifacts furnishes many benefits in that it makes explicit the interactions between agency and structure (Nonaka and Toyama 2003), the dialectic between tangible action and intangible possibilities, and between latent and empirical knowledge (Hargadon and Fanelli 2002). The dialectical framework in KC (also paralleled in CHAT) has been argued to be able to transcend the long-standing frustration of choosing between memorization and membership as the modus operandi in accounting for learning processes. Once we gain a deeper understanding of the production, circulation, and exchange of sociomaterial resources during (epistemic) object-centered activity, it is hoped that this can translate into strategies for making richer, more diverse/unruly objects that catalyze learning in unpredictable paths (cf. Engeström 2008). I now explain more about cultural-historical activity theory, which is a framework that depends on a sociomaterial perspective of knowing.

Cultural-Historical Activity Theory as a Sociomaterial Framework

One of the guiding principles in CHAT research is the notion of activity as the essential determinant of cultural change and psychological evolution (Cole 1996; Roth et al. 2009). Accordingly, activity is taken to be the molar or minimal unit of analytic interest and can encompass large frames of reference such as schooling, doing commerce, and making war and smaller frames such as gaming, sport, and other mundane aspects of life on the opposite end of the spectrum. What unites these diverse levels and settings is the focus on the concrete, situated, and processual nature of the activity rather than forms of armchair theorizing or clinical experiments to gain insight into human psychology. Activity theorists do not dichotomize the social and the material world, for culture and human learning are deeply embedded in and enmeshed with materiality (Wartofsky 1979).

How does one then analyze learning using CHAT? What are the conceptual vocabularies and heuristics available? Human activity here is always understood as motivated toward some collective *object*; when objects are absent, there is no activity to speak of. In the *activity system* of salmon biological research, for instance, the object or motive of the activity system is to perform research and to produce some salient experimental findings so that an acceptable publication like a journal article emerges as an *outcome* (see Fig. 10.1). Cultural-historical activity theory differs from other theories in that it specifies a range of entities that may provide structure to human actions. For instance, within the unit of activity, one finds structure in the form of the *subject* (that which possesses agency) and the object (that which is transformed). Subject and object are not two different things but have to be considered as the nonidentical aspects of a unit. In Fig. 10.1, we can see how the other four moments or entities belonging to an activity system further mediate the relationship between the primary axis of subject/object. As each of these six mediating moments in the system that are equivalent to sociomaterial resources evolves during activity, so do the relations between them, and as a corollary, changes occur within the entire activity system. During favorable circumstances, this results in *expansive learning*, or traversing the zone of proximal development especially in the context of organizational, multiagency learning. It is this dynamic relationship of emerging and contingent tools, the object being (re-) produced, and the concomitant transformations of social relations and cognition in communities that lies at the heart of CHAT research in learning.

To date, CHAT has often been used as a descriptive template in research on technology-rich learning environments or to inform how the notion of contradictions can push (or not) the activity system forward. Either way, there is a dearth of actual explanations to specify how sociomaterial resources that make up an activity system concretely change and effect learning even though they themselves are impregnated with knowledge so to speak. Indeed, I claim that we are no nearer in concretely describing a sociology nor psychology of human/nonhuman during learning although this seems fundamental to unpacking KC. In my field of science

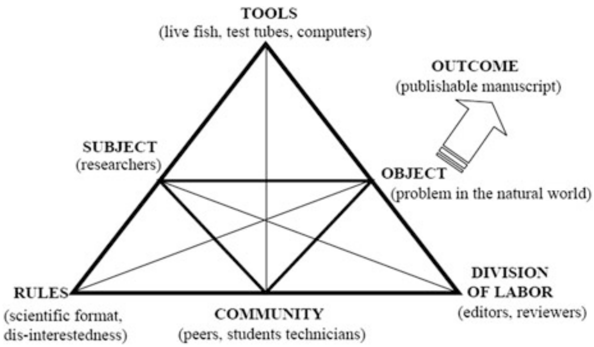

Fig. 10.1 A depiction of an activity system—the minimum ontological unit of analysis—using a hypothetical example drawn from conducting scientific research in salmon biology. This is a commonly used heuristic in activity theory known as the "activity triangle" (Engeström 1987)

education, this problem does not appear to exist because it has not even shown up on the radar of a number of researchers that there exists a mystery to be solved in the first instance. That is, displayed ability in science tests is normally attributed to internal traits or attributes. However, if one were perceptive, the important work of Stella Vosniadou and her colleagues (e.g., Vosniadou et al. 2005) would have alerted scholars that the simple provision of a concrete object such as a globe or balloon completely changes what students can articulate about scientific concepts to an interviewer (Givery and Roth 2006). What this line of research has shown, albeit in an indirect way, is that cognition extends beyond the brain to the material world surrounding the subject—knowledge is in *and* out of the human body. Within the field of education, the difficulty, of course, is to know how, when, and under what circumstances can these sociomaterial resources emerge and fruitfully participate in human learning as object-oriented and expansive learning activity, which is the central purpose of KC.

What Is Knowledge Creation?

In two important articles, Hakkarainen (2009a, b) outlined how KC was an educational paradigm of/for learning that went qualitatively beyond earlier acquisition and participation metaphors of learning. Adopting a "trialogical" focus, KC sets itself apart from the aforementioned approaches when individuals are said to act together within a certain community to advance or develop what is called "knowledge-laden or epistemic artifacts" (Hakkarainen and Paavola 2007). These can take many forms ranging from something as commonplace as an idea to act ethically to science lab reports to student-constructed models of airplanes. In some cases, these are facilitated by nothing other than a textbook and other everyday artifacts although its mediation by Computer-Supported Collaborative Learning (CSCL) certainly represents a sophisticated and easier pathway. Important here is that human knowing and learning are regarded in KC as object centered as well as knowledge laden because of the dialectical relationship between the intentional doing (i.e., acting on the world/transformation) and reflection upon that process—"the focus is not on the certainty of knowledge but how knowledge is used and how it is developed" (Paavola et al. 2004, p. 70).

In this sense, KC is both an ontology and epistemology of knowing that traces part of its roots to Marxist dialectical-materialist thought ("we act intentionally on the world as much as this process changes us in terms of consciousness, sociality, identity") although support from recent philosophy, social studies of science, modern organizational studies, and others can be easily summoned (Hakkarainen 2009a, b). It prioritizes the synthesis and application of existing/novel knowledge configurations as compared to its mere recall or transfer by students. It also facilitates collective knowledge advancement yet with personal meanings rather than just information dumping by learners during examinations. Apart from the aforementioned characteristics, other defining features of KC as a novel and joint meaning-making process include:

- Sustained, long-term engagement with knowledge advancement
- Cross-fertilization of knowledge practices among participants
- Enabling mediation especially with the affordances of technology (see Hakkarainen and Paavola 2007)

The progressive development of knowledge/conceptual practices and knowledge/conceptual artifacts that effectively change the object of activity can help us overcome some enduring problems with regard to the existing narrow cognitive or person-centered focus of change and the threat of merely reproducing rather than critiquing historical practices of learning (Fenwick et al. 2012). Thus, educators need to encourage the creation of new tools, artifacts, and practices (i.e., the sociomaterial) for community knowledge to advance. In order to facilitate knowing as a social practice in KC (see Knorr-Cetina 2001), it requires the involvement of both human and nonhuman actors. Said differently, we need to shift our attention from the mind as container to examine how people collaborate and develop knowledge-laden resources and how these are simultaneously changed by those very same actions. We need therefore to incorporate the mediation of the sociomaterial in our explanations and look beyond the false dichotomy of smart people or smart contexts. And compared to the growth of knowledge by addition—"an organization learns in only two ways: (a) by the learning of its members, or (b) by ingesting new members who have knowledge the organization didn't previously have" (Simon 1991, p. 125)—knowledge growth in KC is organic and can grow exponentially such as how the Internet has radically changed the face of education.

Objects of Activity and Epistemic Objects: CHAT and Knowledge Creation

At the risk of oversimplification, my assessment is that the theoretical lifeblood of KC essentially draws much from CHAT (and knowledge building), especially when the object of activity is epistemic in nature (see Hakkarainen and Paavola 2007; Hakkarainen 2009a, b). By epistemic, I take that to mean when the activity has the potential to generate or develop additional sociomaterial resources/artifacts such as in the form of representations, which the scientific enterprise epitomizes very well (Rheinberger 1997). Teaching and learning activities such as those found in schooling, as a rule, would tend to favor the mastery of abstract forms of knowledge in the form of representations, specialized languages, and other sign systems. It is important to note that we are speaking of the production of new sociomaterial resources at the limits of the learner's knowledge rather than their mundane memorization by learners that is KR by another name.

This downplaying of everyday, practical knowledge is not to be seen as totally negative or restrictive because abstract knowledge allows learners to rise beyond the confines of personal experience to gain important theoretical or context-independent knowledge, especially those found in the subject disciplines. At no time am I suggesting that informal learning environments such as museums or even workplace and factory shopfloors cannot generate epistemic objects and practices—they certainly can as we show later in the case studies—but educational institutions usually provide opportunities for their development better than others (Young 2007).

Together with actor-network theory (ANT), complexity science, and spatiality theories, CHAT as part of sociomaterial-based theories therefore places a premium on:

- Taking a whole systems approach
- Tracing interactions between all components in the system
- Knowledge and learning as consisting of material actions and interactions only (Fenwick et al. 2011)

The last bullet point is especially salient for genuine knowledge advancement according to Hakkarainen (2009a, b) as it is an ideal/conceptual process as well as a material/physical one (cf. the object appears twice [Leont'ev 1978]), which usually precipitates into what is known as "epistemic things." These epistemic objects are myriad, for example, when students engage in a science project or something as complex as working with a particle collider. On the one hand, these objects have material or technical affordances that allow them to be used in certain temporally stabilized or expected ways such as when learners use a slide rule to perform calculations or when they consult an encyclopedia for information. At other times, these "objects of knowledge are characteristically open, question generating and complex" and are "processes and projections rather than definitive things" (Knorr-Cetina 2001, p. 181). This lack of completeness is apparently a sine qua non because genuine epistemic objects or practices are partially known and partially unknown in a continuously unfolding process. To be sure, it is only when such knowledge objects are incomplete that they can capture the need, curiosity, or pleasure of stakeholders, thereby allowing and motivating them in their pursuit. Following Bereiter (2002) who has inspired many of the foundational ideas in KC, these knowledge objects become powerful when people orient themselves to these in a continual effort at improvement (i.e., making new representations) apart from being accessible or public in nature.

Examples of knowledge practices include financial markets (Knorr-Cetina 2001), proposing new mathematical formulae (Pickering 1995), obdurate biochemical processes (Miettinen 2005), and problems written on the blackboard by a teacher to be solved by pupils (Kalthoff and Roehl 2011). As a science educator, one exemplar that rather elegantly capitalizes on this iterative cycle of material resistance (Pickering 1995) and reflection/critique as precursors of deep learning in science is design-based inquiry whereby students are posed a challenge to successfully construct a prototype or working artifact. Rather than front-loading concepts and theories that might not even be used, scientific knowledge is now only appropriated just-in-time as children collaboratively make the object of the activity their personal motive for engagement. In this contrarian but highly effective manner, learning then becomes the by-product of activity rather than its original motive (Cole and Distributed Literacy Consortium 2006).

Not only are true knowledge objects perpetual works-in-progress and have multiple forms of being (e.g., simultaneously in a representation, blueprint, and material object), but they are often multiple, allowing different actions to maintain the same object as well as serving different objects concurrently. For instance, a new science curriculum appeared primarily as a means of having fun to some students whereas their teachers saw it as a vehicle of learning and a source of institutional pride (Lee 2011). In short, activity theory and KC are very closely aligned as they share a common theoretical language to characterize innovations involving sociomaterial resources and the pursuit of epistemic objects of activity.

Forming the Epistemic Object(s)

If my claim that KC and CHAT are fundamentally parallel although the former primarily deals with epistemic objects and practices, then we gain a much easier purchase into the field by examining accounts of how knowledge objects were created, pursued, and transformed and the sociomaterial resources that were involved/generated. This is none other than Marx's method of starting from surface features to uncover any deeper underlying ideas behind a social phenomenon. It is unlikely and indeed undesirable that one can derive causal or technical-rational explanations of KC processes but appreciating the operating conditions and problems will at least afford us insights into the problem of educational change. The latter is a notorious mangle of human and nonhuman agency that often resists large-

Table 10.1 Four case studies of epistemic objects and practices in the mangle of practice

	Helen and her at-risk science class	Using annotated lesson plans	The nature learning camp	Salmon enhancement in British Columbia
The epistemic object	Students' meaningful learning of science through inquiry Students and teacher jointly participated as a community in this particular object	Annotated lesson plans—these are both the object and outcome of ongoing activity	Students' knowledge of science and the environment through the NLC program. Learning was the object of activity, which was not just epistemic but also transformational as it changed these students and the local community through raised awareness of the environment	Pacific salmon and the myriad practices (relations) and representations tied to this creature
Problems/ challenges in the mangle	Many sociomaterial structures such as learning disabilities among learners, societal and school expectations of achievement, and the lack of support among other teachers that these students could indeed learn science well	The creation of a shared set of goals among multiple stakeholders such as what repertoire of competencies that teachers need to teach effectively, the sustained motivation toward this object of activity as well as equitable distribution of rewards/benefits along this journey of learning	Overlapping object of activity for different agencies—boundary object Catering to different interests of students/teachers Tension of learning for school exams versus learning about the environment and pursuing one's own interest in science	Different object of activity for different agencies and people. Salmon means different things depending on the observer Overall tensions of food production versus fish conservation, massive versus small-scale production, and technological versus natural production of salmon

(continued)

Table 10.1 (continued)

	Helen and her at-risk science class	Using annotated lesson plans	The nature learning camp	Salmon enhancement in British Columbia
How were/can the sociomaterial resources be invoked	Helen worked in the interstices of top-down structures to create small epistemic communities	Multiple sources of innovation are welcomed, e.g., from teachers, researchers, that can address common problems of learning	Students were generally given much agency during inquiry, thereby enhancing learning	Pacific salmon are under overall charge of the federal government although when and by whom useful knowledge appears cannot be anticipated fully. Still, innovations/knowledge from various institutions and people can be brought to bear on common problems, i.e., cross-fertilization of ideas
	Students were given high levels of agency	Freely circulating lesson plans for annotation by instructors	Forming new connections and relations with multiple agencies, catering for their needs and expectations	

scale transformations, that is, existing objects are stable (Lee 2011). This section therefore examines four accounts of case studies where epistemic projects are/were a focus of collective activity and the associated challenges (see Table 10.1). I show that the formation of new or enlarged epistemic objects as well as the co-transformation of learner/institutional agency is emergent, fragile, and unpredictable. Because the cases are drawn from rather incongruent scenarios where a casual observer might find it difficult to find any evidence of KC or indeed pinpoint what is the exact object in question, they are arguably more powerful in this respect.

The first study describes the meaningful learning of science as an epistemic object by a "radical" science teacher and her class of struggling elementary students in Singapore. Based on the author's research on teaching in the so-called in-between spaces of curriculum and policy, it makes the claim that an expansive object—student mastery of science via inquiry—can be identified in units as small as that of a single classroom. My second case is a somewhat hypothetical one as it lacks widespread adoption by teachers though not necessarily supporting proof of concept data. Annotated lesson plans are thus an interesting and viable proposal by two American mathematics educators that sit squarely inside how we have characterized epistemic objects and practices, here the production and circulation of ideas by teachers for improving student learning. Compared to locating the object within a classroom, this particular epistemic object now seems more congruent with what we normally consider as part of the activity system of schooling with identifiable societal subjects, tools, rules, community, and the division of labor to produce an outcome. The location of epistemic objects and practices within schools alone, however, need not be the chief criteria for the emergence of knowledgeability and their associated practices as the next two case studies illustrate.

A boundary object arising between formal learning of science in school and understanding environmental principles gleaned from the field; the Nature Learning Camp (NLC) project transcended the rigid walls of content matter, space, and time that have typically confined student agency in local schools. And because the grade 3 and 4 learners here largely raised their own research questions from their personal observations of nature, these outside-curriculum science investigations ranged from the quirky (e.g., "what happens when meat rots") to the sublime (e.g., "effects of rain on soil erosion"). School science often denies opportunities other than verification-style laboratory activities; therefore, student learning in this project was arguably an epistemic object, an amalgam of canonical school knowledge, and conservation/ecological science. The final case study is the most wide-ranging—spatially and temporally—as it involves the creation of a unique knowledge object within government, nongovernment organizations, and concerned citizens in Canada. United in purpose to increase the numbers of salmon fish, these institutions and people over the course of decades have generated vast amounts of knowledge (canonical and non-canonical representations) about their quarry, which in essence was a living epistemic object surrounded by multiple practices for its bountiful cultivation and well-being. The reader would have already guessed correctly that this process has not been smooth; failures have outnumbered successes more so with the imminent threat of climate change and three systemic contradictions that have continued to plague the mangle called salmon enhancement over the past century.

Learning Science Among At-Risk Children as Epistemic Object

Although it might seem unusual to consider how learning within a class of failing and at-risk children might be regarded as an epistemic object, there are some compelling reasons to do so here. In Lee (2008), I describe how Helen was the elementary science teacher in charge of a group of children who were practically written off by other teachers in the school due to their poor academic abilities. Labeled derisively as an unteachable EM2.9 class,[1] half of the students here were

[1] EM3 was then the weakest of the three streaming bands in primary schools in Singapore comprising 7–8 % of the cohort. Thus, EM2.9 indicated that pupils' abilities were bordering this highly unpopular category.

reported to be clinically diagnosed with learning disabilities. However, Helen volunteered to be their science teacher, persevering on over two years despite the objections of colleagues who viewed her many inquiry and student-centered activities with doubt, if not disdain and some antagonism. What happened was that learning science in this class gradually changed from mere coverage of the syllabus and worksheet completion (of which she was once reprimanded for failing to meet mandated targets) toward a deeper, personal understanding of science so much so that the kids frequently moaned and complained whenever they were not learning via inquiry. Inquiry (a mix of hands-on and minds-on activities) is the acknowledged hallmark of modern science instruction although its adoption in schools around the world has been patchy and problematic due to a variety of factors such as the lack of resources (time, equipment, etc.), teacher and student unfamiliarity with the pedagogy, and the presence of high-stakes examinations.

In Helen's class, the students often took charge of their own learning to the extent of telling their teacher what they wanted and deciding on the means as well as the learning objectives for their science lessons. They once requested, and successfully pulled off, their own mini-science fair where groups of students showcased their self-chosen scientific investigations, which was no mean feat for these pupils. At other times, with guidance from Helen, they not only learned the canonical solution sets from the workbooks such as the right configurations of electrical circuits to make bulbs light up but also explored faulty and incorrect circuits in which the bulbs could *never* be lit. And when she discovered that her students did not have any art lessons the previous year, she taught them simple table drawings, incorporating them into making concept cartoons to learn about the topic of ecology. Through these fun and interesting activities as the driving motive of classroom activity, the meaningful learning of science here became the offshoot of inquiry.

It was pleasing to hear that all these learning episodes were ultimately consequential because these students managed to garner high grades in the terminal standardized tests at the end of grade 6, falling just behind those in the top two classes who were previously handpicked for their academic aptitude. It is therefore my contention that Helen and her students together acted in the spirit of mastering scientific literacy in the intertwined domains of the conceptual, epistemic, and social. Her method of working in-between the cracks of top-down structures in Singapore probably achieved much more than had Helen stuck to the ubiquitous drill-and-practice strategies that her colleagues were adopting without much protest. It would further appear that her colleagues made their object of activity a relatively uncontested one of getting good grades in the terminal examinations whereas Helen and her students, with perhaps nothing to lose so to speak, oriented toward a seemingly unattainable goal of the learning of science via inquiry as their expansive object. While it might be counterargued that what the students mastered here was already established knowledge, and a very elemental form at that, the students were operating at the limits of their knowledge—they were truly working in KC modes with multiple expressions of learner agency and identity. It should also be remembered that this was by no means an easy victory for the students as institutional and societal definitions of achievement, prevalent tried-and-tested teacher-centered pedagogies, and the climate of accountability had nearly prevented an unconventional teacher like Helen from teaching in the way that she felt science ought to be taught. After some years, we were told that Helen left that particular school due to the lack of collegial support in attending to the needs of these kinds of at-risk students.

Annotated Lesson Plans

Another project involving epistemic objects in education can be found in the promotion of annotated lesson plans as a means of uplifting teaching practices and student learning across and within schools. In order to build up a useful knowledge base for teaching (with implicit reference to Bereiter (2002)), Anne Morris and James Hiebert (2009a, b, 2011) have encouraged the use of these enhanced lesson plans. These teacher annotations inserted into lesson plans will take the form of tips and advice on students' problems when studying their learning needs, and other teaching suggestions, which in ideal situations are continuously revised or commented upon by colleagues. Of course, teachers are advised to state explicitly the learning goals in these lesson plans so as to inform the selection and implementation process. And by so doing, the evaluation of student outcomes then becomes amenable to scrutiny, which further benefits evidence-based instruction and long-term improvement.

Since these lesson plans are meant to be freely shared or made public in a school or district, they therefore serve as tangible epistemic objects to hasten educational change for the community—they are both the object and outcome of activity. Because teaching conditions undergo constant change (i.e., classroom dynamics are never the same even within a school year), these knowledge products can track "what works" and other useful knowledge practices. By advocating a specific course of action, annotated lesson plans also minimize variations in instructional practices, which are said to be a significant hindrance toward large-scale reform efforts. As epistemic objects, these annotated lesson plans are indubitably "testable" and open to transformation; various stakeholders such as teachers or researchers are welcome to propose innovations based on the collective experience and evidence accrued on repeated tests of say a certain pedagogy tried across many classrooms (i.e., the "common problem"). In this way, one can seed the formation of a virtuous dialectic; local contextualized solutions inform, often in incremental or small ways, more generalized theories of practice that are then (re-)assessed under different operating conditions that they manifest themselves.

Although presently uncommon in American classrooms, the authors have encouraged the wider adoption of annotated lesson plans for knowledge/capacity building as a normative routine for all teachers as opposed to most interventions merely being externally imposed add-ons by policymakers. Some major threats remain as identified by Morris and Hiebert (2009a); the creation of a shared set of goals among multiple stakeholders such as what repertoire of competencies that teachers need to teach effectively sustained motivation toward this object of activity as well as the equitable distribution of rewards/benefits along this bumpy journey of learning. Despite these various challenges (not least being the absence of large-scale implementation in schools as incontrovertible proof that it works), this particular knowledge-increasing object enjoys the author's endorsement.

The Nature Learning Camp (NLC)

The Nature Learning Camp (NLC) started off as a local reforestation-stewardship event in 2000 to allow about 80–150 school children (primary and lower secondary levels) in Singapore a yearly chance to learn environmental science and conservation values in an outdoor setting. Compared to the largely cognitive goals in the formal school curriculum, the NLC offered affective and social learning outcomes through four short science experiments conducted in a patch of rainforest. The activities were planned by teachers for students to carry out in a round-robin manner and included soil studies, stream sampling for invertebrates, assessing water quality, and leaf counting, which typically did not appear in school science. Its success also lay in the volunteer efforts of biologists, school teachers, and two governmental bodies (National Parks Board and Public Utilities Board) in orchestrating this 1-day event whereby students could behave like scientists and conservationists. At the end of the NLC event, the participants come together for a debriefing and presentation of their results from the activities.

With Dr. Jennifer Yeo and the author, we modified the program in 2008 to increase participation and depth of learning by extending the NLC to include knowledge-building activities (over a school term) in four primary schools (Yeo et al. 2011; Yeo and Lee 2012). With care for the environment and rainforest as a broad intellectual anchor, groups of children in grades 3 and 4 were freely encouraged to raise questions about any biological phenomenon in the forest or school garden that piqued their curiosity. After getting group consensus about which of their many questions were most interesting, they then proceeded to conduct small group investigations using the Internet, consulting experts such as family members, and with simple lab equipment with some teacher guidance. Their learning trajectory was enhanced by Knowledge Forum software, which facilitated knowledge building over the weeks. With the freedom to explore, the children pursued their own inquiries; investigations covered plant growth conditions, soil erosion, plant density, earthworms and soil fertility, food chains, and meat decomposition, among many others. They relied on canonical knowledge from school textbooks as well as making sense of information found outside of formal contexts, which ranged from folk knowledge from family members to scientific research found on the Internet. At least for some groups, their knowledge trajectory increased many levels beyond their peers in the same age group as they explained their observations with data, revised their hypotheses, and repeated their investigations.

At the end of the project, there were debriefing sessions carried out at the four respective schools although in one year a symposium was organized where scientists were invited to judge and comment on the quality of the student presentations. With family and guests in attendance, the students experienced a moment of pride as the knowledge that they had collected/discovered was returned back to the community so to speak for inspection and revision. Feedback from participants indicated that they found the program enjoyable and that they had learned something interesting although we did not manage to quantify these forms of learning. We believed that by making the NLC project straddle between formal and informal science learning, this boundary object had allowed for the flourishing of a new epistemic object (student learning incorporating both school science and conservation/ecological knowledge) that would not have otherwise emerged. At the same time, tensions and challenges confronted such boundary spanning practices in Singapore that included but were not limited to high-stakes examinations, the valuing of canonical school knowledge, differing interests and experiences of students/teachers, and getting various stakeholders aligned toward the same object (i.e., there were overlapping objects). Very often, catering the NLC program to fit the needs of the four schools was a mangle of practice for the researchers as some teachers were more concerned with content learning of science while others were more tolerant of freedom of open discovery among students where they all could learn different things. In 2010, research funding for the project ceased; some schools have continued the NLC although adapted into a more manageable version, while others have stopped the program as their local teacher advocates have been transferred to other schools.

Salmon Enhancement in British Columbia

This case study is unusual among the others described here for two reasons. The first lies in its vastness of temporal, geographical, and epistemological spans that it covers (Roth et al. 2008). The second is that the epistemic object here is the Pacific salmon whose fate has been intimately tied with numerous human and nonhuman actors in British Columbia for millennia. In fact, the Pacific salmon is recognized as the supreme object of activity here as it draws upon and (re-)makes relationships of all sorts including identities, economy, materiality, science, culture, climate, space, and nature writ large. Yet, precisely because of its function as a valued sociomaterial resource, its numbers have been depleted with devastating consequences to natural food chains, commercial fisheries, and aboriginal communities along the coast. Since culture, history, and science were so closely intertwined with the salmon here, the author found activity theory a fruitful lens for his interdisciplinary doctoral research on learning.

Many solutions have been proposed to increase fish numbers with varying success over the last 100 years with the most complicated known as the Salmonid Enhancement Plan (SEP) that begun in 1977. Originally a highly technical albeit scientifically primitive venture, SEP manifested itself mainly as the construction of salmon hatcheries whose (artificial) product was the massive release of young fish into the ecosystem to boost adult populations. With very erratic outcomes from the SEP that have partially been attributed to climate change, the program has been toned down in the face of opposition from conservationists and new scientific evidence. Educational programs emphasizing habitat protection have instead blossomed while the building of hatcheries and other large-scale artificial structures have ceased. Although state-sponsored scientific research on the fish has been a regular feature in Canada to inform policies, it is clear that human interactions with Pacific salmon have experienced many tensions. In the vocabulary of CHAT, three inner contradictions are relevant in this story: food production versus fish conservation, massive versus small-scale production, and technological versus natural production of salmon.

Learning, in this case study, is then about how different government institutions, nongovernment institutions, and individuals have come together to address a common epistemic object in salmon enhancement through the enrolment of sociomaterial resources such as hatcheries and conservation outreach, thereby enlarging the activity of salmon enhancement into many new avenues. For example, existing salmon hatcheries do not merely rear fish but also periodically participate in scientific research. Having a strong practitioner bias (e.g., studies on optimization of rearing conditions), such work is still highly regarded as good science. At other times, scientists set model-based catch quotas that limit what fishermen and hatchery staff can harvest from the wild, which is a case of knowledge flowing from specialists to other players. Likewise, all schoolchildren in the province have an opportunity to rear young salmon fry in their classrooms for some weeks before personally releasing them into local streams, thereby gaining knowledge about fish biology as well as an embodied (and hopefully lifelong) sense of ecological responsibility.

The federal government is in charge of the overall status (and main producer of scientific knowledge) of the fish although when and by whom useful knowledge appears cannot be anticipated completely. For instance, conservationists have lobbied hard for the removal of dams along river and have in some cases been successful in their demands—scientists and politicians do not always have the last word. The salmon is thus not a unitary epistemic object for there is conflict and resistance when knowledge from one location flows into another. Imposed statutory fishing limits always invite doubts about the accuracy of scientific theories when fishermen see abundant stocks of fish right beneath their boats. Likewise, when hatchery workers (whose practical knowledge of salmon biology is often impeccable) feel that the time is ripe for the release of juvenile fry into the rivers, they grudgingly have to abide by scientifically calculated release dates while fish continue to die in their holding ponds by the hundreds daily. In such situations, calling the Pacific salmon an epistemic object that elicits learning among individuals and institutions is therefore warranted although it is one where all knowledge claims are undeniably tentative and contested too.

Discussion and Implications

The four case studies introduced in the previous section have a common focus—the creation and pursuit of epistemic objects and practices across settings that span canonical educational as well as nonschool contexts. Recall that these objects are "open, question generating and complex . . . processes and projections rather than definitive things" (Knorr-Cetina 2001, p. 181). Furthermore, they are said to have multiple forms of being and can generate additional sociomaterial resources such as in the form of representations/artifacts. By these aforementioned criteria, some of the objects here appear to be works-in-progress where learning still continues albeit unevenly (salmon enhancement) while others are theoretical projections (the annotated lesson plans) and yet others have ceased or been modified (Helen's class, the NLC). Again, some had a more public flavor involving knowledge movements and coordination across settings and people (annotated lesson plans, the NLC, salmon enhancement) whereas Helen's class was more restricted in this aspect. Generating additional sociomaterial resources related to the object of activity has also been varied: annotated lesson plans are both the object and outcome of activity, while the other three cases produced a huge variety of knowledge products such as project reports, scientific papers, and presentations that have enriched their communities.

In all cases, however, the production of new sociomaterial resources of all kinds had changed the activity itself and demonstrated the possibilities for collective transformation even if not always realized in the long term. In Helen's case, it was vivid proof that science learning could be achieved through inquiry in an East Asian developmental state rather than relying heavily on drill-and-practice modes just as the NLC project showed that science from informal environments could be reasonably grafted onto school science under certain conditions. Sustained educational change in the form of annotated lesson plans does not currently enjoy confirmation from large-scale studies, but nonetheless, it is a tantalizing recommendation that exemplifies much that we cherish in KC and educational change in general. And it is a growing realization that the cross-fertilization of knowledge practices among stakeholders in salmon enhancement has numerous benefits and should be encouraged although whose decisions ultimately prevail is usually a function of political power.

If KC advocates in school are looking for simple templates and solutions, none exists because the mangle called educational change is too unruly to be managed. What could be attempted is perhaps to understand as best as possible the range of sociomaterial components that comprise and sustain the epistemic object, to determine why and how it is distinctively "epistemic" in nature. At this point, one can then endeavor to expand the object—as an intellectual exercise or better yet in practice—by increasing its back-and-forth movements, to complexify its links/relations with other sociomaterial resources and systems (see Engeström and Sannino 2010). Having richer epistemic objects this way necessarily calls for the kinds of reflexive analysis of values and power, of acting phronetically that critical social scientists like Bent Flyvbjerg (2001) have suggested. Acting phronetically means not being able to anticipate all the solutions beforehand because not every answer can be prespecified nor is it desirable to do so. It is not gaining knowledge for knowledge sake, which is the aim of science, but knowledge creation combined with care that is what makes education so unique as a human activity. The four case studies in greater and lesser ways display care: a nascent ethics of the environment and its creatures or classroom plans and actions that make learning more humane or one that begins from pupils' needs rather than from external curricular dictates (Noddings 2013). What about the problems or limitations with regard to the future of KC as a theoretical construct? I can only say that being so closely aligned with activity theory exposes KC to the same questions that trouble its parent such as the appropriate level of analysis (societal, institutional, etc.) and the complexity of its conceptual apparatus that immediately come to mind.

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Chapter 11
Developing Student-Centered Teaching Beliefs Through Knowledge Building Among Prospective Teachers

Huang-Yao Hong

Introduction

The emphasis on cultivating more effective teachers who, in turn, will help to prepare more creative students to tackle future societal problems has become the focus of educational reform in many advanced countries. Teachers play an important role in education as the way they teach can directly and indirectly influence what and how students learn (Cooney 1994; Ernest 1989). The success of educational reform, therefore, depends greatly on whether teachers can perform their jobs productively and effectively.

All other things being equal, an important factor affecting teacher performance has to do with teaching beliefs (Thompson 1992). Given its importance as a major influence on the quality of teaching (Clark and Peterson 1986), it is beneficial that teachers are aware of the existence of different teaching views and beliefs. This is especially important for teacher-education students in Taiwan, who are used to receive a more conventional teacher-centered instruction (Hong et al. 2011). As such, they are generally not aware of alternative teaching views such as the constructivist-oriented teaching stance (Hong and Lin 2010). To help broaden their teaching views, it will be beneficial if they are guided to experience a more student-centered/constructivist-oriented learning process, which is in sync with the current education reform movement in Taiwan. Doing so may also help teacher-education students to be more willing to experiment with, and reflect on, more diverse instructional approaches. To this end, this study employed a constructivist-oriented instructional approach called knowledge building to help provide teacher-education students with opportunities to experience more constructivist-oriented learning and to reflect on their teaching beliefs. As an innovative pedagogy, previous studies suggest that knowledge building is likely to foster more

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constructivist-oriented learning environments (e.g., Chai and Tan 2009; Hong and Lin 2010; Hong et al. 2011). It is posited that, with proper course design, knowledge building can also help guide teacher-education students to practice more diverse and flexible teaching and thus develop more student-centered teaching beliefs and practice. Accordingly, the main research question is: How does knowledge building affect teacher-education students' teaching beliefs and practices? Specifically, we looked into participating teacher-education students' pre-post belief change, online learning activities, and their videotaped practice change in class.

Teaching Beliefs

What is belief? To clarify the concept of belief, it may be helpful to understand its relationship with knowledge. According to Dretske (1981), knowledge is confirmed or sustained belief. Belief represents a person's subjective value judgment, whereas knowledge represents an objective, neutral accumulation of facts about the world surrounding us. In terms of teaching beliefs, it is possible that teachers might have similar subject (e.g., mathematics) knowledge but employ very different teaching approaches (e.g., teacher-directed lecture vs. student-initiated inquiry) due to different teaching beliefs. Beliefs can explicitly or implicitly guide a teacher to decide what and how to teach and thus can affect the results of what and how knowledge should be delivered to or acquired by students (Clark and Peterson 1986; Peterson et al. 1989; Schwartz and Riedesel 1994).

There are, in general, two types of teaching beliefs: teacher-centered and student-centered (Ernest 1991; Handal 2003). When a teacher's teaching beliefs are more teacher centered/content oriented, he/she is more likely to assume teachers to be authorities for imparting knowledge to students. Whereas when a teacher's teaching beliefs are more student centered/constructivist oriented, he/she is more likely to highlight teaching as a means to facilitate students in exploring and deepening knowledge (Kember, 1997) or even as a means to creating or building knowledge (Bereiter 1994; Hong and Sullivan 2009; Scardamalia 2002).

While teaching beliefs are suggested as a key factor that influences teaching practice (Clark and Peterson 1986), previous research findings concerning the causal relationships between teaching beliefs and practice are not at all consistent (Thompson 1992). Instead of a linear causal relationship between teaching beliefs and teaching practice, studies suggest that there exist other possible reasons to explain the relationships between teaching beliefs and practice. For example, Thompson discovered inconsistency between teaching beliefs and teaching behaviors; he found that there were multiple factors simultaneously affecting teaching practice, and belief is just one of them. Handal (2003) expressed a similar view, arguing that beliefs and teaching practice could mutually influence each other. Other studies suggested that even teachers who hold more constructivist-oriented or student-centered teaching beliefs may not necessarily be able to put such beliefs into practice due to certain contextual factors or limitations (e.g., school culture).

Ernest (1989) also stated that the process of transforming beliefs into practice could be affected by many factors. These can include social and cultural factors (e.g., expectations from parents, principal's leadership, and social value) (Thompson 1992). In addition, a teacher's reflective ability can also affect the way they practice teaching. It was argued that teachers who were more reflective are more likely to develop more sophisticated teaching beliefs (Schön 1983). More importantly, teaching beliefs are usually developed over a long period and are largely influenced by a teacher's past learning experiences (Calderhead and Robson 1991; Nespor 1987) such as their learning experiences during the period of teacher education. Teaching beliefs usually also involve personal values and are often supported by certain implicit assumptions that teachers themselves may not necessarily be aware of (Handal 2003). Therefore, while not at all impossible, it is usually difficult to change teaching beliefs that requires a lot of effort in instructional design (Brousseau and Freeman 1988; Feiman-Nemser and Melnick 1992; Raths 2001; Simon and Schifter 1991).

To design an effective teacher-education curriculum or instruction, in order to help prospective teachers change their teaching beliefs and practices, many factors need to be taken into consideration. For example, it might be worthwhile fostering reflective thinking ability among prospective teachers through an instructional or curricular design (Brousseau and Freeman 1988; Feiman-Nemser and Melnick 1992; Raths 2001; Simon and Schifter 1991). It would also be helpful if the designed activities were able to facilitate prospective teachers to reflect on both their teaching beliefs (Stuart and Thurlow 2000) and teaching practice (Van Zoest et al. 1994) while progressively experimenting with different instructional approaches (Anderson and Piazza 1996). To make this reflective process even more effective, Wilkins and Brand (2004) also suggest that collaborative learning be employed as a means of strengthening reflection, especially social reflection. As Sigel (1985) stated, beliefs are a product of both individual reflection and social interaction, that is, they are an individual's psychological construction of social lives and experiences. As teaching beliefs are in great part shaped by one's past learning experiences (Calderhead and Robson 1991; Nespor 1987), in order to help teacher education develop more informed teaching beliefs, it is important to design a learning environment that avoids replicating a student's previous learning experience. As such, knowledge building may be a worthwhile option for change as it represents a new learning approach that values both reflective and collaborative learning experiences.

Knowledge-Building Pedagogy and Technology

As a deep constructivist theory, knowledge building is defined as a social process focused on sustained production and improvement of ideas of value to a community (Scardamalia and Bereiter 2006). Knowledge-building theory has been represented in the *Cambridge Handbook of the Learning Sciences* as one of a few important breakthroughs in the learning sciences field, along with others such as constructionism, cognitive apprenticeship, and situated learning (Sawyer 2006). Arguably, knowledge building can provide teacher-education students with a more constructivist-oriented and collaborative learning experience and can transform the learning experience from one that highlights passive and individualized knowledge growth to one that highlights more active, reflective, and collaborative knowledge exploration. Specifically, knowledge building encourages group knowledge innovation rather than individual knowledge acquisition. As a pedagogy, knowledge building aims to (1) consider knowledge advancement as a group achievement instead of individual achievement, (2) consider knowledge advancement as a sustained improvement of ideas instead of a path leading to absolute truth, (3) transform knowledge-telling activities into knowledge-exploring activities, (4) make good use of community discourse to solve problems, (5) challenge authoritative sources for constructing new knowledge, and (6) collectively validate the newly constructed knowledge (Scardamalia and Bereiter 2006), for example, through feedback and peer review. These pedagogical suggestions are critical in designing a knowledge-building environment that is different from the conventional classroom environments in most teacher-education programs in Taiwan. It is posited that engaging teacher-education students in knowledge building can guide them to practice their teaching in a more adaptive and innovative manner, rather than in a ritualistic manner based on certain teaching scripts. As maintained by Sawyer (2006), conventional approaches to teaching preparation and development tend to favor script-based, direct instruction. Some disadvantages of such an instructional approach are that they may neglect a teacher's creative personality and standardize instructional activities by repeatedly applying the same instructional strategies to address recurring teaching problems. In contrast, a knowledge-building pedagogy can flexibly allow students to initiate, explore, and self-regulate their own learning. It is believed that doing so can help progressively transform prospective teachers away from taking the role of teacher as an authority figure, who sees knowledge as absolute truth, to taking the role of a teacher as facilitator, who fosters a knowledge-creating environment. Therefore, as an innovative instructional approach, this study adopted knowledge-building pedagogy for designing class activities (Scardamalia 2004).

To support knowledge-building pedagogy, a software called Knowledge Forum (KF)—an online platform that runs on a live database—was developed (Scardamalia 2003) to transform idea aversion (Papert 1991) into sustained idea improvement (Scardamalia and Bereiter 2006). It was unlike most online knowledge tools in which idea improvements are usually not valued. For example, Wikipedia focuses on compiling existing knowledge rather than encouraging idea production and improvement. In contrast, KF enables ideas to be externalized from one's thinking and to be constantly revisited for further development. KF makes it possible for users to simultaneously contribute their ideas in the form of notes online, read or reply to other notes, search and retrieve ideas embedded in notes, and organize notes into more complex knowledge representation. KF also shows linkages of postings as a way to represent the dialogical and interconnected nature

Fig. 11.1 A Knowledge Forum view

of ideas. As such, it also enables the development of ideas to be traced. Figure 11.1 illustrates an example of a KF view (i.e., an open space designed for collaborative learning and reflection), within which users are guided to work as a community by posting their problem of interest, producing initial ideas for problem-solving, sharing and synthesizing ideas, and deepening their collective understanding of the problems at issue. Specifically for this study, the main problem of interest is concerned with understanding the nature of mathematics teaching (e.g., "What represents a good mathematics learning environment?").

Method

Context and Participants

The present research was conducted in a "mathematics teaching" course in a national university in Taiwan. The course was offered by the university's Center of Teacher Education to college students who plan to become mathematics teachers at the middle school level. The university is ranked as one of the best universities in the nation and the students enrolled in the university are all high academic achievers considered by society as the elite prospective teachers in the nation. Participants in this study include four female and five male teacher-education students and their ages ranged from 19 to 23 years.

Instructional Approach

The participating teacher-education students were guided to engage in a knowledge-building process during their teaching practice in this study (Hong et al. 2009). The main purpose of doing so was threefold: (1) to help them avoid viewing teaching as merely pursuing the best practices of certain model teachers by means of mastering predefined teaching skills, (2) to guide them to continually think about how to go beyond "best practices" and assume the role of knowledge workers in the continual improvement of their own teaching practice, and (3) to help them implement teaching as a creative and adaptive knowledge-creating process (Sawyer 2006; Scardamalia and Bereiter 2006). The course was divided into four related phases:

1. Initial idea generation: Participants were guided to work on their initial ideas in order to implement their first teaching practice. Accordingly, they prepared lesson plans, learning materials, learning sheet, etc.
2. First teaching practice: Based on their initial teaching ideas, the participants performed their first teaching practice in class, with their classmates serving as audience. Each student's teaching practice was entirely videotaped.
3. Idea improvement: The participants worked collectively online in Knowledge Forum to provide feedback and suggestions to the student who already implemented their teaching ideas into practice. They then further reflected on these suggestions for idea improvement, analyzed the recorded video of their own teaching practice, and reflected with peers to improve their initial ideas by producing a new lesson plan.
4. Second teaching practice: Finally, based on the improved ideas, each participant performed their second teaching practice. The whole teaching process was again videotaped.

KF was used to support the above idea generation and improvement activities. To this end, a tutorial lesson about the use of KF was administered before the beginning of the class. Teacher-education students were guided to use basic features of KF, for example, contributing a note in a KF "view" (i.e., an online discussion space), building on a note, and annotate. To initiate a completely new idea, the participants would need to create a new note. To elaborate, enrich, exchange, or improve ideas, the participants would then build on a note or annotate by providing comments or suggestions. In addition, the course also employed other complementary instructional activities, including whole-class and small-group discussion after each participant's teaching practice, in order to engage the participants in sustained reflection on improving teaching practice. Some questions discussed in class were: What have you learned from others' feedback? Did you see anything worth further discussion? If you were to teach this lesson again, what would you do differently to improve it, and why? The instructor served as a facilitator in guiding class students to explore and discuss the questions that emerged in class in order to help them reflect on their own beliefs about mathematics teaching. KF was only used after class, and it played an important function as a place for the class students to document all key teaching ideas reflected and generated from class discussion activities.

Data Source and Analysis

The data source included a belief survey (which was administered at the beginning and the end of the semester), online feedback and discussion (which were recorded in the KF database), and student teaching practice (which was entirely videotaped throughout the whole process). To explore students' knowledge-building outcome, we analyzed data collected from the belief survey. The coding scheme was based on Handal's (2003) conceptualization of two types of mathematics beliefs concerning the nature of mathematics teaching (see Table 11.1). In this survey, we asked the following questions adapted from Tsai (2002): (1) What is the ideal way to teach mathematics? (2) What are some key factors for successful mathematics teaching? (3) What makes an ideal mathematics teacher? (4) What is the ideal way to learn mathematics? (5) What are some key factors for successful mathematics learning? (6) What does an ideal mathematics learning environment mean to you? To analyze the survey data, we employed an open coding procedure (Strauss and Corbin 1990). Seven codes emerged as shown in Table 11.1. Inter-coder reliability was computed to be .91, using the Kappa coefficient. Nonparametric Wilcoxon signed-rank test was employed to examine whether there were any pre-post differences.

To better understand the knowledge-building processes, we analyzed the online learning activities and process of (videotaped) teaching practice in class. In terms of online student learning/discourse recorded in the KF database, we analyzed basic online KF activity (e.g., notes created and notes read) and interaction patterns by employing descriptive analysis and social network analysis. In terms of student teaching practice, the two cycles of videotaped teaching practice for each participant were content analyzed based on a predetermined coding scheme highlighting the following three general types of learning activity: active, passive, and interactive (Collins 1996). Active activities include independent seatwork, hands-on exercises, practicing quizzes, and the like. Passive activities include lectures, demonstrations, asking factual questions, and the like. Interactive activities include group discussion/debate, group work, and/or collaboration. We examined the percentage of time spent in each type of activity during each teaching practice, using the activity as the unit of analysis. In particular, we presented a representative student's teaching to illustrate in detail how students changed their beliefs during the teaching-as-knowledge-building process.

Table 11.1 Teacher-centered vs. student-centered beliefs in mathematics teaching

Code	Example
1. Teacher centered	
1.1. Lecture	Teaching by telling learners how to do calculation while using visual aids. Doing so can give learners a clear impression about what is taught and help them memorize it (S02)
1.2. Demonstration	Teaching by giving examples and demonstrating how to complete a math quiz and then asking learners to do some exercises (S01)
1.3. Teacher-initiated questioning	Teaching by asking learners to answer some questions that were taught at the same time could help learner be more attentive. It can also help find out whether learners are really learning or not (S07)
2. Student centered	
2.1. Guided problem-solving	Guiding learners to thinking and solving problems can help them better understand the purpose of certain mathematics equations (S03)
2.2. Discussion among learners	It represents a good learning environment if learners can discuss things with one another whenever and wherever they can (S05)
2.3. Student-directed questioning	Waiting for learners to pose questions or encouraging learners (especially those who fall behind in class) to ask questions (S05)
2.4. Discourse and discussion between the teacher and learners	I think the key to influencing the quality of teaching is the interaction between teacher and learners. Teaching without the help of such interaction is like rote learning (S08)

Note: S + number (e.g., S03) refers to a specific participant

Results and Discussion

Mathematics Teaching Belief Change as Knowledge-Building Outcome

We first looked into whether engaging participants in knowledge-building activities had an effect on their mathematics teaching beliefs. As shown in Table 11.2, in terms of teacher-centered mathematics teaching beliefs, there was a significant drop in ratings from the pre-survey ($M = 5.33$) to the post-survey ($M = 2.56$). In contrast, in terms of student-centered mathematics teaching beliefs, there was a significant increase in ratings from the pre-survey ($M = 2.44$) to the post-survey ($M = 9.67$). Overall, the findings suggest that at the beginning of the semester, teacher-education students tended to consider that mathematics teaching was chiefly a means to deliver knowledge (e.g., by giving lectures or by demonstrating certain procedural knowledge to learners). Apparently, they assumed that teachers should focus their instructional goals on helping learners acquire appropriate core

Table 11.2 Mathematics teaching belief change after knowledge-building activities

	Pre-survey		Post-survey		
	M	SD	M	SD	*z*-value
Teacher-centered	5.33	1.94	2.56	1.88	−2.68**
Student-centered	2.44	1.51	9.67	3.87	−2.43*

*$p<.05$; **$p<.01$

mathematics knowledge or skills through routine mathematics practice. After a semester, however, the participants changed their beliefs and they were able to view mathematics teaching from a more student-centered, constructivist-oriented stance; it is likely that the teaching-as-knowledge-building process helped them gradually realize that routine practice may not necessarily help learners to use mathematics in an exploratory and constructive way. So they began to appreciate mathematics teaching as a way to guide learners to seek and explore patterns and orders and as a tool to help learners engage in more meaningful learning and problem-solving.

Knowledge-Building Process

Overall Online Activity

The overall online activity and performance in this class community are shown in Table 11.3. Throughout the semester, participants contributed a total of 171 notes with a mean of 17.8 (SD = 4.29) notes per person. In addition to note creation, other major online knowledge-building measures recorded in this community were number of notes read, percentage of notes read, number of annotations, number of note revisions, number of build-on notes, and percentage of notes linked. Overall, the amount of online activities revealed in the present study was quite similar to previous research using teacher-education students as participants (Hong and Lin 2010; Hong et al. 2011). Nevertheless, these behavioral measures only gave a general picture of how participants worked online in this database. They did not provide much information about how participants actually interacted with one another. To better understand the social dynamics of the community, a social network analysis (SNA) focusing on network density was conducted.

Interaction Patterns

SNA was conducted using two key indicators that can be extracted from the Knowledge Forum database: "note-reading" (which indicates community awareness of contributions made by other peers) and "note building-on" (which indicates contributions by the effort used to build on to others' work and ideas). Table 11.4 shows the detailed results of participant interactions in two knowledge-building stages (the first vs. second teaching practice). This particular analysis employed an

Table 11.3 Descriptive analysis of online activities

Activity	Mean	SD
No. of notes created per person	17.8	4.29
No. of notes read per person	140.2	32.94
Percentage of notes read per person (%)	82	19.26
No. of annotations per person	21.2	12.26
No. of note revisions per person	8.2	3.29
No. of build-on notes created per person	11.3	2.49
Percentage of notes linked per person (%)	64.3	6.17

Table 11.4 Social network analysis (SNA) of interactivity in the community

Network density	Stage 1 (first teaching practice)	Stage 2 (second teaching practice)	Whole semester
Note reading	100 %	100 %	100 %
Note building-on	72.22 %	94.44 %	100 %

indicator, "network density," which is defined as the proportion of connections in a network relative to the total number possible. The higher the number of the density is, the stronger the implied social dynamics of a community. The intention in adopting knowledge building in this course was to transform the traditional knowledge-transmission mode of learning into a knowledge-construction mode of learning that engaged learners in collective problem-solving and knowledge work. It was, therefore, expected that learners would progressively work more collaboratively in KF. As expected, there was an increasing trend of social interaction as reflected by the measures of density recorded online for this community from the first to the second stage of teaching practice. Lipponen et al. (2003) regarded a social network density of .39 for learners building on each other's online messages as adequate. In the present study, the density level was .72 (for stage 1) and .94 (for stage 2), which indicates a fairly strong social dynamics in this community. The SNA findings alone, however, did not tell us much about the quality of interaction in the community. So we conducted content analysis on participants' notes to discover what they actually did to help each other improve their teaching practices.

Table 11.5 shows the total amount of group feedback and personal reflection made after the first, and before the second, teaching practice, in terms of three dimensions: instructional design, learning materials, and presentation skills. There were 106 suggestions/comments in total and 43 occurrences of personal reflections being made. On average, each student received 13.25 suggestions in each practice from other peers and correspondingly made 4.78 personal reflections. This suggests that participants' online interaction was both quite purposeful and practically oriented toward teaching improvement. The next question was how online interaction, group feedback, and personal reflection contributed to the change of student's actual teaching practice.

Table 11.5 Group feedback and personal reflection made after the first teaching practice and before the second teaching practice

Source of ideas	Area of idea improvement	Frequency
Ideas from group feedback	1. Instructional design	44
	2. Learning materials	28
	3. Presentation skills	34
Ideas from personal reflection	1. Instructional design	16
	2. Learning materials	14
	3. Presentation skills	13

Table 11.6 Percentage of time spent in different instructional activities in two teaching practices

Activity	First practice (%)	Second practice (%)	*t*-value
Passive learning	72.1	46.9	5.04**
Active learning	17.9	36.4	−3.79**
Interactive learning	10.0	16.7	−2.15
Total	100.0	100.0	

$^{**}p < .01$

Practice Change

Overall Analysis. Video analysis was conducted to further understand the way the participants changed their teaching practice. Table 11.6 shows the results in terms of percentage of time spent in three different instructional activities from the first to the second teaching practice. It was found that there was a significant decrease in the percentage of time spent in passive learning activities, from the first practice (72.1 %) to the second practice (46.9 %) ($t = 5.04$, $\mathrm{df} = 8$, $p < .01$). In contrast, there was a significant increase in the percentage of time spent in active learning activities, from the first practice (17.9 %) to the second practice (36.4 %) ($t = -3.79$, $\mathrm{df} = 8$, $p < .01$), and a slight, but not statistically significant, increase in the percentage of time spent in interactive learning activities ($t = -2.15$, $\mathrm{df} = 8$, $p = .064$). This implies that the participants were still hesitant to try more interactive and collaborative learning activities in class. This is clearly an area for further instructional improvement and future study. But, even so, overall, the video analysis confirmed that participant teaching practice was shifting from a more teacher-centered approach to a more student-centered approach.

A Case Example. Figure 11.2 further illustrates the case of a selected student, chosen for its typicality, in terms of her change from the first to second teaching practice. Using open coding, the main themes in Table 11.1 were adopted for the analysis of teaching activities, which can be divided into teacher centered (including lecture, demonstration, and teacher-initiated questioning) and student centered (including students' independent problem-solving, discussion among students, student-initiated questioning, and discussion between the teacher and students).

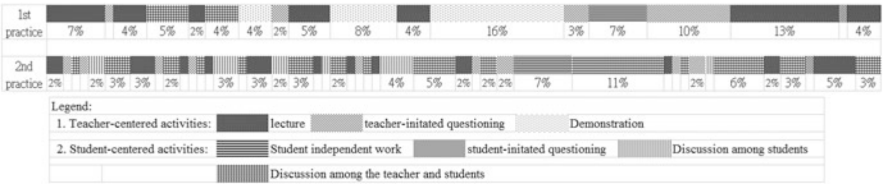

Fig. 11.2 Percentage of time spent in different instructional activities between the two teaching practices (*Note*: The percentage value is not shown in the figure if less than 2 %)

In her first teaching practice, she taught the arithmetic operation of "radical expressions." More than 50 % of her instructional time was spent on teacher-centered activities such as lectures (38.49 %), demonstrations (28.23 %), and teacher-initiated questioning (16.31 %). As the video showed, she hoped that students would learn the content she taught as quickly as possible. There was little time spent on more student-centered activities such as discussion between the teacher and students (8.6 %), independent problem-solving (7.39 %), or student-initiated questioning (0.98 %). The video also showed that the process of interaction between the teacher and students was mainly focused on monitoring students' learning progress and making sure those students completed the assigned exercises. The same topic was taught in the second teaching practice, but it was noteworthy that the teaching approach changed dramatically. She did not directly lecture and teach mathematics concepts and equations; instead, she guided students first to discuss related concepts and equations. Consequently, compared with the first teaching practice, she spent much more time (47.99 %) in discussion between teacher and students and greatly reduced her lecture time (from 38.96 % in the first practice to 22.42 % in the second practice). Overall, the video showed that the main difference in the second teaching practice included activities such as encouraging students to discuss problems together, proposing and testing new solutions/ideas for addressing related mathematics problems, and clarifying and explaining their ideas or the related mathematics concepts discussed.

As illustrated above, this student's initial teaching belief was very teacher-centric. Indeed, the teaching of other students on this course was similar, and this is perhaps because most students' past learning experiences were teacher centered. The illustration of this representative case suggests that student teaching beliefs could become more student centric after engaging in knowledge-building activities. The illustration also suggests the effectiveness of knowledge-building pedagogy in changing student beliefs as it encouraged sustained idea improvement rather than repeated practice on same teaching skills. As such, students were more willing to design more innovative lessons and to open the possibilities for adopting more student-centered activities.

Discussion and Conclusion

In this study, we reported the way an instructional approach designed based on knowledge-building theory and pedagogy and implemented among a group of teacher-education students influenced their views and practice of mathematics teaching. In summary, the pre-post belief analysis indicated that there was a significant decrease in self-reported ratings from the pre- to the post-survey in terms of teacher-centered beliefs. In contrast, there was a significant increase in self-reported ratings from the pre- to the post-survey in terms of student-centered beliefs. Moreover, video analysis showed the participating teacher-education students were able to shift from a teaching mode that highlighted passive learning to a teaching mode that featured more active learning.

The knowledge-building instructional approach highlighted the continual production and improvement of ideas in pursuit of deeper understanding of the nature of mathematics teaching. In summary, the findings indicate that (1) in contrast with the conventionally more didactic instructional approaches commonly seen in Taiwan, knowledge building as an alternative instructional approach was helpful in promoting more interactive and reflective online activities, and (2) after being engaged in knowledge building for a semester, teacher-education students were able to shift away from more teacher-centered teaching beliefs and practice to more student-centered teaching beliefs and practice. Previous studies suggest that preservice teachers (including teacher-education students) are more likely to adopt lectures as a major teaching strategy during their internship and the early years of their teaching career (Fuller 1969; Fuller et al. 1974; Hascher et al. 2004; Rhine and Bryant 2007; Weinstein 1990). They tend to emphasize teaching methods that can quickly impart substantial amount of knowledge to students, and as such, they tend to expect students to submissively receive knowledge passed down via their direct instruction. In the present study, as the survey showed, before engaging in knowledge building, teacher-education students indeed possessed teaching beliefs that were more in line with the conventional didactic instructional approach. It is posited that this is because their past experiences of learning and the kind of instruction they received during their past learning tended to be more teacher directed. When they were guided to experience more student-centered knowledge building, they were given the opportunity to make a comparison with their past learning experiences. Knowledge building thus served as a contrasting case for deeper reflection of their teaching beliefs and practice. In addition, knowledge building also allowed them to adaptively and flexibly experiment with new teaching ideas. This may be why they developed more flexible and innovative ways of teaching practices.

Moreover, the study also found that there were some advantages in using KF. Not only did it allow ideas to be preserved via the posting of teaching feedback onto the KF website, but it was also helpful for the participants to reflect and share their ideas for solving teaching-related problems any time after class in order to improve their teaching practice. Because ideas could be contributed via the instructionally designed feedback mechanism and recorded in KF, teacher-education students were more likely to spend more time outside class reflecting on their own beliefs and practice. At the same time, KF also allowed the participants to be aware of and to monitor their changing beliefs as KF kept a record of what the participants did and revised in terms of their teaching plans and methods.

Overall, the results are consistent with findings from previous knowledge-building studies (e.g., Hong and Lin 2010; Hong et al. 2011; Chai and Tan 2009) indicating that a knowledge-building pedagogy is effective in helping foster epistemological belief change. Arguably, while cultivating teachers' pedagogical content knowledge is important and should always be included as part of the teacher-education curriculum, it is also equally important to help teacher-education students develop more informed constructivist-oriented mathematics teaching beliefs as to be supported by the current education reform movement. To foster such belief change, it would be crucial to avoid traditional didactic ways of teacher preparation and to adopt more constructivist-oriented instruction in order to cultivate future teachers who can view mathematics teaching more as adaptive and constructivist-oriented, rather than routine and ritualistic, practices.

For future research, as pointed out by Clark and Peterson (1986), teaching beliefs not only have a great influence over teacher's thoughts and behavior, but they also affect classroom atmosphere and hence the effectiveness of students' learning performance (see also Ernest 1989). Further research should examine how the learning atmosphere changes due to knowledge building. Also, as a case study and because the participants in this study were all academic high achievers, the generalizability of the findings may be limited so future studies should try to include a control group and to increase the sample size and should also try to conduct studies in different educational contexts.

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Chapter 12
Conceptual Shifts Within Problem Spaces for Knowledge-Building Practice Within a Teacher Community

Chew Lee Teo

Introduction

This study seeks to explore teaching practice through an analytical, exploratory study, using multiple data sources to uncover problem spaces generated and explored by knowledge-building teacher community through their daily classroom experiences.

Knowledge-building practice places students' ideas at the center of the classroom enterprise (Scardamalia and Bereiter 2003, p. 1370); twelve knowledge-building principles (Scardamalia 2002) characterize the complex, interactive system that makes it possible to keep those ideas on a continual improvement trajectory. Knowledge building has continued to grow as an area of intense research along with an increasing awareness of knowledge creation. However, while significant advances are being made in knowledge building (see, e.g., a recent special issue of *Canadian Journal of Learning and Teaching on Knowledge Building* edited by Egnatoff and Scardamalia (2010)), little is known about how teachers engage in knowledge-building practices and create the pedagogical advances associated with it.

This research takes advantage of a unique context – a school that has adopted knowledge-building theory, pedagogy, and technology for more than a decade and where innovative practice has become an integral part of the school's culture (Bielaczyc and Collins 2006; Zhang et al. 2010). It thus provides multifaceted and rich accounts of knowledge-building practices. Data sources include (a) teachers' knowledge-building practices in their classrooms, sampled over a full school year; (b) negotiated understanding of knowledge-building practice, as represented in weekly teacher meetings over the same school year, including reflections of their classroom actions; and (c) teachers' personal reflections, as

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conveyed in their journals. Using these data sources, it is possible to explore teachers' understanding of knowledge-building practices as individuals as well as a collective endeavor and to address features of teachers' individual and community interaction that make these practices sustainable and more likely to lead to improved classroom practices. A problem space model is proposed to frame the research questions that define the investigation into knowledge-building practices.

The research question is: "How do knowledge-building teachers, as individuals and as a community, construct and explore teaching problem spaces related to knowledge-building classroom practice?"

Literature Review

Knowledge Building, Adaptive Expertise, and Reflection-in-Action

Knowledge-building practice requires teachers to continually make decisions using students' ideas as a constant source of new information to transform the classroom into a community of knowledge-advancing members (Brown and Campione 1996; Zhang et al. 2009) grounded on the knowledge-building principles. In these contexts, teachers operate as designers, in the same reflective manner as in design professions requiring deliberative processes that emphasize intentions, plans, and mental effort in learning (Bereiter and Scardamalia 1993).

Knowledge-building practice relies on teachers' understanding and interpretation of knowledge-building principles (Scardamalia 2002) and their translation of these principles into daily practices. It assumes that teachers can make a shift from procedure- to principle-based pedagogy. Principle-based action requires adaptive expertise, a form of "expert knowledge that supports continual learning, improvisation, and expansion" (Bransford et al. 2006). Thus, there is a strong connection between knowledge-building practice and adaptive expertise to negotiate between innovation and efficiency – a connection that is essential for understanding the problems teachers identify as important and the solutions they generate.

Extending from this, reflection-in-action (Schõn 1983) has been postulated as a necessary method to develop adaptive expertise, and likewise, adaptive expertise is a necessary condition for reflection-in-action. Thus, concept of reflection-in-action, as contrasted with reflection-on-practice, has been widely adopted in education and, as elaborated in this study, represents an essential component of an idea-centered classroom. However, there is little empirical data on this aspect of teachers' work (Munby and Russell 1992). Common criticisms of reflection-in-action are that its conception does not consider the "hot and rapid" responses required of teachers in messy and chaotic situations (Eraut 1995) and that the nature of the professions (i.e., architecture, design, music performance) described in Schon's work deviates from that of teachers' work in real classrooms. It is likely that, without a set of principles to govern their teaching and learning, teachers would not be able to perform reflection-in-action on core pedagogical issues. This assumption sets the context for this study as teaching and learning problems are complex and ill defined and require fast-paced decision-making.

General Theory of Problem Solving

Within the problem-solving literature, problem space (Newell and Simon 1972) is a representational concept used in this study to frame the way we understand teachers' thinking in generating and exploring problems in their daily work. A premise pursued in this study is that the nature of teachers' work within these problem spaces enables or thwarts teachers' problem analysis, their shift from procedure-based action to principle-based reflection-in-action, and development of adaptive expertise. The concept of a problem space is generally used to understand how problem solvers move toward their goals through a series of actions, broadly categorized along two dimensions: (1) generating the problem space and (2) exploration of the problem space. The first process includes cognitive processes such as finding the problem, constructing the problem, and reflecting on the problem. These problem-solving processes are distinctive for complex and ill-defined design problems, as contrasted with well-structured problems. Typically, teachers, along with other problem solvers, oversimplify the situation to avoid complexity and address the problem in the time available. They mostly react to events that present themselves and require immediate action, such as classroom management and the failure of students to comprehend a curriculum goal. For other pedagogical issues, they tend to make decisions intuitively, without much consideration of "trade-offs" between new possibilities and efficiency (Dillon 1982). In most cases, the decision is quick and routinized; consequently, there is no attempt to problematize the situation, let alone to consider new possibilities. Follow-up reflection, which comes after the decision is made, is then at best an exercise in rationalization rather than deliberate reflection-in-action. Understanding problem spaces as teachers construct and explore them is essential if we are to encourage reflection-in-action and adaptive expertise in teaching.

The following section provides a brief overview of the concept of a problem space, a space for problem solving, with focus on complex and ill-defined design problems and various accounts of teacher problem spaces.

Problem Spaces in Teaching and Learning

A classical view of problem spaces for teaching focuses on management, effective delivery, and engagement of students in meeting curriculum and teacher objectives. As suggested by the pedagogical decisions to be made in the Skillful Teacher model

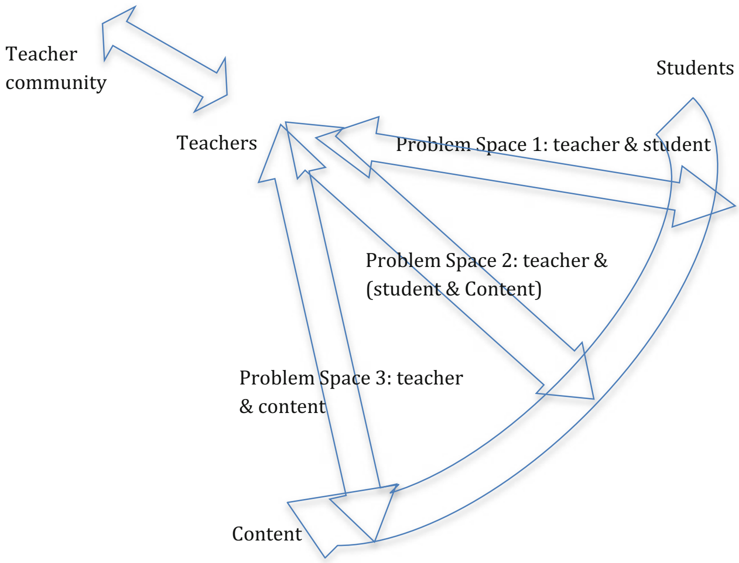

Fig. 12.1 Relational view of problem spaces (Lampert 2001)

(Saphier et al. 2008), the effort focuses more on procedures to be implemented. Saphier et al. (2008) presents a Skillful Teacher model that consists of four main problem areas – classroom management, instructional strategies, curriculum planning, and motivating students – that a good teacher has to negotiate before and during lessons.

On the other hand, Lampert (2001) proposed a relational view of problem spaces for teaching using relationships among teachers and various aspects of teaching and learning to characterize teaching and learning problem spaces (Fig. 12.1). According to Lampert (2001), teaching actions proceed simultaneously in relation with students, content, and the connections between students and content:

> This relationship is a "problem space" in the work of teaching. Working along the practice arrow that connects my work with my students, I can use them as a resource to solve the problems of my practice. They can also constrain my actions and hinder my efforts to support their learning. (p. 31)

Knowledge-building classrooms present unique problem spaces that require a relational perspective. Knowledge-building practice is only possible when a teacher develops an understanding of the 12 principles that define this pedagogical model, and deep understanding requires a relational perspective. The relational model is broad in scope and conveys well-known classroom problem spaces. The knowledge-building principles require a relational perspective so an attempt is made to map the socio-cognitive and technological dynamics of these principles onto the relational model. Toward this end, designs and strategies as set out by Zhang et al. (2010) and elaborated in Table 12.1 (column 1) are used to explore the problem spaces that teachers have to construct and explore to bring about idea-centered pedagogy. Table 12.1 shows how knowledge-building principles can be mapped onto the relational perspective.

This relational model/knowledge-building principle mapping suggests the possibility of a further mapping onto the skillful model problem spaces that deal broadly with curriculum/standards, interaction patterns among peers-teachers-students, classroom structures and management, and student characteristics as they bear on matters such as inclusiveness and individual differences.

A Centrist to Relational Model of Action in Five Educational Problem Spaces in Advance Knowledge-Building Practice

Building on a variety of models of teacher thinking and development, a problem space model is developed and tested in this study, specifically geared to the development of knowledge-building practices. This model posits three pedagogical shifts resulting from advancement from centrist to relational perspectives in each of the five problem spaces: curriculum/standards, social interaction, student capability, classroom structures and constraints, and technology. Table 12.2 provides an overview of the shifts accompanying each problem space.

The model is used to guide data analyses from teacher interviews, journal entries, contributions to weekly teacher meetings, and classroom observations and serves to convey how knowledge-building teachers differ from other skillful teachers in the principal shift from a centrist to relational (or systemic) perspective in each problem space.

Methodology

Research Approach

The research used a qualitative approach, adopting the design of a case study with embedded unit (Creswell 1992; Yin 2003).

Data collection methods included:

1. Teachers' meetings: The researcher attended the teachers' weekly knowledge-building meetings, which lasted approximately 60–90 min and typically included all teachers in the school.
2. Classroom enactments: Three teachers were selected as the focus of in-depth case studies in which the researcher observed a minimum of an hour of each teacher's classroom interactions each week. This hour was either a knowledge-building discussion (a classroom conversation that the teachers and students

Table 12.1 Teachers' design and strategies to support knowledge-building principles

Principles for design and strategies in a knowledge-building classroom (Scardamalia 2002; Zhang et al. 2010)	Relational problem spaces
Real and authentic ideas: Teacher supports students in identifying problems that arise from students' efforts to understand the world and creates opportunities for students to pursue sustained creative work surrounding these problems	These principles can be translated into practice by first viewing and maintaining the relationship between teacher and students differently, that is, what guides the way in which the teacher supports, understands, and builds relationships with his/her students? These problem spaces in which teacher construct and explore includes: Managing social interaction
Collective responsibility for community knowledge: Teacher creates a learning environment where all students are legitimate contributors to the collective goals of the class and where their ideas are valued and they then take high-level responsibility for advancing the collective knowledge of the entire class, not just for their individual learning	Building students' capability Creating conducive environment (physical space and technological space) Using classroom structures and overcoming constraints
Democratizing knowledge: Teacher empowers all students as legitimate contributors to the shared goals, so that all take pride in knowledge advances of the community. Teacher promotes a culture where diversity and differences are viewed as strengths, rather than as leading to separation along have/have-not lines with respect to knowledge	
Symmetric knowledge advancement: Acknowledging that expertise is distributed within and between communities and team members	
Improvable ideas: Teacher treats ideas as improvable, rather than as simply accepted or rejected, so students continue to work on their ideas to improve the explanatory power, coherence, and utility of ideas	These principles can be translated into practice by first reviewing the relationship between teacher and content differently: What guides the ways in which the teacher works with the content and the school curriculum?
Idea diversity: Teacher helps students to understand that knowledge advancement depends on the diversity of ideas. Teacher helps students identify and bring related ideas together, including those that stand in contrast to each other, to help improve their understanding of an idea	The problem space in which the teacher constructs and explores includes: Managing curriculum goals and standards Building students' capability Making use of school structures and overcoming constraints
Constructive use of authoritative sources: Teacher and students access and critically evaluate authoritative sources and use them to support and refine their ideas, not just to find "the answer"	

(continued)

Table 12.1 (continued)

Principles for design and strategies in a knowledge-building classroom (Scardamalia 2002; Zhang et al. 2010)	Relational problem spaces
Pervasive knowledge building: Teacher opening up the inquiry space, acknowledging that knowledge building is not confined to particular occasions or subjects but pervades mental life, in and out of school and across contexts	
Knowledge-building discourse: Teacher and students engage in discursive practices that not only share but transform and advance knowledge, with problems progressively identified and addressed and new conceptualizations built	
Rise above: Teacher allows students to work with diverse ideas in complex problem spaces; they transcend trivialities and oversimplifications and work toward more inclusive principles and higher-level formulations of problems	These principles can be translated into practice by reviewing the relationship between the teacher and the student-content relationship: That is, what guides the way in which teachers manage learning outcomes, expectations of students, and assessment?
Epistemic agency: Students set goals, assess their work, engage in long-range planning, monitor idea coherence, use contrasting ideas to spark and sustain knowledge advancement, and engage in high-level knowledge work normally left to the teacher	Assessing and managing students' capabilities Creating a conducive environment (physical space and technological space)
Embedded and transformative assessment: Teacher designs and makes use of assessment as a way to advance knowledge through identifying advances, problems, and gaps as work proceeds	Making use of classroom structures and overcoming constraints Ensuring availability of information and resources in environment

referred to as KB Talk that focused on getting students to build on one another's ideas) or a session where students worked on Knowledge Forum®.[1]

3. Written journal entries: Notes posted on Knowledge Forum® by the classes and reflection notes posted by the teachers were analyzed to provide a complete and accurate description of the classroom activities.

[1] Knowledge Forum® is the second generation of Computer-Supported Intentional Learning Environment (CSILE) (Scardamalia et al. 1989). It is an asynchronous discourse medium where students and teachers author or coauthor notes that include multimedia elements, ideas, models, problems, plans, and data. Users can create graphic views as workspaces to hold these notes. Knowledge Forum also provides supportive features such as build-on, annotations, reference links to one another's notes, and rise above to allow users to organize and summarize the collective ideas.

Table 12.2 Three pedagogical shifts resulting from advancement from centrist and relational perspectives in the five problem spaces

Surface to deep	Routine to adaptive	Procedure based to principle based
Advancing from a centrist (C) to relational (R) perspective involves a shift from focus on obvious or evident features to ill-defined problems, big ideas, and promising possibilities	Advancing from a centrist (C) to relational (R) perspective involves a shift from routines to adaptive flexibility and novel approaches	Advancing from a centrist (C) to relational (R) perspective involves a shift from procedure-based actions to principle-based reflection-in-action
Curriculum/standards (C/S)		
From predetermined, fixed curriculum content and topic analysis to deeper, more expansive analysis of big ideas and promising possibilities in the light of students' ideas	From use of curriculum scripts to integration of students' ideas to support more flexible and novel approaches	From sequenced activities and procedures embedded in curriculum guidelines to work with principles to invent new, adaptive practices to advance curricular goals and student ideas
Student capability (SC)		
From attributing difficulties to lack of student capability to engagement of all participants in advancing shared goals	From individual differences and segregation to democratization of knowledge with student contributions leading to a whole greater than the sum of parts	From use of fixed-stage developmental sequences and benchmarks to turning over increasingly high levels of agency to students so they can exceed expectations
Social interaction (SI)		
From social interaction to get to know each other to social interaction as a sustaining force for exploration of complex, ill-defined problem spaces; big ideas; and new possibilities	From focus on activities and grouping arrangements to supports for distributed expertise and opportunistic processes that foster emergence of new ideas	From use of procedures and social media for information sharing to design and use of new forms of social interaction to maximize idea improvement
Classroom structures and constraints (CS&C)		
From viewing time, assessment, class size as structures, and constraints that limit possibilities to viewing them as boundary conditions that need to be crossed to explore new possibilities	From small group work and divided responsibility for a finished product to flexible roles and systems of support to allow participants to go where their ideas take them	From meaningful activities that fit within classroom structures and constraints to supportive, organic, and flexible structures that encourage participatory and distributed control and emergent collaboration
Technology (T)		
From familiarity with and ability to use common applications, functions, and web resources to ICT integral to daily work with all participants contributing to and	From use of technology for standard procedures and administrative convenience to reinventing classroom procedures based on special affordances of new media	From use of technology to implementation of best practices to combining principles, technology, and analytic tools to provide mutually supportive

(continued)

Table 12.2 (continued)

Surface to deep	Routine to adaptive	Procedure based to principle based
continually advancing shared goals		contexts for continually advancing high-level knowledge processes extensible to real-world contexts

The video recordings of teachers' meeting and classroom enactment were transcribed. The text, along with teachers' journal entries, was segmented into chronological order to describe flow of planning and classroom enactment. Qualitative analysis of all dataset, namely, teachers' journal entries, records of classroom enactment, and contributions in weekly meetings, was conducted to identify the problem space they identified and worked with in class.

Participants

As the purpose of the study was to examine an authentic and established knowledge-building culture and differences among teachers with different years of experience, the choice of participants and school was obvious. Participants were 13 teachers from the Dr. Eric Jackman Institute of Child Studies (Jackman ICS) Laboratory School, Ontario Institute for Studies in Education, a school affiliated with the University of Toronto. This school has successfully sustained knowledge-building practice for over a decade (Scardamalia 2002; Bielaczyc and Collins 2006; Zhang et al. 2010). The school currently enrolls about 200 students from nursery school (pre-K), kindergarten to grade 6, with 22 students on average per class. Most families come from a middle-class background.

Teachers Operating as a Community to Construct and Explore Problem Spaces Related to Knowledge-Building Classroom Practice

In this analysis, segments of individual case studies of knowledge-building teachers of three different sets of experience (i.e., novice, mid-experienced, and experienced KB teacher) in class were analyzed, with the teachers' discourse from notes collected during weekly meetings to reveal details on how different sets of problem space were negotiated by teachers with different years of knowledge-building experience.

Throughout the school year, all 13 teachers at Jackman ICS, along with the principal, met weekly to discuss advances and difficulties related to knowledge-building pedagogy. In these meetings, teachers with 1–8 years of teaching using knowledge-building pedagogy shared experiences and offered solutions to each other's problems. The meetings served as the primary means of acculturating new teachers into the school-wide knowledge-building community. Each meeting was framed by the following agenda: (a) identification of problems of understanding – this form of problem analysis has a strong basis in knowledge-building communities supported by Knowledge Forum and the theory-building scaffold; (b) knowledge advances; and (c) technology issues. The analyses in this chapter focused mainly on teachers' "problems of understanding" and interactions between teachers, coupled with individual teachers' decision and action to support knowledge advances surrounding those problems.

The problems teachers raised can be classified according to the five standard problem spaces: *curriculum/standards* (C/S), *students' capability* (SC), *social interaction* (SI), *classroom structure and constraints* (CS&C), and *technology* (T).

However, as is evident in the interchanges presented below, conversations shifted between these problem spaces at a fast pace, and the boundaries between "problems of understanding," "knowledge advancement," and "technological issues" became blurred, as group discussions led invariably to work that was deeply relational in nature. In terms of knowledge-building community for professional development, going beyond best practices reflects a shift from a centrist to relational perspective. And as the analyses below suggest, "going beyond" requires shifts as set out in Table 12.2. In line with these shifts, obvious or evident features of classroom activity were reconstructed in ways that had teachers dealing with ill-defined problems, big ideas, and promising possibilities; routines gave way to the generation of suggestions for novel approaches demonstrating adaptive flexibility; and procedure-based reflection was replaced by principle-based reflections. To convey how these meetings supported professional development, the excerpts from three meetings were analyzed below to show interchanges involving all teachers along with description of independent work of teachers in their classrooms. We see how they worked together to co-construct problem spaces, with attention to ways in which conversations allowed *all* teachers to stay on a continual improvement trajectory, as well as how similar ideas discussed at the meeting manifested in their classrooms and continued to be worked on and vice versa. Thus, rather than a unidirectional framework for professional development, in which more experienced teachers passed on their wisdom and "best practices" to the less experienced teachers, we see a teacher community as committed to engagement in knowledge building themselves as they were committed to engaging their students in these practices.

Three analyses of interactions presented below were selected to show how teachers consistently identified a significant teaching challenge and engaged in problem solving. These examples illustrate how this teacher community was structured to allow everyone to advance and how it contrasted with professional development designed to convey activity cycles, step-by-step routines, or other set

Table 12.3 Overview of problems discussed at teachers' weekly knowledge-building meetings that correspond to five problem spaces

Problems discussed, based on teachers' "problems of understanding"	Problem spaces
When and how should a teacher "wrap up" an inquiry?	Curriculum/standards (C/S)
How do we assess how much students have learned at any point during an inquiry, so that we know how much of the intended curriculum has been covered?	Students' capability (SC) Social interaction (SI) Classroom structure and constraints (CS&C) Technology (T)
What is the best way to handle superficial student work?	
How do we decide when to move on to a new topic of inquiry?	
What kinds of questions are needed to start a KB Talk?	
What is the best way to manage a Knowledge Forum view?	
How do we know if a knowledge-building principle is coming alive in the classroom?	
How can we encourage meaningful participation in a KB Talk?	
How do we respond to "the right answer" and not break the knowledge-building momentum?	
How can we ensure everyone participates in a KB Talk?	
Is there a best way to conduct a KB Talk?	
Are there steps to take in a knowledge-building class?	
When and how should we support "rise above"?	

procedures. For example, when a newcomer inquired about the "steps to be used for a KB Talk," more experienced teachers conveyed practices that were not step-like – practices that led them to continually refine procedures rather than follow a sequence of fixed steps. Further, as the experienced teachers reflected on the newcomer questions and offered advice, their reflections often led them to suggest novel approaches that they themselves had not tried but would consider in an effort to refine their own practices. Interchanges additionally convey ways in which the community acculturates new teachers into the school-wide teacher knowledge-building community, which operates on the basis of emergent rather than fixed goals. Table 12.3 provides an overview of the types of questions teachers pursued.

The three exchanges presented below span the five problem spaces identified in Table 12.2. And, as reflected in the discussions, proposed solutions, strategies, and contemplation of new approaches, addressing such questions requires a relational approach. Input from teachers with up to 8 years of experience resulted in discussions that moved flexibly between problem spaces and that demonstrated collective relational efforts.

Curriculum and Students' Capability Problem Space: How Can We Encourage Meaningful Participation in a KB Talk?

Knowledge-building discourse can take place anywhere, in face-to-face informal snack-time conversation, in a more formal classroom discussion, or in ideas posted on Knowledge Forum. This discourse is typical of knowledge-building communities and is perceived to go beyond sharing of knowledge, but more to refine, transform, and advance the collective understanding of the inquiry. From the data, it is clear that this group of teachers considered knowledge-building talk (KB Talk) an essential component of knowledge-building discourse and knowledge-building practices. As such, KB Talk was a common topic of discussion at these weekly meeting.

The following is a description of interactions that occurred when the least experienced knowledge-building teacher asked *what kind of questions* they should use to start their students on knowledge building.

Responding to this, Ronny, a teacher with 8 years of knowledge-building experience, explained that the questions could come in various forms and were rather emergent ("if something comes up then it becomes...").

Nancy, a teacher with 3 years of knowledge-building experience, shared her experience on how she got her students to connect their questions about rats to what they observed of their pet rat in class. She wanted students to come up with questions that they were genuinely interested in. She explained that there might be many reasons why students were not interested in a question and that the teacher had to understand those reasons to keep students motivated.

Ronny added that this process of students owning the questions might happen later, as students needed time to develop and process their ideas.

Nancy went on to share the example that occurred in her class when she tried to get the students to study rats and their living conditions. The students were asking why it was that the rat did not drink from the silver-colored container. They started to postulate some interesting theories such as "it is not warm enough" and "I don't think they like the silver." Once the students began to be engaged in working on something, they conducted research during their library period. Someone found out about using a special tray (the "pee tray") used by rats, and the students wanted to test their ideas. The teacher went to the hardware store to get more information and supplies that enabled student investigations.

Nancy asked how she could ensure that she was guiding the students in an inquiry involving important content knowledge. She felt that her role was to create an environment to support students in raising questions that interested them, and she had helped the process by building up the rooms with books on rats. She reported that she was not anxious about the content, suggesting that she was confident regarding her work on the *curriculum/standards* problem space which moved beyond content coverage. Her approach in this problem space was more adaptive to students' interest than to the curriculum script. She reflected on the way she should design lessons to ensure that students had sufficient opportunity to figure out their question, connecting to *curriculum* to *students' capability problem space*. She was aware that she held control of how the lesson unfolded, as she reflected in her comments that the students came up to her to suggest what they should do next. Running through the various lesson ideas, she commented that "I didn't think I focused on content. . .I have not been anxious about the content at all."

Nancy was quite certain that the initial questions need not be constrained by content, but she was more interested to find out how to sustain knowledge-building momentum. Back in her own class, she explored the *curriculum/standards* problem space by setting an explicit curriculum goals that she wanted to achieve over the course of the year and by designing specific activities to get students to think and ask questions about water. Though she was prepared to embrace students' questions on water, she planned particular questions that she wanted to introduce in her class. She reflected that she "was toying with questions of an island and what would we bring [to an island]," and she felt these questions would be good for their study of water. She did not frame the class inquiry with her questions, but encouraged students to pose questions, and noted great *idea diversity* in their questions. This was consistent with her sharing at the meeting.

Zahra (the most experienced teacher with 22 years of teaching experience and 5 years of knowledge-building experience) reinforced the need to be aware of students' knowledge-building efforts. Interestingly, she conveyed what might be perceived as a dilemma in classroom design: "maybe interest starts to wane, maybe it is time to do a rise above, maybe. . .." Although her intention may not be clear, it suggests a clear relational goal involving students' ideas and curriculum goals, where there is no necessary disconnect between students' ideas and the *curriculum/standards* problem space.

This could indicate that more experienced knowledge-building teachers consider development of students' ideas as more important than content coverage. But the story is surely more complex. Students in this school were doing well on standardized achievement tests and other measures of educational achievement, and teachers had no reason to believe that there was a trade-off between development of students' ideas and content coverage.

Zahra continued to focus on the development of ideas as a guide to the curriculum problem space:

> It is how the ideas grow and – I am also thinking hearing the way the children talk – transcript showing the children in meaningful talk – that is not about content, but about how do you listen, how do their ideas grow: you might forget the content of the talk but it is the way [the talk is done].

Incidentally, Zahra was also the only teacher who started the year by providing enough time for the inquiry focus to come from her class. Zahra reflected in her independent classroom practice that she was "waiting to see what may emerge from the kids." She would start the year by collecting students' emerging ideas on the intended curriculum topic through a series of "morning message times," aligned to the *idea diversity* principle. She engaged the students in working toward common understandings and goals, engaging them in activities designed to create data to help them generate and advance their ideas. For example, she had her students note the daily time of sunrise and sunset and talked about the trend of these recordings. She recorded these data on the side of the board for 2 weeks, during which time she and her intern recorded students' emerging questions and ideas. In the next class, Zahra then had her students contribute notes on Knowledge Forum. She took time to explain the rationale in terms of knowledge-building contribution and, at the same time, allowed her students to suggest other topics at every Knowledge-Building Talk. This was again consistent with what she shared at the meeting.

In sum, the above segment described what happened when a teacher with limited experience wondered what kind of question she could use to kick-start knowledge building (a centrist approach). Through interchanges with other teachers and sharing of actual classroom enactments of the teachers, it became evident that it was important to engage students in identifying questions, that the process was emergent, and that there was often no single question nor a need to be. Taking the sharing by the most experienced teacher and triangulating it with her practice, we could see that from her perspective, getting students to present their "problems of understanding" as a starting point for advancing curricular goals was essential, as was creating a supportive environment. The content would come, the ideas would grow, and the curriculum standards would be addressed (a relational perspective). This perspective was consistent with other comments she made and, with the fact that her students did well, as judged against curriculum standards.

How Do We Know if a Knowledge-Building Principle Is Coming Alive in the Classroom?

In line with their commitment to knowledge-building practice, teachers would regularly commit time during their weekly meeting to discuss specific knowledge-building principles. In one meeting, the knowledge-building teachers decided to explore the concept of "symmetric knowledge advancement" in relation to their own classroom work. This is an interesting segment that illustrates the teachers' struggle to understand the concept of "symmetric knowledge advancement," both for their own professional knowledge and for their students' learning. Their understanding and the degree to which they reconciled the principle with their practice varied significantly according to their years of experience.

Nancy (3 years of knowledge-building experience) began by questioning whether they, as a teacher community, were practicing this concept in their work. Extending from this discourse, Nancy, in her independent classroom work, had often tried to bring this principle alive among her students and her reflection showed that she was also deepening her understanding of the KB principle. For example, she was the only teacher who recorded an episode surrounding a misconception related to a student's theory that rains are produced by "cloud bags." Nancy generated various problem spaces after the emergence of the misconception.

She spent a great deal of time and effort trying to understand the root of the "cloud bag" misconception and to engage students in exploring ideas, rather than directly correcting the misconception. In constructing the *social interaction* problem space, she provided opportunities for the students to talk about two conflicting ideas that had been raised about the formation of rain. She also took time to talk to the student with the "cloud bag" idea, in order to try to identify the root of this misconception. She also got the students to send questions to a Chemistry lecturer in the university:

> Thought a lot about Kenny's statements and theories – how they might be of benefit to all our thinking – how I had maybe got caught up by his "cloud bag theories" and missed some of his bigger questions that could help us ("how can water be in the sky without a container?") – how we might protect him from staying in a polarized position.

After spending 3 months on a few explorations of the misconception that rain resulted from the formation of a "cloud bag" and explorations of related concepts, Nancy felt that the students had advanced as far as they could. She reflected on her role and felt that it might not be fair for her to exert her authority and directly correct the misconception after students had worked so hard to discuss their two views on how rain is formed, yet she felt she could not let the misconception spread within the class. There was no evidence that she searched for deep, underlying big ideas in the domain, which could perhaps have allowed her to engage students in discussions of their disparate ideas, or perhaps she had exhausted the possibilities within her own understanding of weather and rain and was unable to find a connection between the "cloud bag" theory and a scientific account. In any event, she corrected the "cloud bag" idea, and this discussion ended shortly after that. It is evident that Nancy was continually attempting to translate the knowledge-building theories into action in her class, which was consistent with her interest in expounding the theories at the teachers' meeting. Back at the teachers' meeting, Nancy drew an analogy to themselves as teachers, advancing their knowledge both in class and within this teacher community.

Zahra (5 years of experience) created another problem space by asking if there were real communities that achieve such symmetrical advancement. The more experienced teacher, Ronny, shared the original definition of "symmetric knowledge advancement" as one of knowledge-building principles and recognized his own struggle with this particular principle. Zahra advanced their understanding further by defining the technological dimension of the principle as how students' work across views on Knowledge Forum represented this principle. She continued to expand the idea that the measure in ATK (Analysis Toolkit available in Knowledge Forum) showed the kids were working across all the views and asked if that would be considered symmetric as well, that everybody was working on the same things (all the views) not just on theirs? In class, Zahra was also the only teacher who set clear goals to improve knowledge-building practice in a principled way, through the use of data from the ATK. She added, "[I am] really interested in using the Analytic Toolkit at the end of each day to inform my daily teaching. How the tools link to the [KB] principles. How they help the kids to understand the principles better."

As the meeting progressed, the teachers moved on to discuss another knowledge-building principle, *rise above*. Again, it elicited different interpretations from teachers with different years of knowledge-building experience. Nancy explained that for rise above to happen, an idea perhaps needs to exist in a "certain messy state" before it can move into a "higher-level formulation." Clara, a teacher with more than 5 years of knowledge-building experience, provided an explanation grounded in the framework of an idea-centered classroom. She explained it as a point of epiphany, where "certain things come together to move to the next step." Zahra pulled these ideas on *rise above* together and explained how this played out in her class:

> we are getting it, they want to learn how to make *Rise Above*, the idea of what helps them to . . . all those things seem OK . . .not just the epiphany part, we are experimenting, where are we now, so we keep going, it is the time where it comes together and then move forward again.

Alice, the teacher with less than a year of experience, described a superficial feature of an idea-centered event in her classroom, "someone said 'actually now I have changed my mind, I am going with Sage's (student) idea.'" This was her indicator that students were working with ideas, but she was not confident that they would work to improve their ideas. Rather, she felt that young children's mind swayed too easily for meaningful knowledge building to happen.

Exchanges like these show different interpretations of the role of knowledge-building principles in their practice, from a more abstract understanding and a philosophical explanation to concrete manifestation of the principle in the classroom. The most unique interpretation came from Zahra (5 years of knowledge-building experience), which connected explicitly to indicators on Knowledge Forum as well as its direct impact on her classroom work, "not just the epiphany part, we are experimenting. . .."

What Is the Best Way to Manage a Knowledge Forum View?

Knowledge Forum views are graphical representations of a space on Knowledge Forum designed to hold related notes together. They are constructed by participants to give greater meaning to the notes they contain. Every knowledge-building teacher would almost inevitably encounter situation where the number of notes posted on a KF view become too overwhelming for them. The following interaction occurred among teachers with 1–8 years of knowledge-building experience interspersed with classroom practice from individual case studies describing independent classroom practice on such problem of understanding. They provided accounts of the obvious or evident features identified by teachers with limited experience and showed how teachers with more experience addressed these matters and revealed efforts at principle-based action that became more direct with experience.

The conversation started with the "problem of understanding" from an inexperienced teacher on how to manage her class' Knowledge Forum view. The more experienced teachers were able to break down the problem to a deeper analysis regarding students' approach to their ideas on Knowledge Forum. The strategy adopted by the more experienced teachers involved adaptive flexibility to help students relate their ideas to the ideas of the class in order to resolve the problem before determining the procedures to adopt in class.

Nancy, with 3 years (mid-level) of knowledge-building experience, mentioned an obvious or evident feature of her classroom practice that she attributed to *students' capability* and *social interaction* – what she referred to as unproductive notes and a chaotic or messy view on Knowledge Forum. She attributed this, at least in part, to student inexperience in knowledge building:

> Part of what happened, of what is happening in database, it is really chaotic, we are also aware that we are just letting kids go in, not productive, [these] aren't the kind of notes that really help them to build knowledge; I also know that some of them are new, and so I think some of [them] are innocent like they are not realizing what the goal is.

She explored possible strategies, stating them in terms of procedures (use of data projector and whole-group activity), with the latter indicating a possible attempt to address the principle of *community knowledge, collective responsibility:*

> We have been talking about how next to help them work on the database. We did talk about using the data projector and . . . how we can get as a whole group; I felt it has to happen as a whole group because they all have to know it.

Moving on, the possibility that she was searching for a solution with a principle-based component was reinforced in the following comment:

> I am not sure I would like to work with them [that way], I want them to gain more understanding, the goal [is that] they are communicating.

It seemed that the teacher was trying to engage students in a way that would allow them to take more responsibility for their work, as which was consistent with her individual case study.

In class, Nancy had always been guiding her students in making sense of all of the questions and referred them to the following main questions, written on the board in class: Questions in major categories "Water and survival – why do we need water?" "About water: Why does a river move? Why is water wet? Why does it rain? Who made the first language?" Nancy went through the class database and picked up three ideas that she felt would help in advancing the class inquiry on water. In her journal entry she wrote interesting conversations in the database that would be worth following up on: (1) Clouds burst/don't burst – this could be a great topic for us to do more research on; (2) NHL hockey ice – I would love to find out more about this because I think the kids would be interested in it; (3) "Why is water wet?" – this is not a big topic, but I'd like to share the etymology of the word if I could find out something about it. Even though she had these ideas that she wanted to explore, Nancy did not use them to start off the KB Talk. She was guided by the principle of *real ideas and authentic problems*. She tried to create the conditions to help students connect their talk to their ideas on Knowledge Forum, by projecting the Knowledge Forum view on the screen in class and asking students if they had any interesting notes on Knowledge Forum that they would like to discuss. This represents a conscious shift on the part of Nancy toward a more relational *curriculum/standards* (C/S) problem space – a problem space expanded by her contributions to that space. This is aligned to the *knowledge-building discourse* principle, in which everyone has a responsibility to contribute to the discussion.

Nancy followed up by sharing her experience with a similar problem. She was more certain and specific and clear that the procedure to be implemented needed to provide the infrastructure for the principle of *idea improvement*, giving ownership to students: "We have a lot of notes that are like yes, no, why are you saying that? – notes that didn't advance our idea." She went on to explore her strategies to achieve idea-centeredness: "We talked about every note that needs to have an idea in it. They can go right to the person to tell the person and talk to you." And shared her recognition of the need for continual improvement was evident in her follow-up comment: "Still in that process, I got some silly notes, this year this is a huge problem." Nancy, who started the conversation, continued to explore the problem that she and the more experienced teacher framed: "How did you get the students started to look at their own notes?"

Zahra, the more experienced teacher, continued to identify strategies for addressing the problem in light of *improvable ideas* principle, mainly from the students' perspective, and riding on the affordance of Knowledge Forum (*technology* problem space):

> We talked first, and they searched for their notes [that] they created just for this year. They put in the note, it is really easy. . .it also gives them a sense of, you can refine the search, the note they created is always there to be improved.

In class, Zahra would always be trying to get students' input onto the database and have a say about their notes on the database. She reflected about her practice, "I felt it was important for the children to have a chance to talk about what was going on the view." She reviewed students' posts frequently and constantly adapted her classroom design based on the emerging students' problems of understanding and set homework for the students based on their own problem of understanding:

> I went through the database and identify problems of understanding that they are curious about right now, and then the child who wrote the note, we wrote it on these cards so we can hang them up and have them off the database and see what we are up to. And then next week for their homework, on their sheet, they are going to write the problem of understanding that is most pressing to them now.

As the conversation continued, Rhonda (less than a year of knowledge-building experience) identified a challenge related to a scaffold support in Knowledge Forum, that students were "really hesitant to say that they have a problem of understanding." Ronny, the most experienced knowledge-building teacher in the group (8 years), responded according to his own experience by reconstructing the problem to let students own their learning:

> I made it clear that you are not responsible for any follow-up to the questions on the database; the question will be worked on if there is an interest, [it is] not something they need to work on, we were just getting them.
>
> …No, I don't want children to think, oh, I have three questions and so I have to do three times more work; it is just to get all the questions and theory on there and see if people [are] interested.

Helen, a teacher of less than a year of knowledge-building experience, identified a similar issue with the "problem of understanding," though she reflected on her role as a teacher in a KB Talk, which is quite a relational reflection, but she continued to explore the format of the KB Talk. She wanted a procedure "so that all students feel successful and get a sense of themselves as someone who can participate in these talks." For example, in class, she got students to use duplo-blocks, with each plastic block building on another to represent building of ideas. The format was to ensure that everyone had an equal chance to contribute.

In this sequence, more experienced teachers were able to relate problems to the knowledge-building principles. In the case of "chaotic activities on Knowledge Forum view," they encouraged the less experienced teachers to look at the deeper feature involving concepts of students' views of their ideas on Knowledge Forum. In the case of students not wanting to admit that they had a problem of understanding, they encouraged them to look beyond and see how to get students to own the problems. In general, the strategies adopted by the more experienced teachers were aimed at helping students generate and improve ideas, relate their ideas to the ideas of others, and experience a risk-free, supportive environment for idea improvement.

Summary of Analysis of Meeting Transcripts and Individual Classroom Practice

Meeting transcripts revealed that teachers with different levels of experience construct similar problem spaces throughout their knowledge-building practice, with the more experienced teacher conveying a much more elaborate and extensive repertoire of strategies from a relational perspective. Records of classroom enactment of teachers within the group also showed a consistency between what they shared and their classroom practices. We see an indication of less experienced teacher shifting more readily back to centrist problem space in their class as compared to the more experienced teachers, though this needs confirmation from further analysis and case studies beyond what is presented here. For example, when the less experienced teacher asked about KB Talk, the discussion that followed indicated that all teachers viewed students' ideas as important, but the inexperienced teacher focused on format and the question to kick-start the talk. On the other hand, the more experienced teacher took a longer view of the challenge and focused on how to support idea generation and improvement in a community context. This kind of interaction opened up new possibilities for all teachers to advance their practices. Such interaction also illustrates what is meant by the claim that knowledge building operates on the basis of emergent rather than fixed goals. The analyses of interactions among these teachers help to clarify how the co-construction and reconstruction of problem spaces in a teacher community facilitates shifts from centrist to relational perspectives, which then impact their independent practices in their classrooms. This represents an important consideration in teacher professional communities as well as a critical move from skillful practitioner to principle-based practitioner. Both of these factors would sustain work to elaborate deep features of problems and adaptive approaches to the generation and implementation of strategies, and principle-based reflection within problem spaces represents necessary components of idea-centered pedagogy.

Discussion

Changes from Centrist to Relational Perspectives Within Five Problem Spaces Constructed and Explored by Teachers with Different Levels of Knowledge-Building Experience

This study investigates the problem spaces constructed by teachers and the means by which they achieve continual improvement in their practices while fostering continual improvement of students' ideas. To accurately depict teachers' problem space, we need to capture more than snapshots of their practice so as to describe a continuum of events in and out of their classrooms. Understanding the shift in teachers' problem space in this approach helps to inform the design of teachers' professional development programs and professional learning groups beyond lesson design protocol and teaching strategies. Many current professional development efforts place an emphasis on what teachers should know and what their practice should be like, rather than on deeper analysis of the ways to scaffold the thinking and decision-making process of teachers in their day-to-day classroom work.

In addition to describing the problem space, to provide a theoretically consistent and empirically based understanding of the pedagogical shifts within these problem spaces that are necessary for knowledge creation to take place in classrooms, the analyses focus on an overarching dimension of change from a centrist to a relational perspective. The underlying belief, from the centrist perspective, is that the teacher's procedures and presentation of content represent the primary determinant of effective action in these problem spaces. The underlying belief for the relational perspective is that students' ideas and actions represent an underutilized resource and that effective action within these problem spaces requires turning over high-level controls to students so that they can act more effectively and responsibly. In essence, the relational approach requires effective action from both perspectives.

Both perspectives are meant to represent "good teaching" from a constructivist approach. The centrist perspective is reflected in the teacher's construction and elaboration of problem spaces that establish effective curriculum plans, social interaction patterns, expectations, or other "best practices" as used by skillful teachers. The relational perspective is reflected as reinvention of those plans, interaction patterns, expectations, and so forth, as work proceeds to accommodate student input and shared responsibility. This centrist to relational shift is used to characterize three embedded shifts, all of which need to be made to foster knowledge-building pedagogy: (a) surface to deep interpretation of problems and processing of information, (b) routine to adaptive approach to classroom activities and student engagement, and (c) procedure-based to principle-based reflective action.

Accordingly, in knowledge building, construction and elaboration of the problem space represents a dynamic, ever-changing enterprise. This characterization of knowledge-building practice seems to be a double-edged sword. On one hand, embarking on knowledge-building practice naturally puts teachers in a position to design and innovate in a principle-based approach; on the other hand, it has also made formulation of professional activities for such practice extremely difficult due to its need of the implicit shift in practice. This difficulty is even more prevalent because any one point of enactment in a knowledge-building classroom, teachers could be conducting an activity that could look identical to that of a procedure-based classroom. The distinguishing factor is the teacher's focus of practice and her intentions behind the laboratory work. For example, a lesson that involves students testing a hypothesis through experimentation in a science laboratory could occur in either a principle-based classroom or a procedure-based classroom. A knowledge-building teacher would consider the follow-up activities in relation to student's formulation of a theory to be tested or from an exercise prescribed in a curriculum guideline. In view of these varied dimensions of teachers' cognition, description of their problem space becomes essential in understanding the relation between their explicit theories of action and the implicit theories underlying those actions (Argyris and Schõn 1974; Eraut 2000). In addition, considering these characteristics of classroom teaching and learning, detailed accounts of problem space are critical in addressing the immediacy and ongoing nature of teachers' work, especially as action unfolds (Arygris 1995). It is also worthwhile to note that the study of problem space also led inevitably to sharper notion of teachers' reflective practice in their natural setting because reflection-in-action and reflection-on-action are only possible if classroom problems are interpreted as ill-defined problems and not as well-defined problems within prevailing categories of classroom activity.

Once the problem spaces of teachers are shifted, we can be certain that there could be variations on the ways to integrate strategies and activities picked up at different professional development program into their knowledge-building practices. Some may choose to begin with a few basic activities; others may decide to try to integrate as many principles as possible. How much a teacher does and does not do in class is no longer important; what matters is that a shift is made and that the students' ideas take center stage in their budding knowledge creation practices.

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Chapter 13
Knowledge Building Pedagogy and Teachers' Technological Pedagogical Content Knowledge

Nancy Law

Introduction

Knowledge building (KB) is advocated by Scardamalia and Bereiter (1999) as a pedagogical approach that engages learners in a process of inquiry to advance the collective knowledge of the learners about a meaningful problem or issue as a community (in much the same way as researchers work to advance the knowledge of the academic community they belong to). Discourse plays a central role in this approach, but KB would not happen "naturally" just by putting a group of people into discourse, be they face to face or online. An important educational goal of KB pedagogy is to foster students' socio-metacognitive capacity to build knowledge through intentional collaborative inquiry (Bereiter and Scardamalia 1989). Scardamalia (2002) further identified 12 socio-cognitive determinants (or KB principles) that underpin the functional design of KF as a KB technology.

Teachers face a lot of challenges in their efforts to implement KB in their classroom (Lakkala et al. 2005), including not only the need to understand the theoretical underpinning of KB but also how to apply the theories in practice. The latter involves task design, organization of the collaboration, and the role given to the web-based collaborative learning environment. Bielaczyc (2006) goes further to argue for the need to design an appropriate, four-dimensional social infrastructure (cultural beliefs, practice, socio-techno-spatial relations, and interaction with the "outside world") in order to realize the potential of technology tools to support learning that involve social interactions.

Research on teacher professional development to promote KB adoption points to the importance of creating a knowledge building community among teachers (T-KBC) (Chai and Merry 2006; Chan and van Aalst 2006) as a key success factor. In recent years, sustained network communities of KB teachers and researchers

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connected locally and internationally have demonstrated success in fostering an expanding community of teachers who make progressive improvements in their KB pedagogical practices (Laferrière et al. 2010). These successes are encouraging evidence that deep changes in pedagogy are possible even though the larger educational context in terms of curriculum standards and public examinations remains largely traditional. On the other hand, in our observation as participant co-learners since 2001 in the Learning Community Projects for Knowledge Building in Schools (http://lcp.cite.hku.hk, to be referred to as LCP in short) of more than 100 teachers who have participated in the LCP projects at some stage, only a small number have made sustained and progressive improvements in their pedagogical implementation of KB. Apparently, the teachers follow different learning trajectories, with different learning outcomes in terms of beliefs, knowledge, skills, and practices.

While there are research findings about teacher learning for KB implementation, there is not much in the literature that describes the pathways of change that a teacher goes through from being a novice KB teacher to becoming an "expert." Teacher learning *and* progress in teacher practice are connected, emerging processes. How does a teacher's understanding evolve alongside his/her practice? Is there a progressive set of phases in the implementation path that a teacher would need to go through as Bielaczyc (2006) anticipates, or are there identifiably different pathways, which may be context dependent? If a teacher progresses in KB pedagogy, then arguably his/her students' engagement in and outcomes from their KB activities should also demonstrate greater advancement. Following this line of reasoning, there have been preliminary attempts to study teachers' trajectories of learning through examining changes in students' discourse behavior (Law and Wong 2003; Law et al. 2011). However, these studies do not include examinations of changes in teachers' beliefs or practices. We have reported in Law et al. (2012) a study of a teacher's journey over a period of 3 years in her efforts to introduce KB in her classrooms, from the time when she was a novice teacher making the first attempt in introducing KB in her classroom to becoming fluent and confident in designing and executing curriculum units that will be successful in advancing students' understanding through their engagement in asynchronous discourse on Knowledge Forum® (KF). That study reveals a gradual shift in the teacher's design focus, followed by a refinement in facilitation skills. This paper builds on that study to examine what advances in knowledge and skills the teacher has to make in order to have achieved such deep advances in her pedagogical practice.

Teacher Knowledge for Pedagogical Adoption of the Knowledge Building Approach

The use of discussion forums as a channel to support collaborative learning and inquiry has become commonplace with the increasingly easy access to the Internet. There is abundant research evidence that students may not have high motivation to participate simply because a forum is made available for discussion (Hew et al. 2010; Yang et al. 2007), and there have been many studies that examine the characteristics of asynchronous discussions that contribute productively to student learning (Guzdial and Turns 2000; Penny and Murphy 2009; Ruberg et al. 1996). Much attention has been given to research on pedagogical strategies to enhance student engagement and learning outcomes (Dennen 2005; Mazzolini and Maddison 2003; Moss and Beatty 2010), but few studies have tried to tackle this problem from the perspective of the necessary teacher knowledge for teachers to be able to adopt such strategies effectively in their everyday practice.

Drawing insight from Shulman's (1987, 1999) work that points out the need for teachers to have not only requisite content and pedagogical knowledge to be a competent teacher but that they also need pedagogical content knowledge to be able to cope with the demands of deploying particular pedagogical approaches for specific subject content, Mishra and Koehler (2006) identify seven types of knowledge that are needed for teachers to be able to effectively integrate the use of ICT in teaching and learning. These are content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPCK or TPACK). Many teacher education programs designed to help teachers promote teacher adoption of ICT in their pedagogical practice have focused on the requisite knowledge beyond TK, that is, TPK, TCK, and TPCK.

In a comprehensive review of the research literature on TPCK, Voogt et al. (2012) point out that there is no common agreement on the nature of TPCK as a theoretical construct, nor is there a commonly adopted set of measurement for TPCK. On the other hand, whether TPCK as a construct is seen as an extension of PCK (Cox and Graham 2009; Niess 2005), as a distinct body of knowledge (Angeli and Valanides 2005), or as an interplay between the three areas of technological, pedagogical, and content knowledge (Mishra and Koehler 2006), there is general consent that the intersection and interaction between these three areas of knowledge and performance are important in the development of teacher competence to integrate ICT use in their teaching.

In this study, we would like to explore what changes in the teacher's knowledge (as demonstrated through competent performance) can be observed as she advanced in her competence in implementing the knowledge building approach that integrate discussions on Knowledge Forum® as a core part of the pedagogical practice over the 3 years of her pedagogical journey that we have documented. This would provide us with a deeper understanding of what it takes for teachers to be able to develop competence in the design and implementation of science curriculum units that adopts knowledge building as its pedagogical approach. In particular, we would like to examine the nature of the advances over time during the years to identify if one can discern features of a trajectory of growth and development in the process.

Research Context and Research Design

This paper reports on a single case study of a teacher who has participated since 2005 in a University-School Partnership project titled Learning Community Projects (LCP) and organized as a design research (Barab and Squire 2004). The LCP is a university-based project involving teachers and teacher educators working together as coresearchers and co-learners in a professional network to implement KB as a scalable pedagogical innovation in Hong Kong schools. Teachers within the project held scheduled meetings to co-plan KB curriculum units and share teaching plans, which were collected and archived in the LCP project database. All online discourse posted by students and teachers on Knowledge Forum® since the beginning of the project were also archived and made accessible for research and professional development purposes. Teachers in the project were encouraged to write reflection notes on their practice and invited for interviews from time to time. This rich archive of LCP data constitutes a core data source for the current study.

In selecting a teacher for this study, we first identified a number of teachers known to have made significant advances in their understanding of KB as well as in their teaching practices over the years. We finally selected TH as the focus for our case study as she taught the same subject at the same class level over a period of 3 years. TH had 5 years of teaching experience in schools when she joined LCP in September 2005. She was attracted to the use of a discussion forum, which she considered to be an additional channel for students to learn some important scientific concepts in a more interesting way when she attended a teacher workshop on KB in 2004. She joined LCP in 2005–2006 when she moved to a new school whose principal encouraged all teachers to adopt more student-centered inquiry-oriented approaches to teaching. She tried to implement KB in her grade 7 science classes during each of the 3 years she worked in that school. In addition to working collaboratively with teachers in the local network, TH participated in the Knowledge Building International Program (KBIP; Laferrière and Law 2010) during the 2006–2007 and 2007–2008 school years.

In Law et al. (2012), we report on the changes in pedagogical design and execution observed through an analysis of the teaching plans and the teacher interviews (interviews additional to those in the archive were conducted for the purpose of the study). In the present study, we take the outcomes of our analysis of the teachers' curriculum and pedagogical design as the starting point and use that as the basis to further analyze the kinds of teacher knowledge observed in the process, categorizing them into the seven domains of knowledge based on the TPCK framework.

Data, Analyses, and Results

Irrespective of the specific theoretical stance of the researchers, TPCK is valued and studied as the necessary knowledge base teachers need to effectively teach with technology. Also, similar to studies on PCK (Kagan 1990), teacher knowledge is conceptualized within the broader context of teacher cognition for decisions and action and includes knowledge, skills, and teacher beliefs (Koehler and Mishra 2005). In fact, knowledge (including skills) and beliefs are so intertwined that these two terms are sometimes used interchangeably in the PCK/TPCK literature (e.g., Kagan 1990). Baxter and Lederman (2002) argue that PCK as a construct encompasses what a teacher knows and does, and the reasons for his/her actions. This study adopts the same perspective in studying TPCK. While many different methods of assessing PCK/TPCK have been reported in the literature (Voogt et al. 2012), there are debates on the ecological validity of some of the methods (Baxter and Lederman 2002). On the other hand, the link between teachers' decisions and teacher knowledge is well acknowledged in the literature on TPCK, regardless of the position taken on the nature of TPCK (e.g., Angeli and Valanides [2009], Koehler and Mishra [2005], Niess [2005]).

In this study, we consider data collected on teachers' decisions (pre-active, interactive, and post-active) and their actions in real-life classroom settings over sustained periods of time to be ecologically valid data sources for identifying teachers' TPCK and their development over time. Teacher knowledge is manifested through the pedagogical decisions made about the curriculum goal(s) targeted, through the design of learning and teaching activities, and through the execution of the pedagogical plan, including facilitation and feedback given to the students. All seven types of teacher knowledge are expected to play a role, as well as to be reflected through the teacher's decisions and actions.

Whether knowledge building is taking place in a classroom (here, classroom refers loosely to organized learning as designed and facilitated by a teacher, both inside and outside of the physical classroom, including online activities and interactions) cannot be determined by the activities that happen, but depends on whether the learners are engaged in exploration of ideas to advance their collective knowledge and understanding. On the other hand, learning and knowledge building in the classroom are mediated through the activities orchestrated or facilitated by the teacher. Hence, we use the sequence of activities/tasks that students experience as the basic framework to organize the classroom data collected. For each activity or event, we identify from the primary data (teaching plans, curriculum resources, online discourse data on KF, and the teacher interview protocol) the targeted learning goal(s) and the activity details to identify the pre-active decisions made by the teacher and the knowledge and beliefs reflected through such decisions.

Further, because of the importance of online discourse in the theory and practice of knowledge building, and in particular the critical role of questions in driving knowledge building inquiry, we have also identified all the questions the teacher put forward for the students to work on in KF. As is revealed through the data analyses reported below, the nature of the questions posted and the process through which the inquiry questions were identified/generated reflect important aspects of the teacher's knowledge in relation to KB implementation.

While observations of classroom interactions and student presentations were made over the 3 years to TH's KB classrooms, these were not done systematically. Hence, identification of interactive decision making and the teacher's knowledge reflected in such processes are not conducted in this study. On the other hand, there have been systematic data collected in the form of end-of-school-year interviews with her at the end of each of the three school years to reflect on her KB implementation for the year, her own assessment of students' KB performance and ability, and which aspects of her KB implementation she wanted to improve on for the following school year. An additional interview with TH was also conducted by the researcher after reading the three interview transcripts and other related data to seek further clarifications for the rationale behind decisions or actions when necessary. These interview data contribute to our analysis of teacher knowledge manifested in their pre-active and post-active decisions.

Extending CK, TK, and TPK Repertoire: Introducing Forum Discussions

TH experimented with the use of KF in her teaching for the first time during the academic year 2005–2006. She was very much attracted to the idea that students could continue to learn through discussion after school hours. Table 13.1 presents a summary of the key teaching activities and forum discussion questions TH designed and implemented and the types of knowledge that she made use of in the process. She chose the unit on energy in the grade 7 science curriculum as the context for her KB implementation. There were three core concepts for this unit: different forms of energy, transformation of different forms of energy and the principle of energy conservation, and fuels. The teaching plan basically followed the topic sequence and activities in the textbook. There was no real change in the way teaching and learning were conducted except for the introduction of KF to the students and posting some related seed questions for students to discuss. Some end-of-chapter questions were selected for the students to discuss on KF.

The last column in this table records the main areas of knowledge under each of the seven domains based on the TPCK framework that were evidenced through TH's planning and teaching activities. Of these, three entries are knowledge called into play specifically to introduce the use of KF to support student learning, and these are highlighted in the table. From the list of activities and knowledge entries

Table 13.1 Table summarizing the key teaching activities and forum discussion questions TH designed and implemented in 2005–2006 and the knowledge evidenced in the process

Pedagogical design sequence summarized from teaching plan and archive of teaching materials				**Teacher knowledge evidenced (based on TPCK framework)**	
Topic	Core content	Teaching activities	Questions for forum discussion	Type(s)	Description*
Forms of energy	Introducing the different forms of energy: heat, light, sound, kinetic, potential, etc.	Conduct textbook expt. and identify the forms of energy Build roller-coaster using online simulator Collect information from web on energy change in roller coaster ride	How do different types of energy affect the motion of a roller coaster? What is potential energy? At what point in a roller coaster ride does potential energy become kinetic energy?	CK	Knowledge of the topic The discussion questions selected are on core scientific concepts.
				PK	Ability to guide students in experiments, group work, etc.
				TK	Use of online roller-coaster simulator Use of search engines to look up information Use of Knowledge Forum® for discussions
				PCK	The experimental activities and learning resources (e.g. video) selected
Energy changes	Energy conversion: controlled and uncontrolled, intermediate forms of energy during conversion	Conduct activities and expt. in textbook Watch video on gas explosion, discuss energy changes involved	What are the intermediate forms of energy in roller coaster and horror tower rides?	TPK	Teach students to use the roller-coaster simulation Select Knowledge Forum® for discussion and teaching students how to use it
Fuels	Common fuels, safety in using fuels	Follow textbook activities Find out the major forms of fuel used in Hong Kong	What makes a good fuel? What are safety issues in the storage and transporting of fuels?	TCK	Selection of online roller-coaster simulator
				TPCK	How to use the online roller coaster simulator with students to highlight the energy conversion processes involved.

* Highlighted elements are teacher knowledge evidenced that are directly related to the design and implementation of online discussion on Knowledge Forum®.

in the table, it is clear that TH was a very fluent science teacher who incorporated experiments and various resources and activities into her scheme of work. Furthermore, the use of ICT to support student learning is not new to her. Within this unit, in addition to the use of KF, she also engaged students in using a roller-coaster simulator and collecting information online using search engines. So, within her professional knowledge repertoire, she already possessed the TK, TPK, TCK, and TPCK to conduct these ICT-supported learning activities. In introducing online forum discussions to her students, she expanded her knowledge repertoire in three ways. First of all, she demonstrated her TPK in selecting KF instead of other threaded discussion platforms because she appreciated the availability of some unique features that would provide enhanced support to collaborative co-construction of knowledge such as scaffolds, keywords, rise-above notes, etc. She also demonstrated TK in the use of various features of KF and CK in the selection of the most pertinent conceptual questions on the topics for discussion. Unfortunately, these extensions of her professional repertoire were not sufficient to engage the students in sustained discussions on the questions she selected. In fact, the students did not respond seriously to the questions. What they posted were mainly off-task chitchats. When she was interviewed later that year about her experience for the year, she expressed disappointment at the students' apparent lack of serious interest in the online discussion. The interviewer asked her how she expected the online discussion to have helped the students to learn if they were seriously engaged. She said she wanted to find out what kinds of misconceptions students held on energy so that she could deal with them in greater depth during class teaching. This reveals that to TH, the online discussion is simply an extension of the classroom talk that she normally held with students using the IRE model of classroom discourse (Cazden 1988).

TH started reflecting on the reasons why the students did not find interest in discussing these questions. When she discussed these questions with members of the LCP community, one of the responses she received was: "End-of-chapter questions generally have 'model answers.' What is there to discuss about these questions except to find out what the right answer should be?" So one big question that TH thought much about after this first experience was to find out which kinds of questions would really engage students.

Expanding PK, PCK, and TPK Repertoire to Incorporate Student Discussions as a Core Learning Activity

TH decided to incorporate the knowledge building approach into her teaching of the same curriculum unit on energy as she did for the previous year. In preparing for this unit, she thought seriously about the rationale for introducing discussions as a pedagogical activity and decided that this would be worthwhile only if the learning goal targeted was difficult to achieve otherwise. Upon recommendation from a member of the LCP community, she read up on the science education literature related to conceptual difficulties and common misconceptions students often have related to energy and energy transformations. She also realized from her readings the importance of understanding students' preconceptions and was attracted to the use of cognitive conflicts as a strategy for stimulating conceptual change.

It can be seen from the summary of the sequence of pedagogical events she designed for this year's trial presented in Table 13.2 that her teaching plan was totally restructured. It no longer contained any reference to specific curriculum topics or activities mentioned in the textbook. Instead, the plan was structured into two phases, the first to prepare students cognitively for conceptual explorations of core concepts around energy and energy conservation, while the second phase was designed to allow students to further explore and consolidate their understanding through a variety of group- and class-level activities. A most significant change in her pedagogical design was the role of the online discussions within the entire scheme of work. Unlike the previous year's design in which the online discussions were simply added as an activity to "enrich" the students' learning experience, the entire unit on energy for this year was designed as an "extended discourse" focusing on identifying and dispelling (or changing) students' misconceptions in this topic area. The online discussion played a central role in providing a conceptual focus for all the learning activities. While the plan did not mention the experiments and computer simulation on roller coaster, etc., she actually conducted those activities in phase 1 before introducing the online discussion task. So, these "standard" activities were used to "set" the scene for the discussion questions she thoughtfully put to the students. At this point, the concepts energy transformation and conservation of energy were already introduced to the students. She then tried to engage the students in the online discussion through introducing a paradox that links with a topic that is familiar to students and the media: energy crisis. The paradox "If energy is conserved, why is there still an energy crisis?" would be a conundrum for those who cannot differentiate between energy and fuel, which is a common misconception that students often have. In phase 2, three parallel sets of activities were planned. The first was an online discussion task for the whole class, focusing on the differentiation between fuel, energy, and power and the relationship between renewable energy, nonrenewable energy, and energy conservation. The second was a group design activity that required students to construct an artifact related to the theme of energy conservation. The third task was for the students to engage in discussion with students from a Canadian classroom also working on the theme of energy.

In reviewing the knowledge evidenced in the new learning design and her execution of the planned activities gathered from the notes in her teaching plan and the interviews with her, TH has expanded greatly her professional repertoire, particularly in relation to the use of discussion as a pedagogical activity. As can be seen from the highlighted items in Table 13.2, the greatest expansion was in fact in the PK area, concerning the setting of questions and guidance to students in the discussion process. For the former, she developed a deeper understanding of different types of questions and their role in the process of inquiry and knowledge

Table 13.2 Table summarizing the key teaching activities and forum discussion questions TH designed and implemented in 2006–2007 and the knowledge evidenced in the process

Pedagogical design sequence summarized from teaching plan and archive of teaching materials	Teacher knowledge evidenced (based on TPCK framework)	
	Type(s)	Description*
Phase 1	CK	• Knowledge of the topic • The discussion questions selected are on core scientific concepts
Aim: To elicit students' concepts about energy and energy source/fuel, relationship between fuel & energy. Seed questions (questions posted by the teacher to stimulate student discussion): Initial seed questions in December: 1. What is energy? 2. What is energy crisis? In January, introduce new seed: 3. If energy is conserved, why is there still an energy crisis? (N.B. The first two seed questions focus on the "what" in energy crisis, followed by a "why" question.) Notes on facilitating students' work on KF: • It is the first time for students to use KF, a good starting point to get them to use scaffolds. • This is a stage of exploration and sharing of ideas, and students should demonstrate a few KB principles, community knowledge, collective responsibility, democratizing knowledge. • Besides the open exploration and sharing of ideas, students need to know that ideas can be improved, and to demonstrate the constructive use of authoritative sources.	PK	• Ability to guide students in experiments, group work, etc. • Differentiates between factual and explanatory questions and set the former before the latter • Use of paradox to stimulate student interest in discussion participation • Set discussion participation requirements for students • Guiding students to reflect on their learning process in knowledge building • Guiding students to understand that ideas are improvable and to write rise-above summaries • Guiding students to collaborate with peers in another country
• Students are also expected to write their learning diary on KF. Towards the end of phase 1, rise above notes will be written under teacher's guidance.	TK	• Use of online roller-coaster simulator • Use of Knowledge Forum® for discussions
Phase 2 Three learning tasks are designed for the students to conduct in parallel. Task 1: Class level activity - Tackling problems of understanding through discussions Seed questions: 1. What are the differences, if any, between these 3 words: energy, fuel and power? 2. What is the difference between renewable and non-renewable energy? Are both forms of energy conserved during energy transformations? Student engagement: 1. Read notes on KF at least twice a week, and post at least two notes by mid-Feb.	PCK	• The experimental activities and learning resources (e.g. video) selected • Seed questions for discussion selected based on common student misconceptions found in science education literature and cognitive conflict model • Identifying and showing students' "thoughtful notes" as examples of good discussion notes
2. Write a reflection note on the most impressive/important ideas learnt from the discussion in the learning diary view by the end of Feb. Task 2: Group level activity - Solving the energy crisis by designing or developing something. Each group of students may decide to work in one of the following ways: • Designing artifacts (e.g. posters, songs, movie clips, animations, etc.) that would contribute to public education on energy crisis and energy conservation; • Designing technology (an operable product or a design plan) to help solve the energy crisis;	TPK	• Teaching students to use the roller-coaster simulation • Selecting Knowledge Forum® for discussion and teaching students how to use it • Teaching student how to use scaffolds in KF as metacognitive devices to structure their writing • Using rise-above note function in KF for summaries • Use of learning diary on KF to encourage reflection
• Developing energy conservation policies/plans/proposals, with rationales, for the government/schools/families/individuals in Hong Kong to implement.	TCK	• Selection of online roller-coaster simulator
Task 3: Community level activity – Deepening discussion with the broader international community Six very thoughtful notes from students' work in phase 1 will be identified and posted on the view "(IC) ENERGY-Thoughtful Notes from Discussions" to stimulate further discussions by all students from all schools. This IC view is a shared space for idea bouncing and further discussion.	TPCK	• How to use the online roller coaster simulator with students to highlight the energy conversion processes involved

* Highlighted elements are teacher knowledge evidenced that are directly related to the design and implementation of online discussion on Knowledge Forum®.

building, including the differentiation between factual and explanatory questions, putting the former before the latter as an easier starting point to get the discussion going but that explanatory questions are the more important in advancing understanding, as well as the choice of a paradox linked with a familiar topic, energy crisis to stimulate student interest and engagement. She also demonstrated a much deeper pedagogical knowledge in the knowledge building principles and in strategies to motivate student participation and managing discussions involving international collaboration.

The other major areas of knowledge expansion observed were in PCK and TPK. In TH's choice of seed questions based on common student misconceptions found in the science education literature and in her selection of students' "thoughtful notes" to highlight for students' further discussion, we see a major advancement in her PCK for facilitating knowledge building discussions. As the online discussion was no longer structured as end-of-topic discussions on end-of-chapter questions but as a discussion on a single theme (energy) extended over several weeks, she was able to guide students in the use of the more specialized features in KF, including scaffolds, rise-above notes, and the writing of learning diary notes in a view set aside to encourage student reflection, thus demonstrating her broadened repertoire of TPK.

It is clear from this analysis that the more successful implementation of knowledge building during the 2006–2007 school year was primarily due to her expanding PK and PCK, though her expanded TPK also contributed to more effective use of the KF as a discussion and knowledge building platform. When interviewed about this year's experience, TH was not entirely pleased with the outcome. On the one hand, she was encouraged by the more positive engagement of students and the fact that some of the students were able to demonstrate some rather profound understanding such as the following excerpt from one of the students' notes:

> Observation: I notice: energy crisis just means shortage of petroleum and coal. . . . human being rely too much on non-renewable energy like petroleum and coal. Once they are burnt into other form of energy, we can NOT obtain them back in reversed way. . . . they are non-renewable, ... Then eventually, ALL of them will be consumed in the future. . . This is known as energy crisis. . . To conclude, the term energy crisis is just for our convenience. It has nothing to do with the physical law conservation of energy....

However, she also noticed that only a minority of the students was interested and able to engage in this level of discourse. Many of the other students soon lose interest and were not even able to grasp that significant scientific concepts are being discussed and differentiated. As TH had the opportunity to visit the physical and virtual classrooms (i.e., discussion views on KF) of some other teachers with very rich experience in knowledge building pedagogy in the LCP community, she became aware that some teachers were able to engage the majority of students in serious inquiry on questions of understanding that were identified by the students themselves. This became the starting point of her knowledge building pedagogical journey in the following school year.

Enhanced PK, PCK, TPK, and TPCK for Designing Learning Experiences That Nurture Students' Epistemic Agency for Knowledge Building

In the 2007–2008 school year, TH took a totally different approach to curriculum design to integrate the knowledge building approach into her teaching of the formal science curriculum. This time she was very bold in not restricting her "experiment" to a few weeks' teaching on a specific curriculum unit but expanded her plan to almost half a year, around the theme of *sustainability* which does *not* appear in any part of the grade 7 science curriculum. From her previous year's experience and what she learned from other teachers in the LCP community, she was convinced that to nurture in students a knowledge building orientation and culture required extended periods of engagement. Sustainability was the theme selected by the IKIT (http://ikit.org) community for international collaboration among classrooms as this is an important global issue and can be flexibly linked to many different curriculum topics irrespective of the specific country or education level concerned.

The plan for implementing knowledge building that she shared with other teachers in the LCP community at the beginning of the school year was relatively brief even though it covered a 5-month period for its execution. In her curriculum planning for the previous year, the content focus for knowledge building was a number of key concepts for a particular curriculum topic—energy—and the seed questions she placed on KF for the online discourse provided the conceptual anchor for students' cognitive engagement throughout the different curriculum activities. For this year, sustainability constituted a high-level concept that was not confined to a specific topic or area of science. Students' understanding of sustainability can be deepened through learning about different domains in science. TH chose two major units in the grade 7 curriculum, living things and water, as the subject domains of learning and investigation to develop students' understanding of sustainability. As TH explained in the interviews, all the standard curriculum activities and resources such as experiments and computer simulations normally included for these two units were deployed. As she was very familiar with these, there was no need for her to put these details down in her plan. Furthermore, the pedagogical goal she wanted to achieve was not only the science curriculum goals but also to foster students' ability to engage in inquiry-based learning through providing learning-to-learn opportunities. It was clear that at this point, she was very confident of her own pedagogical competence. Whereas, in the previous years, her venture into KB pedagogy was to serve the purpose of achieving the science curriculum goals more effectively, her pedagogical goal for this year had already risen above the curriculum specification to include the more challenging, higher-level goal of developing students' KB capacity.

As shown in Table 13.3, online discussion using KF was planned to take place only after the teaching of this curriculum unit had started for 2 months! During those first 2 months, in addition to the standard curriculum activities related to the two focal curriculum units on living things and water, a field trip was organized for the students to explore the characteristics of plants and animals living in different habitats. The standard curriculum activities related to living things and water were to be completed before April, even though the international collaboration activities were not scheduled to take place until the end of April. Hence, there was a loose coupling between the learning activities taking place in the classroom and the online discourse that explored various issues and concepts that students cared about.

An inspection of the analysis presented in Table 13.3 reveals that the major expansion of TH's professional knowledge repertoire during this year was again in PK and PCK, as similar to that in the previous year, followed by TPK and TPCK. There is a sophisticated refinement in the pedagogical skills and knowledge exhibited in the facilitation of students' discussion. Whereas in the previous 2 years there was a tacit assumption that students would be able to engage in a productive discussion if they were interested and willing to participate, TH spent precious classroom contact time during the first 2 months to *model the discussion process* for the students. In order that students would understand knowledge building discussions as distinct from casual discourse or social chat, and integral to in-depth inquiry requiring serious thinking and preparation, she modeled a discourse cycle that involved individual-, group-, and class-level exploration and sharing of ideas. A complete cycle often began with students writing down their own thoughts on pieces of sticky notepaper before sharing with other students in the same group. Each group then further discussed and wrote down their collective views on the topic. Each group was then invited to present and share their ideas to the whole class, followed by a whole class discussion.

Another important change in discussion design was in how the questions for online discussion were generated. In the previous 2 years, all the seed questions were constructed by the teacher, TH. While the questions selected were conceptually important ones, demonstrating a high level of cognitive understanding of the content knowledge involved, students may not necessarily find these questions relevant or interesting. Further, the ability to generate questions and to identify good ones for sustained inquiry is an important benchmark of a person's knowledge building capability. During this year, questions for inquiry were generated by the students themselves. TH also spent time in drawing up "key questions to be investigated" during her planning, which are included in Table 13.3. These questions were ones that TH used in focusing students' attention when conducting different learning activities, such as "What lives in this area?" and "How do human activities impact on this area?" These questions helped the students to generate some pertinent observations, which then served as the basis for generating some further questions that students found to be intriguing and wanted to conduct inquiry on, for example, "Why is there a hole in the [ozone layer of the] atmosphere?" and "How planktons give birth to their babies?"

Besides asking students to generate questions for investigation, she also demonstrated a new pedagogical competence: guiding students to identify which of the questions generated were good questions worthy of inquiry and discussing with

Table 13.3 Table summarizing the key teaching activities and forum discussion questions TH designed and implemented in 2007–2008 and the knowledge evidenced in the process

Pedagogical design sequence summarized from teaching plan and archive of teaching materials	**Teacher knowledge evidenced (based on TPCK framework)**	
Phase 1: Field studies <Dec-Feb 2008>	Type(s)	Description*
1. Students' field work in January 2008 to (i) explore	CK	• Selection of the field trip location & activity suitable for the KB theme *and* the set curriculum units • Selection of good questions from student discussion
- what lives in the areas (understanding of life cycle and growth of specific plants and animals) - the relationship among plants, animals, humans and the environment (ii) prepare short description of the site with photographs ready to be shared. 2. Initial exchange between teachers by Skype of their chosen local areas, through photos and text. Phase 2: Discussion on KF < Feb 2008> • Pupils work on perceived threats to their sites using KF. Students generate their own inquiry questions, first individually, then in groups in class, followed by sharing with whole class face-to-face. After modelling this discussion process, get students to follow similar process on KF.	PK	• Plan, design & lead the field trip & activities • Plan & organize overnight camp for web conference • Curriculum plan built for emergence of students' ideas • Belief in extended (5 months) conceptual engagement, loose coupling between scheduled learning activities & KF work • Confidence in steering learning around a broad theme not specified in the curriculum (sustainability). • Decision to start KF discussion after field trip (from phase 2) • Careful design & modeling of discussion process in class: individual, group then whole class, before starting online discussions • KB talk in class on criteria for good inquiry questions
• Students write weekly learning diary on KF to reflect on the learning process. • KB talk in class on criteria for good inquiry questions and identify examples of good questions. Phase 3: international collaboration < Mar – April 2008>	TK	• Techniques in designing Views on KF to structure discussion in the different phases, and to facilitate collaboration with the international partner
Exchange of databases and rise-above notes between schools. Phase 4: Web conference <25-26 April, 2008> Web conference between all concerned (Arrange a camping night at school for HK students so that they can have web conference with students from Quebec and England). Key questions to be investigated 1. ***What are the threats to the area? / How human activities impact the area?***	PCK	• Equipment and materials for field trip and tasks set for students during field trip • Setting of discussion questions to focus on perceived threats to the field trip site, and how humans impact these areas • Getting students to conduct investigation on adaptation of one organism and to link it to the discussion on KF • Conduct "KB talk" in class and guide students to identify which are good discussions
– Investigate through experiments, field trip, KB talk, KF discourse. Identify which are authoritative sources. a. What lives in the area? (Understanding of life cycle and growth of specific plants and animals) i. Construct a food web of the organisms in the area – incorporating observations of organisms in water samples collected in field trip under the microscope.	TPK	• Organize Web conference • Use of view design feature on KF to facilitate & guide the different phases of the plan • Mark on KF some good questions raised by students to attract student attention to further build-on
ii. How do organisms (animals and plants) adapt to the natural habitat? Choose an animal in the area and study its special features/characteristics for adaptation in terms of food and habitat.	TCK	• Knowledge of search terms and authoritative online sources for the topics
iii. How do the habitats and living organisms in one site differ from the other? (Let students in two schools read each other's notes on this question.) iv. Why are oceans filled with salt water? Is the salt in the sea the same as table salt? What is salinity? Can animals from the sea live in fresh water? (Conduct related experiments.)	TPCK	• Guide students to construct food web from field trip observations • Guide students to research online on relationship between food, habitat and sustainability of ecological environment, concept of authoritative sources
b. How are the organisms affected by their environmental conditions? Conditions to include: i. Water quality: salinity, water temperature, visibility/turbidity, dissolved oxygen, pH,… ii. Air Temperature, wind direction, wind speed. iii. What relationships exist among the living organisms in the area and the above conditions? c. What are the threats to the area? How do human activities impact the area (e.g. urbanization, pollutions, garbage, oil pill, climate change, chemicals, acid rain, etc.)		• Plan meetings on Skype with collaborating teacher in Quebec • Guide students to write rise-above summary notes and place them in the collaboration view for phase 3

2. **How do the threats to the area affect the organisms in the area?** – To investigate this problem, each student will choose an animal living in the area and: a. Research what each animal needs in terms of food and habitat, b. Research how the threats affect the habitat and food supply for the selected animal. There will be KB talks throughout, and a microscope available for examining microscopic life in water.	

* Highlighted elements are teacher knowledge evidenced that are directly related to the design and implementation of online discussion on Knowledge Forum®.

them what constituted the criteria for good inquiry questions through KB talks in the classroom.

Once online discussion started, TH would regularly conduct KB talk in the classroom and ask the students to identify which of the discussion notes posted they would consider to be good discussions, i.e., discussions that would advance their understanding of the topic or problem and the criteria for a note to be considered as a good discussion note. Competent performance in this requires a high level of PCK.

During this year, TH also advanced in her sophistication in using KF to provide more effective support for the knowledge building discourse, such as marking directly on KF the good questions raised by students and using the view design features to guide and focus the different phases of the discussion. These demonstrated her advancement in TPK. She also guided students in the construction of rise-above summary notes and to place them in the collaboration view as the seed notes for online discussion with their Canadian counterparts. This involves the exercise of appropriate TPCK.

With the much expanded repertoire of knowledge, mostly in the PK and PCK areas and also including TK, TPK, and TPCK, the main role of TH as a teacher has gradually evolved into a designer and orchestrator of student learning experiences and a facilitator of inquiry learning by modeling the knowledge building principles through both classroom-based and online discourse activities.

Discussion

In the present study, we have analyzed the advances in knowledge evidenced by TH through her planning, teaching, and facilitation activities in her efforts to implement the knowledge building (KB) approach in her teaching of one science class at grade 7 each year, over three consecutive school years, using the seven domains of knowledge in the TPCK framework. The analysis reveals that the greatest advancement observed was in the area of PK—her knowledge about the theory and practice of KB, particularly in her understanding of the 12 KB principles and what characterizes a KB discourse and the strategies to stimulate and guide students to raise inquiry questions, as well as ways to help students to formulate the criteria for good questions and good discussions. Another major area of professional knowledge advancement observed was in the area of PCK—her ability to integrate her strong pedagogical knowledge in science education such as the organization of field trips, experiments, and computer simulations to support her facilitation. This finding may be somewhat surprising if we consider the primary focus or challenge of KB as an innovation to be the use of KF as the technology platform. As the findings from the present study clearly demonstrate, KB is fundamentally a pedagogical innovation and would only succeed if the teacher can expand his/her professional repertoire in PK and PCK.

KB can be categorized as one approach to computer-supported collaborative learning (CSCL) and hence clearly involves the use of technology. In fact, Scardamalia and Bereiter (2003, 2006) have argued for the critical role technology plays in supporting KB and the importance of providing appropriate technological support for the social and socio-metacognitive dynamics encapsulated in the 12 KB principles. So is technological knowledge important for teacher professional development in order to implement KB pedagogy? Perhaps, a closer inspection of the trajectory of professional development presented in Tables 13.1, 13.2, and 13.3 would provide some insight to this question. During the 2005–2006 school year, TH's main knowledge expansion exhibited was in the areas of TK and TPK, that is, in knowing the features of KF and how to teach students to use KF. However, without a deep understanding of KB and the KB principles, the unique features and affordances of KF would be lost. It is not that TH did not know about the specific technological features such as scaffolds, keywords, rise-above notes, etc., during her first year of implementation. In fact, she was very much attracted to these special features as well as the graphic interface of KF when she attended a course on knowledge building in the first half of 2005. One of the attractions for her in joining the LCP project was exactly to be able to make use of KF in her teaching through the project. However, without the requisite PK and PCK associated with KB, there is simply no way for her to succeed in engaging students in the discourse to the level that would provide a meaningful context to introduce these technological features.

As mentioned earlier in this paper, three views of TPCK can be found in the literature (Voogt et al. 2012): TPCK as extended PCK, as a distinct body of knowledge, and as the interplay and intersections of PK, CK, and TK. Reflecting on the methodology used and findings from this study, each of these three views has its utility depending on the context and purpose for its application. Based on our analysis of the professional development trajectory of TH over the 3 years of her pedagogical experimentation with KB, it is argued here that the first view is the more appropriate and helpful one for interpreting what it takes for a teacher to adopt ICT for effective implementation of a pedagogical innovation. The learning required in PK and PCK is pivotal for a pedagogical innovation, while the new knowledge needed in the TK domain and associated intersections are just extensions of the broadened PCK. On the other hand, this conclusion is not intended to be extensible as a general claim to the nature of TPCK within the broader debate. It is in fact the view here that the nature of the teacher's knowledge required for effective integration of ICT in pedagogical practice depends importantly on the nature of the practice and the specific role of technology in it. Compared to the first view, the third view of TPCK as an interplay and intersection of the three knowledge domains gives a more prominent role to TK in teachers' competent practice. This will probably be the case if the pedagogical approach involved is already familiar to the teacher concerned, but he/she has to explore or experiment with different technologies (e.g., in exploring and comparing the affordances of different wiki tools to foster students' writing skills and media literacy) to develop the requisite e-learning practice. In this case, all three dimensions, technology, pedagogy, and content, are being explored simultaneously and the resulting pedagogical practice is the product of the interplay and intersection between these three domains of knowledge. As for the second view of TPCK as a distinct body of knowledge with seven identifiable domains, it is useful in serving as an analytical framework for investigating and understanding the dimensions of professional development and their developmental trajectory, as illustrated by the methodology adopted in this study. However, based on the analyses results from the present case study, there is no evidence that the nature of TPCK is a distinctive body of knowledge. Angeli and Valanides (2009) argue that TPCK is a distinctive body of knowledge, as TPCK cannot be developed purely through the process of accumulating or integrating different kinds of constituent knowledge, but has to be developed through "specific instruction targeting exclusively the development of TPCK" (p. 158). In this study, the growth in TH's TPCK is primarily gained through a strong focus on pedagogical understanding of and pedagogical strategies for KB.

What insight can we gather from this study about teacher learning for knowledge building implementation? In tracing a teacher's developmental trajectory in learning to implement KB in her classroom, we have gained a deeper understanding of the fundamental changes that took place in here: conceptualization of the purpose of discussions and of her own role as a teacher. Similar to TH, many teachers are attracted by the idea of enriching students' learning experiences through the introduction of online discussions. This is the most "dangerous" stage as this conceptualization rarely works in practice and many teachers "drop out" after some initial experimentation. To see student discussions as a core learning activity that needs to be designed and supported by different learning activities is a necessary step for discourse to bring about productive outcomes. In this particular case study, there was a fundamental transformation in the third year during which TH assumed the role of a learning designer, choreographing and orchestrating students' learning experiences such that the learning goal was not simply focused on specific content but in developing students' epistemic agency for knowledge building. We observe fundamentally different and very impressive learning outcomes in TH's students when that transformation took place (Law et al. 2012).

What roles did the LCP community of KB teachers play in TH's learning and growth in knowledge? This is not a focus of the present study. However, there was evidence from the interview data that the regular network meetings and professional development workshops, as well as peer classroom observations, organized by the LCP project played an important role in her learning and professional advancement. For example, when asked why she decided to continue in the second year when none of her students participated seriously in the online discussion in the first year, she explained that she was impressed by reading students' discussions on KF from other, more experienced network teachers' classes and convinced that KB by students was possible if she could do it in a better way. Her second year's experience helped her to realize that to get KB discussion going required much more attention to the design of the discussion process and the importance of classroom-based guidance and modeling. Her advancement in KB pedagogy in the third year reflects extensive uptake of the ideas and skills being promoted through the LCP professional development workshops: the importance of having students generate and own their inquiry questions, the need to help students identify good inquiry questions and the characteristics of good discussions, and the importance of facilitating and guiding reflection.

While we can see from this particular case study that the LCP network community played an important role in supporting TH's learning and significant advances in KB pedagogical practice, participation in the network per se is clearly not a sufficient condition, as evidenced by the large numbers of teachers who either dropped out of the network or remained at rather low levels of understanding and KB pedagogical practice. What are the necessary and sufficient conditions for teacher learning to achieve such quality outcomes is a question for the international KB community to further explore. Perhaps, more in-depth case studies of teachers' learning journeys in KB pedagogy would be one way to tackle this problem.

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Chapter 14
Teacher Learning in a Professional Learning Team: Of Contradictions and Action Possibilities

Lai Har Judy Lee and Seng Chee Tan

Introduction

The clarion calls sounded to schools are familiar: in this knowledge age, there is an urgent need to raise citizens who have the capabilities to deal with uncertainty in a rapidly changing world where knowledge is in constant flux, and the only way to stay relevant is to be able to learn, unlearn, and relearn. It has become a worldwide phenomenon to focus on how schools could respond to such calls for educational reform, often seen as a critical and strategic intervention to transform society to meet the needs of an increasingly globalized world (Fullan 2001). Since the turn of the century, schools have been confronted with demands for reform and for fundamental changes to the extent that "(f)ew schools remain untouched by new standards, structures, or ideas about practice" (McLaughlin and Oberman 1996, p. ix).

One of the changes that have been called for was for schools to function as "places where students become proficient in all aspects of knowledge work, including its creation" (Bereiter and Scardamalia 1998, p. 690). In order for schools to nurture students who are able to engage in knowledge creation, consideration has to be given to how the curriculum and learning environment could be designed to provide opportunities for such knowledge work. This involves a change in the roles taken by teachers, such as how teachers could design learning experiences to help students go beyond viewing knowledge as mere facts that they either know or do not know, to recognizing knowledge as personally constructed objects to which one may add value. This change in roles in turn necessitates a change in teacher's knowledge and skills in order to assume these new roles (Bransford et al. 1999; Darling-Hammond 1997). These roles touch on many facets such as (a) instructional tasks performed with students' learning as the primary goal,

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(b) institutional tasks performed in response to calls for changes made by governing authorities such as school districts and states, (c) collaborative tasks in which teachers engage in collective inquiry to improve educational outcomes, (d) learning tasks in which teachers develop new knowledge and skills, and (e) relational tasks in which teachers work with students, parents, and fellow colleagues while attending to the general well-being of students (Valli and Buese 2007).

In view of the multifaceted nature of the roles played by teachers and the need to help them better negotiate the increase, intensification, and expansion of their roles arising from educational reform (Valli and Buese 2007), a key component of school change lies in the area of teacher professional development. Research evidence suggests that the success of educational reform hinges upon the building of teachers' individual and collective capacity to promote and sustain professional learning, not just at the level of individual schools but also at the systemic level such that knowledge sharing may occur between schools and their communities (Stoll et al. 2006b). Drawing upon literature related to school improvement, change management, and capacity building, Stoll et al. highlighted the importance of focusing on learning processes, making the best of human and social resources, managing structural resources, and interacting with and drawing on external agents that will help teachers harness individual learning in order to attain collective goals through "collective knowledge creation" (p. 235) that involves engaging in communal dialogue and joint decision-making. The building of teachers' individual and collective capacity is for the ultimate purpose of building students' capacity for learning, as it is deemed that student achievement can only be brought about by building the capacity of school systems to foster teacher learning and for building teachers' capacity to improve their instructional practice (Wei et al. 2009). Hence, in order for schools to nurture learners who are able to thrive in the knowledge age, teachers need to experience for themselves the kinds of learning experiences that they have been called to design for their students (Tan 2010) – learning experiences that reflect the educational philosophies advanced by school reformers.

However, there are concerns about the readiness of schools to foster the kind of professional development that is required for educational change:

> Teachers of today and tomorrow need to do much more learning on the job, or in parallel with it – where they can constantly test out, refine, and get feedback on the improvements they make. They need access to other colleagues in order to learn from them. Schools are poorly designed for integrating learning and teaching on the job. The teaching profession must become a better learning profession – not just incidentally, at teachers' own individual initiatives, but also in the very way the job is designed. (Fullan 2001, p. 266)

This concern suggests that schools now have to design not only for the learning of their students, they would also have to incorporate opportunities for teacher learning to take place. This prompted schools to explore professional development models that meet the twin needs of fostering teacher learning as well as student learning. It is against such a backdrop that schools began to explore reorganizing themselves into professional communities with the aim of engaging teachers in collaborative work and professional learning that will in turn lead to improvement in student learning.

This is one reason why *professional learning communities* (PLCs) have become popular in the education landscape in recent times (DuFour 2004; Feger and Arruda 2008; Stoll and Louis 2007). A central idea behind PLCs is the development of in situ professional learning that includes on-site, school-based forms of professional development, deemed as enablers of professional learning that will bring about the kind of students' learning that is envisioned in the reform literature. This is because such an approach involves teachers in professional learning that requires them to interact and collaborate with one another to solve authentic instructional challenges they meet on a day-to-day basis within their specific contexts in order to improve instruction and their students' learning (Ball 1996; McLaughlin and Talbert 2006). Due to the collective effort required in such professional learning approaches, PLCs are believed to be able to break down isolation among teachers and to foster shared goals among school staff (Stoll et al. 2006b).

Despite the promises held by PLCs, there is still a lack of clarity with regard to how teachers learn and what they learn as members of professional learning communities. To do so, it is important to examine the inner workings of collaborative teams such as the *professional learning team* (PLT), which comprises teachers grouped according to some commonalities, such as teachers teaching the same grade level or the same subject in a school (Sather 2009). This is because the collective learning of teachers working in collaborative teams is central to PLCs (Hord 1997; DuFour and Eaker 1998; Bolam et al. 2005). As the quality of student learning hinges upon the quality of teacher learning, there is a need to understand what enables or constrains teachers' learning at the level of the PLT. The lack of research investigating how teachers shape their own learning as well as their peers' learning in a PLT is a concern, especially when the responsibility for teacher learning has been placed upon teachers themselves during a time when educators tout the PLC as a more effective school-based professional development approach compared to off-site professional development approaches (Grossman et al. 2001; Lieberman and Mace 2008; Mullen 2009).

In this chapter, we shall discuss the use of Engeström's Cultural-Historical Activity Theory as a lens through which teacher learning in the form of teacher knowledge creation in schools may be understood. We shall first examine the concepts of PLCs and views on teacher learning. The definition of learning is highly contested and conceptions of what constitutes teacher learning abound in the literature. To help us navigate the literature to better understand how teacher learning takes place in PLCs, we consider the metaphors of learning that have guided thought on the nature of learning (Paavola et al. 2004; Sfard 1998). The use of Engeström's Cultural-Historical Activity Theory as an analytical framework to study teacher learning in a professional learning community will be explored, and learning points arising from the analysis will be discussed.

Professional Learning Communities and Teacher Learning

The notion of a PLC does not have a singular, universally accepted definition (Hord 1997; Stoll et al. 2006b). However, there is general agreement that the concept describes a "group of people sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-oriented, growth-promoting way" (Stoll et al. 2006b, p. 223) and that the purpose of the professional learning is for the enhancement of pupils' learning. Table 14.1 summarizes some definitions and features of PLCs as articulated by key authors in the PLC literature. One similarity that could be seen in the different definitions is that the professional learning undertaken by the teachers must impact the students they serve. In terms of attributes/characteristics, the different authors also agree on the presence of shared vision and collective/collaborative efforts in terms of learning.

The popularity of PLCs has brought teacher learning to the fore because the collective learning of teachers working in collaborative teams is deemed as a key characteristic of PLCs (Hord 1997; DuFour and Eaker 1998; Bolam et al. 2005). For McLaughlin and Talbert (2006), a school-based teacher learning community such as a PLC is a means for fostering the collective learning of teachers to develop new forms of teaching practice that will bring about a reform in student learning. The technical modification to teacher practice alone will not suffice as there is a need for a more fundamental cultural change, which alters teachers' work and the workplace and fosters a teacher professionalism that is committed to lifelong professional learning and collective responsibility for student learning. Such a change could not be brought about without a change in the way professional development is approached.

The professional development approach traditionally involved the attendance of workshops and seminars defined and delivered by personnel that are external to the school. However, professional development involving in-service seminars is often perceived to be fragmented in that they do not take into consideration how teachers learn and that they are unrelated to problems encountered during classroom practice (Borko 2004; Lieberman and Mace 2008). It has been argued that the best externally designed resources lack a nuanced sensitivity of teachers' knowledge and daily challenges faced in their classrooms, and do not provide opportunities for teachers to reflectively situate what they have learned in their own classrooms (McLaughlin and Talbert 2006).

In contrast, the best conditions to foster teacher learning are to involve teachers in activities that provide them with sustained and continual opportunities to collaborate with fellow educators in examining teaching and learning situations that are specific to their own settings (McLaughlin and Talbert 2006). Research that examined learning communities' impact on teachers' learning and classroom practice noted that the participation in collaborative processes provides teachers with opportunities to share their perspectives and experiences, to question their assumptions and understandings, and to construct new knowledge especially when they interact with people with differing conceptions and opinions (McLaughlin and

Table 14.1 Summary of definitions and attributes/characteristics of PLCs provided by key authors

Key authors	Shirley Hord	Richard DuFour and colleagues	Louise Stoll and colleagues
Definition of professional learning communities	One "in which the teachers in a school and its administrators continuously seek and share learning and then act on what they learn. The goal of their actions is to enhance their effectiveness as professionals so that students benefit. This arrangement has also been termed *communities of continuous inquiry and improvement*" (Hord 1997, p. 1)	"A professional learning community is a group of educators committed to working collaboratively in ongoing processes of collective inquiry and action research in order to achieve better results for the students they serve" (DuFour et al. 2006, p. 14)	"A professional learning community is an inclusive group of people, motivated by a shared learning vision, who support and work with each other, finding ways, inside and outside their immediate community, to enquire on their practice and together learn new and better approaches that will enhance all pupils' learning" (Stoll, et al. 2006a, p. 5)
Attributes or characteristics of professional learning communities	Five attributes (Hord 1997):	Six characteristics (DuFour and Eaker 1998):	Eight characteristics (Bolam et al. 2005):
	Shared values and vision	Shared mission, vision, values, and goals	Shared values and vision about pupil learning and leadership
	Collective learning	Collective inquiry	Collaboration focused on learning
	Supportive and shared leadership	Collaborative teams	Collective responsibility for pupil learning
	Supportive conditions	Action orientation and experimentation	Professional learning: individual and collective
	Shared personal practice	Continuous improvement	Reflective professional enquiry
		Results orientation	Openness, networks, and partnerships
			Inclusive membership
			Mutual trust, respect, and support

Talbert 2001; Putnam and Borko 2000; Stokes 2001). Darling-Hammond and McLaughlin (1995) were of the opinion that professional development that enables teachers to teach in the ways envisioned by school reformers needs to involve teachers as both learners and as teachers. In other words, the teaching profession needs to be a learning profession as well (Darling-Hammond and Sykes 1999). This highlights the importance of what teacher learning entails.

Putnam and Borko (2000) advocated the adoption of the situated learning perspective for the investigation of teacher learning, especially with regard to how teachers learn new ways of teaching. The situated learning perspective views learning as a social process, by which a social actor learns how to participate in the discourse and practices of a community. In his social theory of learning, Wenger (1998) emphasized upon learning as social participation, where the learning of individuals is deemed as involving the engagement of and contribution to the practices of their communities, and the learning of communities as involving the refinement of practice and ensuring new generations of members. As such, communities of practice are sites where newcomers may gain access to the shared practice of a community by progressing from more peripheral to more central participation in the community in order to maintain the practice (Lave and Wenger 1991).

The notions of peripheral participation and communities of practice hold much promise in the study of teacher learning in PLCs. Wenger (1998) explained notions such as *participation* and *practice* that might have been taken for granted. For him, the term *participation* describes the "social experience of living in the world in terms of membership in social communities and active involvement in social enterprises" (p. 55). Distinguishing it from the mere engagement in activities with people in a context specific to a community, he positioned it as an active and complex process that involves the whole person, body, mind, emotions, and social relations so much so that the participation affects the person's experience and shapes his/her action and identity in a community. Wenger used the term *practice* to refer to "doing in a historical and social context that gives structure and meaning to what we do" (p. 47). Wenger also characterized learning in practice as processes whereby members of the community evolve their forms of mutual engagement, understand and tune their enterprise, as well as develop their repertoire, styles, and discourses.

On the one hand, the ideas by Lave and Wenger (1991) and Wenger (1998) have provided the research community with conceptual tools to understand the notion of participatory trajectory and how a teacher changes his/her participation in a community over the course of his/her career. Hence, it is helpful in examining how beginning teachers learn on the job or of how experienced teachers take on new roles in new job scopes. On the other hand, there are certain aspects especially with regard to the definition of learning that could perhaps be further elucidated (Edwards 2005). For example, the close link that Wenger established between learning and practice is that "(l)earning is the engine or practice, and practice is the history of that learning" (p. 96) and the links made between learning and knowing and between learning and meaning in his social theory of learning seem to suggest a complex web of relations that perhaps could be teased apart in order to clarify the nature and mechanism of learning in a community of practice. Other areas of concern raised pertained to the lack of an account for the kinds of learning other than those experienced by newcomers to a community, for example, kinds of learning that could occur among experienced teachers who are already engaged in central participation in the practices of a community (Levine 2010). It also does not account for the changes of practices over time, the invention of new practices, or the production of new knowledge; to do so, the metaphor of learning as knowledge creation may be employed (Edwards 2005).

As collaborative work lies at the heart of what teachers do in PLCs, a framework that allows the study of the aims and nature of collaborative teacher learning activity is needed. Taking into consideration the need for teachers to engage in learning experiences that equip them to design learning experiences for their students that involve knowledge work, the use of Activity Theory as a lens offers conceptual tools that could be useful (Levine 2010).

Activity Theory as a Lens for the Study of Teacher Learning

The concept of "learning" is one that has been fraught with a multiplicity of meanings, underlying assumptions, and cases (Hager 2004). As the definition of learning is highly contested, it helps to consider the metaphors of learning that have guided thought on the nature of learning. Sfard (1998) argued that there are two metaphors of learning that have been influencing educational thought: learning as *acquisition* and learning as *participation*. To these two metaphors, Paavola et al. (2004) added a third – that of *knowledge creation*. They examined three models of innovative knowledge communities: Bereiter's (2002) theory of knowledge building, Engeström's (1987) theory of expansive learning, and Nonaka and Takeuchi's (1995) model of knowledge creation. Out of these three models of innovative knowledge communities, Engeström's model of expansive learning seems the most suitable for the purpose of studying teacher learning in PLCs due to its emphasis on the sociocultural and historical context of the human activity of learning. This is a consideration that is especially crucial when we consider the context that teachers work in and the expectations that have been placed on their shoulders – expectations that have arisen from the calls for educational change and reform.

For the teaching profession to be a learning profession, teachers need to simultaneously consider the twin goals of student learning and professional learning. This calls for a consideration of a learning experience offered to the teacher as a learner, and the nature of teacher learning. The knowledge creation approach conceptualizes learning as a collaborative effort for developing shared objects of activity and mediated artifacts, which in the case of Engeström's model consist of practices and activity systems (Paavola et al. 2004). In addition, learning is the expansion of one's action possibilities (Roth and Lee 2007). Hence, to study teacher learning in PLCs, one needs to examine whether and how teachers conceptualize their shared object of the activity of *professional learning* and transform this activity system, and develop practices that not only meet the learning needs of their students but which also address their own professional learning needs. To do this, we turn to the conceptual tools offered by Engeström's Activity Theory.

Engeström (1999a) developed the Activity Theory by building upon the idea of mediation in the works of Soviet cultural-historical psychologists such as Vygotsky, Leont'ev, and Luria. A central tenet is the view that the behavior of human beings can only be understood when viewed in their sociocultural context. Human activity, which is mediated through the conceptual and material cultural artifacts that people use, constitutes the basic unit of analysis in Activity Theory. Engeström's theory of expansive learning is based on what he termed as an "ideal-typical sequence of epistemic actions in an expansive cycle" (Engeström and Sannino 2010, p. 7) as follows: (1) *questioning* some aspects of the current practice and wisdom; (2) *analyzing* the situation to surface the underlying causes or explanatory mechanisms; (3) *modeling* the solution in terms of the newly found explanatory relationship; (4) *examining* the new model to understand its potentials and limitations; (5) *implementing* the new model; (6) *reflecting* on the process; and (7) *evaluating* the process and consolidating its outcomes into a new, stable form of practice. Engeström viewed the process of expansive learning as a "construction and resolution of successively evolving tensions or contradictions in a complex system that includes the *object* or *objects*, the mediating *artifacts*, and the *perspectives* of the participants" (Engeström 1999b, p. 384). As such, in an expansive learning cycle, participants reconceptualize their activity system, transforming the motives and objects for the activity system in the process.

As schools are organizing themselves into PLCs where teachers take charge of their own school-based professional development, teachers need to bear the responsibility of facilitating their own and their peers' learning on top of focusing on their students' learning such as the planning of lessons, teaching, and formatively assessing their students' learning. What do teachers need to do in order to meet the learning needs of their students while at the same time facilitating their own and their peers' learning? What are the models of teacher learning to guide such school-based teacher educators to formulate practices that are not yet there? According to Engeström (1991), unlike formal educational institutions where the curricular content is determined ahead of time by knowledgeable adults, knowledge creation in work organizations is not provided by a competent "teacher" who knows what is to be learned but is initiated by contradictions between and within activity systems (Engeström 2001). Indeed, teachers given the responsibility of facilitating their peers' learning often struggle with determining what is to be learned ahead of time due to the complexity of teachers' work: each teacher faces different classroom contexts, and each teacher has different learning needs. As such, the very practices they need to learn are in the very process of being defined, and they are learning new forms of activity that are not there yet (Engeström 2001).

This was the case for a group of teachers who made up a professional learning team (PLT) of teachers of children in the same grade in an elementary school. The first author joined the PLT for their weekly meetings as an observer during the year when the school first organized itself into a PLC, which is further subdivided into 13 PLTs according to grade levels or language of instruction. The team consisted of

Table 14.2 Roles of teachers in the PLT

Name (pseudonyms)	Roles within the PLT
Ms. Poh	Facilitator for book discussions during semester 2
Noraini	Member
Ying	Advisor to the level manager during semester 2
Nina	Facilitator for book discussions during semester 1
Alice	Level representative at the health education committee
Zainul	Level manager
Larry	Level representative at the mathematics committee and coordinator for lesson studies
Jane	Assistant level manager, level representative at the English language committee, and coordinator for lesson studies
Siti	Level representative at the science committee
Olivia	Member
Rani	Member

teachers with a wide range of teaching experiences, from “untrained” teachers in the school to gain teaching experience while waiting to be enrolled in the teacher education college, beginning teachers who had only been teaching for 6 months, teachers with 2–5 years of teaching experience, to teachers with 8 through 28 years of teaching experience. One of the teachers, Ms. Poh (all names used in the case study are pseudonyms), was the school staff developer (SSD) who looked into matters pertaining to teacher professional development. The school structured common PLT meeting times into all teachers’ timetables so that all PLTs were able to hold weekly meetings that lasted for 1 h each. Two of the teachers in the group were given the roles of level manager and assistant level manager and were in charge of duties such as determining the agenda for each week’s meetings, arranging for different teachers to record the notes of meetings, and working with the SSD to schedule professional development activities. Table 14.2 summarizes the roles of the teachers in the PLT.

The weekly hour-long PLT times were set aside for the teachers to engage in various forms of professional learning activities. One of these activities included book discussion sessions where teachers read and discussed chapters from the book entitled *The Skillful Teacher: Building Your Teaching Skills* (Saphier et al. 2008). The school incorporated book discussion sessions for the purpose of exposing teachers to literature to help them gain a shared pedagogical language. The objective was that the professional learning would eventually translate into improved classroom practice, as shared by Ms. Poh, when she spoke to the teachers during the first PLT meeting of the year to explain the rationale behind the professional learning activities that had been planned for the school year: “All these, whatever we have in the school, all these, the idea is classroom outcomes. It should all be translated back to classroom outcomes. So our teaching and learning should be improved.”

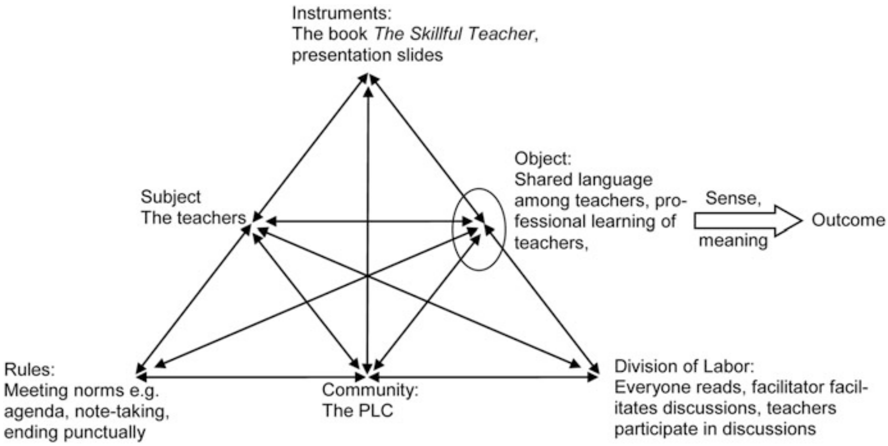

Fig. 14.1 The structure of the book discussion activity system

As part of the instrumental case study (Stake 1995), field notes were recorded during the meetings, which were also video recorded with the permission of the teachers. There were a total of six book discussion sessions spread over the year, held during the PLT's weekly meetings. Video logs were generated by viewing each video from start to finish in one continuous sitting whenever possible, with notes being taken to provide a record of major occasions, the approximate timings of the occasions, and the transitions between occasions (Erickson and Shultz 1981). The discourse that took place during the meetings was also transcribed. One-to-one interviews were also conducted with the teachers.

The book discussion sessions may be represented using Engeström's (1987) depiction of a human activity system as shown in Fig. 14.1. In this collective activity system, the *subject* refers to the group of teachers who were going through the book discussion sessions with the guidance of a facilitator. The *object* refers to what is being done and learned together by the group (Engeström and Kerosuo 2007) or the "raw material" or "problem space" at which the activity is directed (Engeström and Sannino 2010). In this case, the object is the professional learning of the teachers and a shared language among the teachers with which to discuss pedagogical issues. The object is turned into *outcomes* with the help of *instruments*, which in this case refer to the book and accompanying materials used during the book discussions. The oval around the object in Fig. 14.1 indicates the "inherent ambiguity of the object of the activity" (p. 6) in the sense that it is in a state of flux and subject to change. The individuals and subgroups who share the same general object is the *community*, and is taken to be the school-wide PLC as a whole in this case. *Rules* refer to "explicit and implicit regulations, norms, conventions and standards that constrain actions within the activity system" (p. 6). They include norms related to the weekly PLT meetings such as informing the level manager ahead of time when a teacher needs some time to address the rest of the teachers during the PLT meetings. The *division of labor* refers to "horizontal division of

Nina:	(Shows Side 1) Okay. Okay, ready? (Walks to the computer to start the slide presentation) Teachers, may I have your attention?
Larry:	Yes, yes!
Nina:	Thank you! Okay, I've asked around, and I think majority have not read chapter 2, so that's alright. I will just go through the slides and then I will give you this handout, we will do this exercise, and then, if we have time, we will do chapter 2, if not, we will then, the next round, okay? And then at the end of today, we also need to select one more chapter to do, because actually, Ms. Poh has selected the introduction chapter which is what we are going to do today, as well as Clarity. That means, how we teach with clarity. Okay? So, ah, in between, we have about two sessions which is up to us to select as a level, because depending on the needs of the level, we can select topics to do, okay? So, we will have to think about that later. Okay (sing-song manner)! (Clears the throat) I must have a disclaimer there (pointing to the presentation slides), this is not done by me. This is done by the master teacher (laughs), this is done by Sandra, and so, I'm actually standing on the shoulders of giants, okay? And because there are no speaker notes, so I have to think like her and trying to understand what she, what she wants to do with this slide. Okay, I think what she is trying to say here is um, just like when you want to cook a dish, we have to, um, be skillful in how we manage the dish, and also to cater to the needs of the person who eats the dish. Okay? We need to be very good in what we are doing. Okay? …

Fig. 14.2 Excerpt from the first book discussion session

tasks and vertical division of power and status" (p. 6). In this case, it refers to the roles of the facilitator in relation to the subject, that is, the group of teachers.

Figure 14.2 shows the first three turns of talk that took place during the first book discussion segment. Although copies of the chapters were distributed to the teachers and the main agenda of the session was for the teachers to talk about what they had read, it turned out that the majority of the teachers did not read the chapter. It is interesting to note that Nina commented "*so* that's alright" which seemed to suggest that it was a situation that she had perhaps expected and empathized with to a certain extent. The "disclaimer" she made about the slides – that the slides were not created by her and that she did not know what the originator of the slides had wanted to convey – seems to suggest that she might have perceived her role as facilitator as conveying information about the book to the teachers, instead of facilitating a discussion of concepts in the readings assigned for that day. She then proceeded to read information off the slide and continued to do so for a number of slides following slide 1.

One of the central tenets in the theory of expansive learning is the consideration of contradictions, described to be “historically accumulating structural tensions within and between activity systems” (Engeström 2001, p. 137). For example, contradictions may arise when an activity system adopts a new element (such as a new tool or new object) that collides with an old element (such as established rules or division of labor). Developmentally significant contradictions may manifest as conflicts, dilemmas, disturbances, and local innovations (Engeström and Sannino 2010). Some manifestations of contradictions, indicated as lightning arrows in Fig. 14.3, could be seen during this first book discussion session.

Considering that this was the first session that would set the tone for future book discussion sessions, it is interesting to note the very long turn of talk by Nina, the facilitator, which lasted for about 6 min as she went through the prepared slides. It was the first time that the school embarked on the use of book discussion sessions for almost all the PLTs in the school. To prepare for this initiative, facilitators were given the book to read during the school vacation period prior to the new school year. Also, presentation slides were prepared by the school’s senior teachers and shared as facilitation resources with the facilitators. However, the presentation slides, which were meant as a scaffold, became the source of a contradiction when Nina read off them in place of facilitating a discussion about the book, possibly due to another contradiction, the teachers not reading the assigned chapter in preparation for the session.

Although the object of the activity was to develop a shared language among the teachers with which to discuss pedagogical issues, the teachers did not complete the assigned readings (contradiction represented as a lightning arrow between subject and division of labor in Fig. 14.3), and, instead of discussing the ideas in the book, the ideas were presented by Nina using the prepared slides (contradiction represented as a lightning arrow between instruments and object). In addition, it was the usual practice for a designated notetaker to record for each meeting, documenting key decisions made and actions that need to be taken. This rule of note-taking continued for the book discussion sessions, even though some teachers were not sure what should go into the notes, such as whether they were expected to summarize everything that was shared during the presentation segments. This practice of recording notes was another potential source of contradiction, indicated as a lightning arrow between rules and object in Fig. 14.3.

While there appeared to be some resistance on the part of the teachers (in fact, Nina jokingly referred to the teachers as “resistant students” later on during the first session), the uncertainty expressed by Nina about what the slides were intended to convey by the teacher who created the slides also points to the need of the school to provide relevant support to facilitators. For example, arrangements could be made for all facilitators to meet to provide them with opportunities to clarify the objective of the book discussion sessions and to share with one another strategies for facilitating interactive discussions among teachers. A skilled pedagogue may not

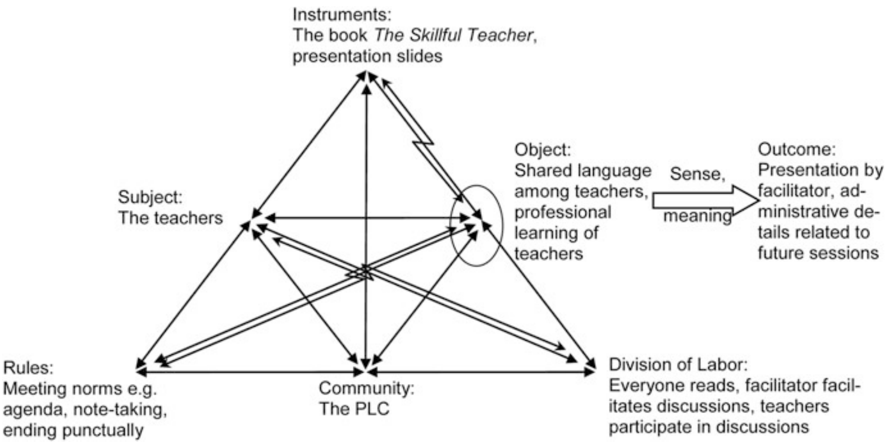

Fig. 14.3 Contradictions in the book discussion activity system

necessarily be a skilled andragogue; something needs to be done to help classroom teachers make the transition to being a school-based teacher educator, that is, someone who can facilitate the learning of fellow teachers.

About 5 months later, Nina was deployed to teach at another level, and Ms. Poh took over the facilitation of the book discussion sessions. By then, the PLT had already completed two sessions out of the total of six scheduled for the whole year. Ms. Poh facilitated the third session, which focused on the introduction of some concepts related to tuning-in or how teachers may prepare their students to learn something. In the following short excerpt (Fig. 14.4), we see Ms. Poh introducing the concept "Reason It's Worthwhile."

She invited the teachers to discuss the concept by positioning herself as one who had not used this strategy before, and she gave a non-example of "Reason It's Worthwhile." What ensued was a session where the teachers contributed their views and collectively arrived at examples of some reasons that could be given to explain why the learning of certain topics was worthwhile and how teachers could go about deriving reasons. During the session, Ms. Poh made presentations about the concepts being discussed during the session, but she would often try to engage the teachers in short episodes of discussions by posing relevant questions.

At the end of the session, Ms. Poh showed the teachers a list of eight strategies taken from the book. She then asked the teachers to choose and read up on a strategy so that they may try the strategy in class and present what they had learned at the following session. She stressed that the reason for her to do so was so that the book sessions would focus less on her teaching the teachers about various strategies but more on all the teachers sharing with one another and learning together. By doing so, Ms. Poh introduced a change in the activity system, particularly in relation to the division of labor, as depicted in Fig. 14.5.

At the following sessions, the teachers took turns to make short presentations about the strategy each of them had read up on, explained the meanings of terms

Ms. Poh:	(Shows the presentation slide with the words “Framing the Big Picture – Reason It’s worthwhile) This is something that I personally do not do much of. I don’t know about you, maybe you can share with me.
Larry:	Reason?
Ms. Poh:	Reason it’s worthwhile to learn something. I don’t tell them why it’s worthwhile to learn about tenses. I say “You learn because I’m the teacher!” (Teachers laugh). Yea? I don’t know whether you’re like me?
Larry:	Like, um, learning about decimals, what is the purpose? When they are exchanging money, they need to know that aspect.

Fig. 14.4 Excerpt from the third book discussion session

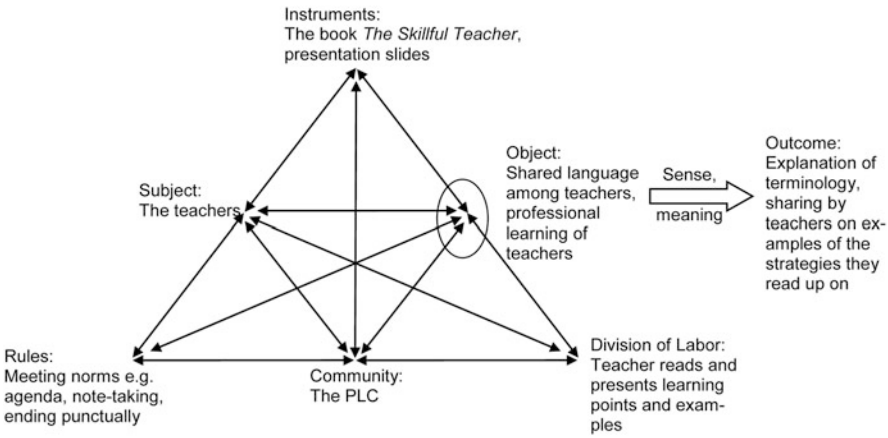

Fig. 14.5 Book discussion activity with a modified division of labor

used in the book, shared concrete examples of how they had or could use the strategies in their classrooms, and elicited examples from the other teachers. A few teachers presented their material in creative ways. For example, Olivia, who was asked to present the segment on graphic organizers, presented her points in the form of a graphic organizer. Larry, who was assigned to present examples of mental imagery, brought the teachers through a brief imagery exercise. Not only did the change in the division of labor result in a different mode of participation by the teachers, it also provided the teachers with an opportunity to make use of the language in the context of what they had done or would do in their classrooms in relation to the strategies discussed in the book. In the process, for those brief moments, they opened up their classrooms for their fellow teachers to have a glimpse of how they applied the strategies in their own teaching and shared their personal views about the effectiveness of those strategies.

The theory of expansive learning views learning as a "longitudinal process in which participants of an activity system take specific learning actions to analyze the inner contradiction of their activity, then to design and implement a new model for their activity that radically expands its object, opening up new possibilities for action and development" (Engeström and Kerosuo 2007).

By introducing the change in the division of labor, Ms. Poh took a small step toward opening up new possibilities for action by the teachers in the PLT. During the interviews, two teachers shared that they felt that they had benefited from reading and presenting what they had read:

> Breaking up the large portion and everybody took a small portion to present really helped, rather than everybody reading and trying to make sense. Helpful to see it from the perspective of other teachers. Don't really remember much from reading. All of us remembered what we presented, can't remember what was presented verbally by others.

> Instead of reading all the chapters, I prefer to read only one section and share with the teachers because the chapters are sometimes quite thick; it is not that we don't want to read but because we simply don't have the time.

In terms of achieving the object of having the teachers gain a shared language and gaining professional learning that impacts classroom practice, more could be done. Teachers with fewer years of teaching experience reported having learned useful concepts from the book discussion sessions. The more experienced teachers, however, tended to feel that they did not learn new concepts through the sessions:

> The book gives a name to the practice. Reaffirms that I have been doing the right thing. Gives a name to the practice, and gives more steps to it.

> Most of what was discussed in *The Skillful Teacher*, we have already learnt or heard from other people, but just given a nice name, packaged nicely. Whatever was shared, I believed we have covered it before.

These teachers were of the view that while they did not necessarily feel that they had learned new concepts through the book discussions, they felt that the book affirmed their existing classroom practices and gave a name to the practice that they had either already learned or already put in place in their teaching.

With regard to the object of helping teachers attain a common language with which to discuss pedagogical matters at a conceptual level, the teachers were seldom observed making use of the nomenclature found in the book outside of the book discussion sessions. One of the more experienced teachers, Ying, shared that teachers should have been given more time to articulate how they applied what they had learned from the readings to their classroom practice. The PLT underwent lesson study sessions as a means for the PLT to collaboratively plan a "research lesson," conduct the lesson in class with one member teaching and the rest gathering evidence on student learning, reflect upon and discuss the evidence gathered, and use the lessons learned to further improve the lesson (Lewis 2002). Despite the scope for the nature of lesson study, the teachers were seldom observed using the shared language supposedly gained during the book discussion sessions to discuss issues during the lesson study sessions. It was observed that other than Ms. Poh, Alice, and Noraini who mentioned a few concepts from the book during their individual interviews and Ying who made an explicit link between questioning techniques as discussed in the book and the questioning techniques employed by a research teacher during a lesson study research lesson, the other teachers hardly made use of the vocabulary used in the book when discussing matters related to teaching and learning outside the book discussion sessions.

Engeström (1991) wrote about the encapsulation of school learning where students separate what they had learned from school textbooks from the rest of their experience, rendering much of the knowledge they gained from school inert. He noted that making the school text the object of the school learning activity system instead of making it the instrument for understanding the world robs the activity of its instrumental resources. Likewise, a focus on the book *The Skillful Teacher* itself may render it to become the object of the activity system, in the process obscuring the espoused object of helping teachers gain a shared conceptual language.

Engeström advocated the application of Davydov's (as cited in Engeström 1991) method of ascending from the abstract to the concrete so that subjects might attain "a new type of theoretical concepts, theoretical thinking, and theoretical consciousness" which entail "high-level metacognitive functions, such as reflection, analysis and planning" (p. 250). According to Engeström's argument, in order for expansive learning to take place, teachers should be provided with opportunities to "analyze critically and systematically their current activity and its inner contradictions," what Engeström termed as "the context of criticism" (p. 254). One possible means of doing so could be to hold a candid discussion about the inner contradictions that surfaced during the first book discussion session when it was noticed that the teachers did not read the chapter prior to the session. The underlying reasons could stem from factors as varied as time, beliefs about the book, priority placed on reading, the amount of material to be read, and access to the book. Such a discussion could perhaps help the facilitator to better understand what the underlying reasons were and what could be done to address them.

Engeström (1991) also recommended the provision of a "context of discovery" (p. 251) that can be reconstructed for the formulation of practical solutions instead of a closed key text, as well as a "context for application" which refers to "meaningful contemporary social use and formation of knowledge about the phenomena to be mastered" (p. 253). We argue that the context of discovery and context for application have to be deliberately designed for the teacher learning experience to be rooted in the kinds of authentic issues that teachers face daily. For example, besides preparing reading materials and presentation slides, the facilitator could also design a context within which teachers may make use of the common language to discuss the issues at the conceptual level. This could come in the form of a scenario encountered during teaching. It could also come in the form of the shared classroom context that the PLT teachers would have experienced when they observed research lessons during the lesson study sessions. This also suggests that instead of viewing the activity system for book discussions as being separate

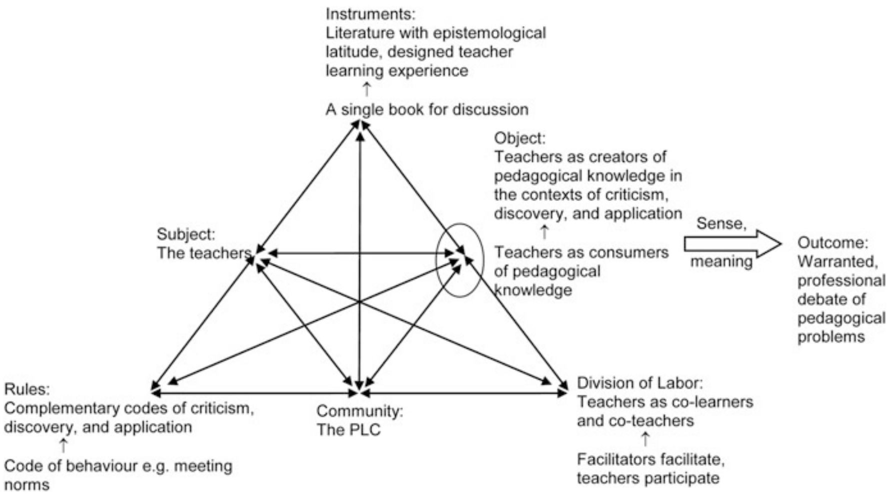

Fig. 14.6 An expansive learning model for the book discussion activity system

from the activity system for other professional development activities (e.g., that for lesson study) undertaken by the PLT, the teachers in the PLT could be helped to see that the boundaries of the seemingly separate activity systems are not impermeable and that their professional learning could be enriched if they allow elements to cross the boundaries. The use of vocabulary gained from the book discussions to discuss issues faced during lesson study sessions is an example of such boundary crossing.

Perhaps, to prevent encapsulation of teacher learning that is bound to specific texts chosen for book discussion sessions, we could apply Engeström's recommendations to design for a book discussion activity system that could foster expansive learning, as depicted in Fig. 14.6. A key consideration lies in an expansion of the shared object of book discussions such that teachers shift from being consumers of pedagogical knowledge to being creators of pedagogical knowledge. In order for teachers to transform their pedagogical practice with the view of reforming student learning, schools need to go beyond positioning teachers as "mere recipients of authoritative discourses about 'research knowledge', 'best practices', or 'teaching techniques'" (Greenleaf and Katz 2004, p. 197) to positioning teachers as authors of pedagogical knowledge who engage in informed and warranted professional debate of pedagogical problems. As shown in Fig. 14.6, this entails a redesign of professional learning experience offered to the teacher as learner, through an expansion of action possibilities related to the instruments, rules, and division of labor within the book discussion activity system.

In terms of the instruments, time spent on preparation of slides that summarize the chapter readings could instead be apportioned to the design of authentic teacher learning experiences that engage the teachers in applying the strategies discussed in the book and to compare their relative merits. For example, scenarios drawn from the lesson study research lessons could be discussed in relation to the specific topic selected for the book discussion session. As all the teachers would have attended the research lesson, they have a common classroom context in which they may discuss pedagogical issues at a conceptual level using the shared language gained from the assigned readings. Also, a single book may not be able to provide teachers with a wide enough access to epistemological views with which they may make informed judgments when faced with pedagogical problems. Instead, the book could be supplemented with literature that takes other perspectives on learning in order to provide teachers with greater epistemological latitude.

In terms of rules, norms that will best serve the purposes of the book discussion session could be articulated. For example, it may be helpful to remind the teachers that the object of the book discussion sessions is not to master the content of the book or literature (the instruments) per se but to use the context of the discussion sessions to help the teachers articulate connections between what has been addressed in literature and what they practice, apply new-found connections, as well as critique and challenge assumptions. This is needful as teaching is highly contextualized and the answers to the pedagogical problems that teachers face in class may not be found in books or literature but perhaps in how they critique existing practices, discover new connections, and apply pedagogical concepts.

In terms of division of labor, the PLT could consider involving teachers as co-teachers and co-facilitators like what Ms. Poh had done. Instead of the facilitator helming all the book discussion sessions, the teachers could be involved in anchoring the discussion of different aspects. Guidance could be provided by the key facilitator with regard to the design of teacher learning experiences, as not all teachers may be able to readily take on the role due to differences in competencies that are required in facilitating student learning and in facilitating teacher learning.

Conclusions

A study of learning that unfolds in the sort of multifaceted environments like what we have in schools requires conceptual tools that account for such complexity. The study of human learning needs to consider the culture in which the activity of learning occurs and the historical dimension of the learning (Roth et al. 2012). As the Activity Theory contains heuristic tools to help us examine relationships between various elements within a system, it serves as a suitable framework for the study of development and change.

We have applied the use of the Activity Theory as a lens for examining what took place during a few book discussion sessions that spanned over a year in an elementary school. Used as an analytical framework, Activity Theory afforded the examination of what was taking place from a perspective that "transcends traditional dichotomies of micro and macro, internal and external, mental and material, individual and social, thought and action, quantitative and qualitative, observation and intervention, as well as agency and structure" (Roth et al. 2012, "Background to

Activity Theory" para. 1). It facilitated the asking of questions in a range of aspects that might not have been asked otherwise.

The application of Activity Theory uncovered contradictions that were inherent in the PLT's book discussion activity system. A consideration of these contradictions affords the researcher with conceptual tools to surmise how the activity system could be developed in such a way that teachers could rise above the contradictions to transform the entire book discussion activity system from being one whose object is to foster teachers as consumers of pedagogical knowledge to one whose object is to foster teachers as creators of pedagogical knowledge. By breaking the encapsulation of learning that may arise from a focus on the text per se, it is possible to expand the possibilities for action by the teachers by focusing on what they could do as a result of gaining a more nuanced understanding of the text. This could only be achieved through a redesign of the learning experiences offered to the teachers and that revolve around the text. This calls for teachers who are skillful in designing for teacher learning as well as being skillful in designing for student learning. In the hurried contexts of school, it is a challenge that teacher educators and especially school-based teacher educators are grappling with. Engeström's Activity Theory may be used to reveal contradictions inherent in the practices and activity systems of professional learning teams. It also offers conceptual tools that could help in the expansion of action possibilities to create practices that are not there yet.

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Chapter 15
Reflections and Commentary on Knowledge Creation in Practice

Peter Reimann

Transforming Experience: It's Not Only About Problem Solving

KB is typically related to problem solving. This has to do with the focus on knowledge advancement and idea improvement, the yardstick usually being the extent to which these two help to overcome puzzles and problems, often set by teachers ("Why are plants green?") or problems grounded in the world of students. The proximity to problem-based learning is therefore not surprising (e.g., Yeo, Chap. 9). But knowledge can be more than a contribution to individual and collective problem-solving capacity.

Richard Prawat's writings (1991, 1993, 1999) have helped to identify the limitations of seeing knowledge and learning solely in the service of developing problem-solving competencies and of the corresponding pedagogical interpretation of constructivism as engaging students in solving practical problems. The tendency to equate the value of learning with its practical value, its relevance for individuals' everyday life, goes back to interpretations of Dewey's educational philosophy. However, as scholars of Dewey's work have been at pains to point out, he was profoundly ambivalent about the relevance issue. In contrast to much popular interpretation, Dewey can be read as seeing the relevance of education not so much—and certainly not only—tied to the improvement of practical knowledge and procedural skills, but to *the enrichment and expansion of everyday experience*. This is the interpretation that Pugh (2011) suggests based on Dewey's late work on aesthetic experience (Dewey 1934/1980), which has not been brought into contact much with his writings on education (Dewey 1938).

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The upshot is that we ought to consider not only the *impact of experience on learning* but also the *impact of learning on experience*. Dewey elaborates in his work on arts the notion of an experience as a special kind of experience, as explained by Jackson (1998):

> Our interactions with art objects epitomize what it means to undergo an experience, a term with a very special meaning for Dewey. The arts do more than provide us with fleeting moments of elation and delight. They expand our horizons. They contribute meaning and value to future experience. They modify our ways of perceiving the world, thus leaving us and the world itself irrevocably changed. (p. 33)

An experience is hence transformative—it expands both perception and value. Things more fully perceived can be subjected to more discerning value judgments, positive or negative. An experience is not just a passive phenomenon, something that happens to a person; instead, it equips the perceiver with certain anticipations and a sense of closure; it is ". . .so rounded out that its close is a consummation and a not a cessation" (Dewey 1934/1980, p. 35). This sense of anticipation is also characteristic for Dewey's notion of "an idea." Ideas are possibilities; each idea "is anticipatory of some possible future experience" (Dewey 1933, p. 117). Like an experience, an idea is transformative in that it guides attention, perception, and action.

Pugh (2011) suggests the notion of a "transformative experience," conceived as "a learning episode in which a student acts on the subject matter by using it in everyday experience to more fully perceive some aspect of the world and finds meaning in doing so" (p. 111). This definition includes the three elements found relevant by Dewey to characterize an experience: (a) expansion of perception, (b) experiential value, and (c) motivated use. Motivated use involves the trying out of ideas in everyday experiences. Experiential value refers to the valuing of content for the experience it provides. Specifically, it "involves attachment of additional meaning to those aspects of the world more fully perceived and to the concepts that brought about the expansion of perception" (Pugh 2011, p. 113). Thus, grounding knowledge building not only—and perhaps not even primarily—in problem solving but in an expansion of the capacity to perceive and experience would contribute to tempering a purely instrumentalist view of (school) learning and building links to the affective dimension of learning.

An orientation to students' experience—and experiencing—as part of what can be enriched by engaging in knowledge building focuses on the role of the individual learner. Since, as we have seen, ideas are in certain ways similar to experiences, and since ideas are the central object in knowledge-building theory and pedagogy, this orientation affords a closer look at the interplay of the individual and the social in knowledge building.

Ideas and Knowledge

Knowledge-building theory (KBT) does not make a systematic distinction between knowledge and ideas. Since idea improvement is perhaps the most important principle of knowledge-building pedagogy, and the central object in software supporting knowledge building, such as Knowledge Forum™ (Scardamalia and Bereiter 2006), it seems important to consider what the relation between ideas and knowledge might be. Reflecting on the nature of ideas will also help to be more precise about the interplay of the individual and the social.

As a tentative distinction, the notion of an idea seems closer to individual reasoning, and to psychological constructs, whereas knowledge by definition is a social construct. At least, *coming up with an idea* is something we would locate primarily in the individual. From another perspective, the notion of an idea is very close to Popper's World 3, because *sharing an idea* comes to us so easily; they are not as skin-bound as the carriers of individual knowledge (schemas, scripts, neurons) are said to be. It is probably fair to say that with the exception of Bereiter's early work on the learning paradox (Bereiter 1985), KBT glosses over the point of how ideas get generated and moves rather quickly to the question how they get shared and collectively improved. Besides being a gap in the theory, this also leads to pedagogical problems. Like Popper's falsifiability criterion for scientific theories (Popper 1962), improvability as a criterion for good ideas serves better as a constraint than a goal, as something to maximize: While it makes sense to advise students to create improvable ideas, it may occur to them that the worst ideas seem most improvable.

To learn more about the process of idea generation, and to clarify the ambiguities regarding the individual and social aspects of idea generation, one can again refer to Dewey and, to his contemporary, Charles Sanders Peirce. Both Dewey and Peirce did us the favor of providing a rather elaborate answer to the question where (new) ideas come from; they both suggest a process called *abduction*. Abduction is complex but has the benefit of shedding light on the learning paradox (the question how something new can be learned at all), helping us understand the relation between the individual and social in idea production and providing insights into the role of language and extralinguistic processes. I build on the analysis of Dewey's and Peirce's work on abduction in Prawat (1999) to provide at least a cursory description of the process of abduction here.

Ideas can be generated in three ways: by deduction (from what is already known), by induction (generalizing from instances), and by abduction. Only via abduction can we create really new ideas; deduction reveals only what is already known, albeit indirectly; induction as such does not produce new descriptors and concepts. Abduction, on the other hand, consists of devising a new theory to explain facts. In the formal sense, abduction is straightforward: "The surprising fact, C, is observed; but if A were true, C would be a matter for course; hence, there is reason to suspect A is true" (Peirce 1931–1958, p. 117). But to come to A, the explanation for C, or the mechanism that brings about C, usually requires intensive and creative thinking. This is because one cannot suggest just any cause or reason, but needs to come up with explanations that are acceptable within a discourse community (such as mathematicians, scientists, historians), hence are related to existing bodies of knowledge and world views.

Abduction is often a metaphoric process; deep insights are gained by reasoning analogously from what is known in one area to another area that is in need for explanation. Metaphorical reasoning—for instance, seeing an atom as a miniature planet system or a plant as a miniature food factory—can provide deep insights for students and has provided deep insights for scientists (Miller 1996). The metaphorical core of abduction can be elaborated with Peirce's theory of signs. As a communicative act, abduction involves a sign (e.g., the food factory), an interpretant (the set of experiences one anticipates having in relation to an object), and the object and event one wishes to understand (Prawat 1999, p. 62). The sign relation can be of three kinds or stages: iconic, indexical, and symbolic. In its iconic function, the image of the food factory is all that is needed to invoke certain experiences. If the food factory is used in the indexical relation to a plant, it focuses attention on the structural relation between two entities or processes. At this stage, one would think about similarities and differences between a plant and a food factory. In its symbolic function, the relation to other more general and abstract concepts is expressed. The metaphoric process involves a blending of all three sign functions, reaching from the prelinguistic to the symbolic.

The role of society and of specific discourse communities in abduction is complex. Not only does society provide the resources for the symbolic stage in form of language and concepts, but it also provides resources for the iconic stage, as the example of the food factory makes clear. However, both Peirce and Dewey insist that abduction has also a strong individual aspect in that the value of the metaphor must be evaluated and appreciated *by the individual*; without the personal experience that a metaphor plays out well, that an idea provides productive "epistemic access" (McEwan and Bull 1991), the idea will not be further pursued by the individual. For an idea to be of social value, it needs to be not only improvable but go beyond what is known so far or open up a new perspective for seeing something that has been explained before. In academic contexts, good ideas are good explanations; they make the natural and social world more understandable. Particularly good ideas "unify" ideas that have been suggested for explaining different phenomena.

It is probably fair to say that the aspects of idea creation that are closer to the individual-psychological side have not received much attention in the writings of Bereiter and Scardamalia. From the pedagogical point of view, this has had the disadvantage that methods and techniques for idea generation have not been systematic part of the knowledge-building classroom. However, the recent surge in interest in developing creativity and innovation capacity in students begins to remedy this point. There is really no strong reason why idea generation should be treated as a black box and why creative thinking should not be taught and practiced, in particular in the knowledge-building classroom. The scientific and not so scientific literature on creativity is enormous, making it sometimes hard for teachers to identify good sources, such as Johnson (2010).

The role of the social in knowledge construction has found considerable more attention, in the form of research on knowledge practices, to which I turn next.

Knowledge Practices and Artifacts: It's Not Only About World 3

As Lee (Chap. 10) and Hakkarainen (2009) note, while knowledge-building pedagogy is in practice massively concerned with (mostly classroom) practices, as a theory introduced and elaborated by Bereiter and Scardamalia, it lacks nevertheless an explicit account of the socio-material aspects of knowledge practices. Practices of two kinds are under-theorized. Firstly, classroom practices: The effects of software tools such as CSILE and later Knowledge Forum have rarely been analyzed in terms of how they change classroom practices other than those directly related to using the software. For instance, in most studies, the Knowledge Forum log files get analyzed, and/or students' communication around knowledge objects represented in the software, but not the classroom organization and practice more generally. But, as Hakkarainen argues, a comprehensive analysis of the knowledge practices, including those outside of the software itself, may be necessary to explain the causes for successful and unsuccessful take up of knowledge-building pedagogy.

Secondly, knowledge practices outside of the classroom, those that take place in authentic settings such as a research lab, a design meeting, or a quality control circle, have been rarely made the subject of knowledge-building pedagogy. Instead, knowledge-building implementations yielded their own practices: those that are characteristic for the school classroom, usually in science education. Activity theory (Engeström 1999) is used in many KB studies—including a number of studies reported in this book—as the conceptual backdrop and methodological framework, in particular for describing tensions between KB pedagogy and the existing dominant classroom practices and culture. However, it is less used to understand knowledge practices outside of the classroom for the purpose of making those practices more accessible in the classroom. Exceptions exist, for instance, in Hakkarainen's and colleagues' work, which is characterized as breaking boundaries between knowledge communities. More generally, mobile learning has the potential to expand learning beyond the classroom walls (see also So and Tan, Chap. 8) but so far has had more focus on "outdoors learning" rather than on making contact with knowledge practices.

A better understanding of knowledge practices is necessary for theoretical as well as pedagogical purposes. For the purpose of theory development, an understanding of the socio-material practices around knowledge objects contributes to demystifying the process of idea and knowledge creation. As the entanglement of cognitive work with physical, symbolic, and social resources becomes ever better documented and understood—in general (e.g., Clark 2011) and for specific areas such as scientific research (e.g., Latour and Woolgar 1986)—it becomes clear that a theory of creativity and idea generation will need to be grounded not only in psychology but also in sociology, organization science, and semiotics. Any specific study will need to capture knowledge practices in a comprehensive sense.

From a pedagogical perspective, describing and theorizing practice contributes to more authentic learning and to a broader approach to advance practices. Importantly, knowledge often takes the form of practices, in addition to tools and artifacts; they are hence worth knowing and learning about (and practicing). Related to the pedagogical purpose, a better understanding of technology—mediation in knowledge practices will also contribute to developing technology for supporting knowledge building as part of formal education.

The extension of knowledge-building theory by sociocultural and socio-material aspects has been well advanced, in particular in form of trialogic learning theory (Hakkarainen 2009; Paavola and Hakkarainen 2005; Ritella and Hakkarainen 2012). Yet, I would argue that even this line of research has not fully succeeded in reducing the gap between knowledge practices in schools and in professional contexts. We need more pedagogically inspired research on authentic knowledge practices, i.e., research that aims at documenting knowledge practices in real work contexts and aims for making these practices accessible in the classroom. While there needs to be space for knowledge practices that are specific to the world of schools, there also needs to be room to learn about knowledge practices originating outside of schools. Crucially, the latter comprise *specific* conceptual and physical tools, specific to professional communities of practice, for instance, the tools and representations used by engineers, health professionals, fashion designers, and urban planners. Providing students during their school years with a sense of the richness of representations, tools and practices will go a long way to prepare them for participating actively in the knowledge society. Knowledge-building tools specifically developed for schools, such as Knowledge Forum, are essential for learning about the generic ways of working with ideas, but they are not sufficient to learn about the many specific ways in which knowledge gets reified, shared, and advanced.

Teachers as Knowledge Builders

Compared to many other professional disciplines, such as health services or engineering, education lacks a widely shared culture of continuous quality improvement by small changes or what Kenney (2008) calls a "science of improvement." In K–12 education, the predominant innovation model is one of large-scale quasi-experimental field trials (at least, this is the purported "gold standard," National Research Council 2002). However, this method is chronically slow and faces many challenges on the way to affecting actual educational practices. Also, it suffers from the "one model fits all" constraint. Alternative innovation methods that can be deployed in a more agile manner, and with more concern for local contexts, are slowly making their way into policy-relevant areas, for instance, design research (Plomp 2009) and design-based research (Barab 2006).

In the absence of useful innovation and quality enhancement methods that work at scale, quality improvement and innovation in K–12 and higher education often take the form of "tinkering" with local solutions. Tinkering in itself is not the problem; the problem is that the tinkering remains a local or a private practice, with lessons learned not disseminated to other practitioners, and with no systematic means to engage with others in *collective* tinkering. The Internet and related communication technologies have, in principle, made it easier to collaborate in innovation and to share solutions and experience worldwide, with the click of a mouse button. However, it turns out that this kind of infrastructure is necessary, *but not sufficient*, for ongoing innovation and quality improvement to occur.

I agree with Morris and Hiebert's (2011) suggestion that a major reason for the lack of continuous improvement and innovation in education is the absence of public, changeable knowledge products and shared practices around such products. In K–12 education, the only globally used knowledge product is the *lesson plan*, and even that is scarce/missing in higher education. Educational knowledge products are important for guiding practice and for providing a repository for the continuously accumulating knowledge about practice. In their absence, practice becomes highly fragmented, and knowledge does not accumulate. Building on research on innovation practices in a number of disciplines, in particular in health services, Morris and Hiebert (2011) identify three features that enable the development and refinement of jointly constructed knowledge products:

1. *Shared problems across the system*: For instance, in health it is not only the frontline practitioners but also researchers and everybody else involved in the chain from basic research to application, who agrees on the shared goal of fighting diseases.
2. *Small tests of small changes*: In addition to large-scale field trials and evaluation studies, many practitioners engage in experimenting with small changes, in gathering data just sufficient to document the outcome of these small changes, and in sharing these data so that they add to the larger picture. Knowledge is thus created through the accumulation of small trials and through the replication of small trials in diverse settings.
3. *Multiple sources of innovation*: For instance, *every* employee in a hospital agrees that his or her primary task is to help patients regain their health; it is not only the doctors' task. The hospital provides the means for all its employees to improve processes.

In K–12 education, *lesson study* (originating in Japanese schools) is the best example of approaches that embody the second and third of these innovation features. In higher education, educational design patterns offer an example of innovation aligned with the second feature (Goodyear and Retalis 2010; Laurillard and Ljubojevic 2011). Given the rather thin knowledge and innovation practices in the teaching profession, creating opportunities for systematic knowledge building during their pre- and in-service education, as demonstrated in Chaps. 11 and 14, is an excellent approach. Over time, this could lead to a richer set of representations, tools, and practices for creating and improving pedagogical knowledge.

The Chapters

A number of chapters in this section address the topic of knowledge building and teachers' professional development. Teo (Chap. 12) and Law (Chap. 13) follow teachers who practice KB over some time, tracking and documenting changes to teachers' beliefs and the enactment of KB practices in their classes. While their focus is mainly on descriptive accounts of teachers' knowledge and how it changes over time, Hong (Chap. 11) and Lee and Tan (Chap. 14) describe intervention studies with teachers. In Hong's study, preservice math teachers use the Knowledge Forum software to experience what knowledge building means from the student perspective and to develop and reflect ideas on math education. I consider this as important enrichment of teaching students' representational and social practices, one worth following through beyond the preservice stage: How can such richer knowledge practices be implemented for in-service teachers? What are the actual pedagogical innovations that result from such knowledge practices? Lee and Tan's intervention uses an older but tremendously important knowledge technology: the book. Using activity theory, they document and analyze the knowledge practices emerging when groups of teachers read and discuss books of relevance to their work. Yew-Jin Lee describes in Chap. 10 among other case studies one where *annotated lesson plans* play the role of shareable knowledge objects, building on the work of Morris and Hiebert as described above. This chapter makes an impressive case for the socio-material extension of knowledge-building theory, expanding on what I have described above in terms of Hakkarainen's work.

The insights on teachers' knowledge, learning, and practices around knowledge-building pedagogy communicated through these five chapters are profound. This line of research is tremendously important for developing knowledge-building pedagogy further and for scaling it up to more schools and systems. As is the case with all reforms in schools, without an understanding of teachers' beliefs and concerns and without the development of their capacities and practices, the reforms are doomed. Importantly, knowledge building *by teachers* holds the potential of a second level innovation: Not only are specific pedagogical practices innovated, the *manner innovations are brought about* in schools can be innovated.

The two remaining chapters, Chap. 8 by So and Tan and Chap. 9 by Yeo, have their focus on students' knowledge building. So and Tan's study is a nice example for the potential of mobile technology to lead to "pervasive" knowledge building, thereby addressing what I identified above as an area of concern and in need for further research: bringing authentic knowledge practices into the classroom or the students into sites where they can experience authentic knowledge building. As mentioned before, I think that future research should use mobile technologies not only for exploring knowledge artifacts outside of the classroom, such as in the outdoors, but also for documenting, if not participating in, respective knowledge practices. To use a metaphor, we might be thinking of involving students in doing ethnographic work on knowledge practices outside of the school.

Yeo's work (Chap. 9) on combining elements of problem-based learning with knowledge building touches on the theme I labeled "transforming experience." While Yeo employs knowledge-building pedagogy to counteract students' tendency to overly focus on solving a problem instead of learning from the problem solution process, my point was that we need to be broader also regarding what the goal of learning (from problem solving, from knowledge building) ought to be: to expand students' capacity for experiencing and for valuing culturally provided means to do so, not only for problem solving. A focus on experience and value is not an alternative to the focus on increasing individual and collective capacity for problem solving, but the two can go hand in hand; likely, they need to go hand in hand for students to become lifelong knowledge builders and idea advancers.

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Section III
Conclusion

Chapter 16
Knowledge Creation in Singapore Schools: Our Journey and Ways Forward

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Introduction

As we reach the concluding chapter of this book, it is pertinent to revisit the genesis of this book. This book is part of the Education Innovation Book Series spearheaded by the Office of Educational Research, National Institute of Education in Singapore. This book series aims to document innovations in Singapore Education System, specifically in the area of pedagogy and classroom practices. This book, titled *Knowledge Creation in Education*, highlights our research effort in introducing pedagogies of knowledge creation paradigm to Singapore classrooms. We draw on the knowledge and research within the international community of knowledge innovation and, at the same time, document our unique experience in Singapore educational contexts. This book documents our 12-year journey of integrating knowledge building pedagogies into Singapore classrooms, across school levels from primary schools to high schools, working with both students and teachers. It also records our effort in developing teachers' capacity in building professional knowledge and in facilitating knowledge creation pedagogies. In this concluding chapter, we reflect on the paths we have taken in introducing pedagogies of

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knowledge creation paradigm into Singapore classrooms and provide a glimpse into our possible directions in the near future.

Using Steven Jobs' (2005) analogy, a reflection of our journey is akin to connecting the dots looking backward. Taking this analogy further, we could connect the dots in different ways, depending on which perspective we take. This seems to be the challenge when we examine our journey of experimenting with knowledge creation pedagogy in Singapore schools. In the following sections, we will first give a chronological account of the research trajectory in three phases. We will provide more information on research that, for one reason or another, was not included in this book. We are mindful that there are some key characteristics within each phase, but the division lines are more fuzzy than distinct. The timeline corresponds to the project funding duration rather than the actual implementation or years of publications resulting from the projects. We will then discuss some of the key trends of research over the years.

2001–2004: Exploration

We call this phase the *exploration phase* because it was an initial attempt to introduce knowledge building pedagogies into schools. Supported by a research grant from the Ministry of Education, one of the researchers (first author), who was drawn to the constructivist aspect of knowledge building pedagogy, began to introduce the pedagogy to several schools. In the early 2000s, the predominant perspective of learning in many schools was that of knowledge acquisition, where students assumed the role of knowledge recipient and teachers as the key messengers and transmitters of knowledge. The researcher found Scardamalia and Bereiter's (1999) argument of transforming schools into learning organization an attractive alternative to didactic teaching. Although K–12 students may not have the ability to produce groundbreaking theories, the value is to develop the culture and the ways of knowing among the students, so that they have the epistemic agency of engaging in productive talks about their understanding of a topic or a phenomenon.

The process of introducing knowledge building pedagogy to schools was initially fraud with failures and premature termination (Tan 2014) but was eventually fruitful in a secondary school that implemented it as an after-school enrichment program. In terms of research, the main goal was to test the effectiveness of pedagogical intervention (Tan et al. 2005). The research design was quasi-experimental study that involved two existing classes participating in a scientific inquiry course. The scientific inquiry course was designed and implemented by the school teachers, with one class using Knowledge Forum, a computer-supported collaborative learning tool for discussion of their inquiry activities, and the other class discussing ideas face to face. The measurement was a pre-post design using the instrument "Test for Integrated Process Skills II" (Tobin and Capie 1982) to assess changes in students' scientific inquiry skills. There was a clear division of labor – the research was handled solely by the researcher, while the school teacher designed the enrichment lesson (scientific inquiry).

Although this project had limited impact, it helped to build the foundation for subsequent developments. First, the researcher gained experience in implementing knowledge building pedagogy, and evidence of success was established in local schools. Second, relationship was established with the pioneers of knowledge building research, Marlene Scardamalia and Carl Bereiter. Participation in the annual Summer Institute by the researcher helped connect local researchers to the international community. Third, some extent of capacity building took place in Singapore as graduate students began to embark on knowledge building studies. In particular, Teo (one of the coauthors of this chapter) conducted knowledge building intervention in her classroom for her master's thesis. She proceeded to study PhD in University of Toronto and became a core member in the local research community. She is instrumental in developing a teacher knowledge creation community in the current phase of research development.

2005–2012: Deepening Knowledge Building Practices

From 2005 to 2012, we saw a phenomenal increase in research activities due to the timely establishment of the Learning Sciences Lab in the National Institute of Education (Singapore). More research funding was available for educational research, and many researchers joined the knowledge building research team. This phase of research is characterized by a strong representation of design-based research method, applications in different contexts (primary school, secondary school, high school, and teacher education), and different perspectives of knowledge creation. In addition to knowledge building (Scardamalia and Bereiter 2006), we have research that has strong influence of cultural-historical activity theory, and even a proposal of rapid knowledge building. With the extension of perspectives of knowledge creation, there is also more variety of technological tools.

Several key projects were conducted during this phase of research: (1) the Ideas First project by Bielaczyc and Ow (2007) that aimed to deepen knowledge building practices in a primary school; (2) the project "Designing pedagogical supports for enabling inquiry learning through a learning community approach" by Yeo and Tan (2011) that began to bring in the lens of cultural-historical activity theory; (3) the project by Hyo Jeong So (So et al. 2012) "Designing a pervasive knowledge building environment with mobile technologies" that featured the use of mobile technologies; (4) the Group Scribbles project by Chee Kit Looi and Wenli Chen (Looi et al. 2010) that explored rapid knowledge building; and (5) the project by Tan (2012) "Fostering a knowledge building community among teachers through cogenerative dialogue" that focused on teacher professional development in knowledge building.

Ideas First: Deepening Knowledge Building in a Primary School

Ideas First (Bielaczyc and Ow 2007; Ow and Bielaczyc 2007) was a design-based research program undertaken in a local primary school from 2006 to 2012. The goal of the research program was to design support for students and teachers on a trajectory toward a vision of a knowledge building community (Scardamalia 2002; Scardamalia and Bereiter 2006), where students worked to advance the science understanding of the classroom community by engaging in collective knowledge building to better understand common problems of understanding. A 2-year science program, "Ideas First," was designed to embody the principles of a knowledge building community (Scardamalia 2002) and to develop theories to support students and teachers on implementation paths (Bielaczyc 2006; Bielaczyc and Collins 2006) as they transitioned from existing ways of teaching and learning to learning in a knowledge building community. This 2-year science program has been operating in grade 3 and grade 4 classrooms in the primary school since 2006.

The content and activities in the science program "Ideas First" were organized to support students' extended inquiry based on knowledge building principles. Overarching problems (e.g., "Why are flowers important to plants?" "How do living things grow?") were developed to organize content that contributed to the classroom community's understanding of the problem. Students' ideas and questions about the problems became the centerpiece of lessons to advance the classroom community's understanding of the problem. During lessons, students carried out activities designed to support the classroom community's knowledge building efforts. These activities provided opportunities for students to contribute their ideas and questions about the problem; improve ideas by collecting evidence, gathering new information, and building on others' ideas; and pull together ideas by reading and synthesizing ideas to advance the classroom community's understanding of the problem.

Learning science in a knowledge building community necessitates supporting teachers and students to navigate shifts in the classroom culture from one that is more traditionally focused on individual learning to another where the emphasis is on the progressive improvement of ideas and collective efforts toward common goals of understanding. It entailed the construction of implementation paths or trajectories that classroom communities could traverse in order to navigate the desired shifts (Bielaczyc 2006; Bielaczyc and Collins 2006). Informed by the lens of the Social Infrastructure Framework (Bielaczyc 2006), supportive tools and practices (Bielaczyc and Ow 2007, 2012; Ow and Bielaczyc 2007, 2012) were designed to scaffold teachers and students from their initial entry point toward the vision of a classroom as a knowledge building community. These tools also provided the researchers with a better understanding of the critical processes for the shifts (Bielaczyc et al. 2012). Some of these tools include material artifacts like the Think Card and Sun Chart, which are paper-based physical materials for students to record their ideas and to pull their ideas together, before they used an online forum for discussion. New conceptualizations were also important in supporting teachers and students to navigate these shifts. The reconceptualization of knowledge building as a multiplayer epistemic game (Bielaczyc and Ow 2012) made visible the moves of inquiry in the classroom communities. Based on this concept, a material artifact, the hypothetical game configuration, was created. This artifact allowed the isolation of specific knowledge building moves for practice and evaluation. Information about the evaluation and generation of knowledge building moves supported the classroom community's efforts to make meaning of knowledge building moves and better understand knowledge building when learning science.

Besides informing understanding about designing for the enactment of knowledge building, the research program, Ideas First, also provides valuable insights into students' knowledge building. Analysis of students' work in the hypothetical game configurations suggested that over the course of the program, students were better able to generate valid knowledge building moves that helped the classroom community advance their understanding of problems. Students were also better able to recognize questions that helped clarify the community's understanding of the problem. Importantly, analyses of students' drawings of learning science in knowledge building communities appeared to suggest that over time, students who learned science through the "Ideas First" program perceived learning science to be a collective and collaborative activity, where ideas were viewed as conceptual artifacts that they worked with and activities were connected to work on their ideas (Ow and Bielaczyc 2013). These insights provide important indications of progress toward the design goal of Ideas First.

Environmental Science Through CSCL: Introduction of Cultural-Historical Activity Theory

With an emphasis on environmental science and nature of science (NOS) in the local primary science curriculum, the aims of this study (see Chap. 9) were to (1) deepen students' understanding of nature of science (NOS), particularly the role of theories in experimentation and scientific knowledge creation during inquiry activities, and (2) advance students' knowledge and affect toward environmental science. This study rode on an existing nature learning activity with four participating primary schools. Participation rates among pupils varied across schools and across years and ranged from a handful of children from science clubs to two intact classes of students. During the 3-year design research, different inquiry activities were designed to support students in building a deeper understanding of their environment. Data collected included participant observation, interviews of teachers and students, student group artifacts, and a corpus of data from the Knowledge Forum software platform. Using Engeström's (1987) cultural-historical activity theory as an analytical framework, the mediating factors that supported students in scientific knowledge construction work were identified.

Eight key features that supported knowledge building work among the primary schools pupils were identified: (1) natural phenomena as trigger, (2) idea generation, (3) social platform (4) argumentative discourse, (5) investigative work, (6) rise above, (7) teacher's role, and (8) students' role. These features are not unfamiliar to knowledge building researchers, but they were vital to the success of student meaning-making related to environmental issues. Through working with different schools, different models of collaborative knowledge building emerged from the design research cycles: (1) knowledge oriented, (2) process oriented, and (3) affect oriented. These different orientations could be explained using the concept of boundary object, as the researchers worked with the stakeholders (i.e., teachers from the four schools) to implement knowledge building in their NLC (nature learning camp) activities according to the objectives of their schools while keeping fidelity of a common object that bound the community (i.e., the principles of knowledge building and the focus on environmental science). Interestingly, these three models did appear to have an influence on the types of knowledge of environmental science and NOS among students. For example, a knowledge-oriented approach tended to result in a set of generalized knowledge about the phenomena studied, while a process-oriented approach would include an improvement of experimental design and processes, and an affect-oriented approach steered students' focus toward developing a deeper understanding of the impact of their actions on the environment or to the society.

Designing Pervasive Knowledge Building Environments: Weaving Formal and Informal Learning Spaces

The "Pervasive Knowledge Building with Mobile Technologies" project (see Chap. 8) was conducted in a secondary school under the FutureSchools@Singapore initiative by the Ministry of Education in Singapore. This initiative aims to support exemplar schools that can demonstrate a high level of technology integration using a whole school approach where information and communications technologies (ICT) are integrated across all subjects and levels. As a future school, the research school has a strong ICT infrastructure where each student owns a notebook computer, and the teachers integrate various ICT tools to support student learning. Leveraging on the school's 1:1 computing environment, the research team designed *pervasive knowledge building spaces* where the affordances of mobile technologies are appropriated to continuously engage students to pursue their inquiry process across multiple contexts and time scales. Pervasive knowledge building is one of the key knowledge building principles proposed by Scardamalia (2002) that emphasizes progressive improvement and advancement of cognitive artifacts. Under this research goal, mobile technologies play a critical role in mediating knowledge building practices across multiple learning contexts, supporting both formal and informal aspects of learning.

In this project, the research team positioned a *mobile learning trail* as a core mechanism to anchor pervasive knowledge building practices. The team, together with the participating teachers, codesigned mobile learning trails, defined as "a series of learning activities in and out of school, mediated by mobile devices and applications" (So et al. in press) in the areas of geography and history. The pedagogical intention was to scaffold students to make explicit connections between knowledge learned in their classroom context and knowledge in authentic environments, moving away from understanding history as a body of abstract and disconnected facts to history as coherent and solid interpretations of the past.

How to design mobile learning trails to promote pervasive knowledge building practice was central in this research work. Employing a design-based research approach, which supports the iterative and improvable nature of learning design, the research team experimented and implemented their design ideas of mobile learning trails in various locations in Singapore. Several design considerations were explored in and derived from their research trajectory for the past 3 years. First, the FAT (Facilitation, Activity, and Technology) framework that articulates design elements in epistemic activities, the nature of necessary facilitations, and seamless technological support was developed (Tan and So 2011). Under this overarching framework, a three-stage learning model where specific learning activities were designed for pre-trail and post-trail stages under a *big question* that guided the whole inquiry process was developed. Second, through the research implementation, the research team found the criticality of situational variables and contextual (re)interpretation in learning activity design to engage students in collaborative knowledge building discourse that promoted deeper understanding about core ideas and concepts in a given topic. This design consideration was derived from our observation that the level of collaborative knowledge building discourse tended to be high when student groups were engaged in user-generated activities that required them to deal with the complexity of situational variables and their interpretations. Last, Knowledge Forum and other mobile applications as a technological mechanism were used to provide "common grounds" that can foster and sustain collaborative knowledge advancement across varying contexts. While the use of Knowledge Forum was useful to engage students in collaborative knowledge building practices in classroom contexts, the research also highlighted the critical need to develop a one-stop CSCL technological platform that could support the advancement of collaborative discourse across multiple time scales and locations.

Group Scribbles: Rapid Knowledge Building

This project by Looi and Chen (Looi et al. 2010) focused on rapid collaborative knowledge building (RCKB), which is characterized by rapid cycles of collaborative generation, collection, and aggregation of ideas in a face-to-face setting. Supporting the RCKB is the Group Scribbles technology, which is codeveloped by SRI International and the National Institute of Education of Singapore. One distinctive feature of RCKB, compared with the knowledge building pedagogy, is the "lightweight" participation by students, which translates into a contribution of about four posts (written, sketched, or typed) within the constraint of a typical classroom exchange. It thus excludes long paragraphs or detailed drawings. The technology aims to mediate and support verbal discussions; knowledge improvement could start with the ideas represented in the notes and continue in the face-to-face discussions mediated by the knowledge representations captured by Group Scribbles.

Through design-based research, the research team deepened their understanding on how to help school teachers transform their teaching practices with researchers playing a meso-level role that helped interpret broad MOE's policy directives and helped teachers to enact lessons that meet these directives, for example, how to generate productive classroom discourse based on the digital artifacts and the collaborative discussions. This research also generated principles on how to design activities that require and foster differing opinions, negotiation, consensus, and cooperation. RCKB builds on the foundation of knowledge building principles (Scardamalia 2002) of "improvable ideas," "idea diversity," "epistemic agency," "symmetric knowledge advancement," and "democratized knowledge." In addition, this research proposed four other principles: volunteerism (choice of activity to participate in), spontaneous participation (quick, lightweight interactions), multimodal expression, and higher-order thinking (synthesis, analysis, categorizing).

In terms of scaling up of the practices, since 2007, the research team has reached out to seven schools for intervention; 109 lesson plans have been created in various subjects (Math, Science, English, and Chinese language); and 146 Group Scribbles lessons have been enacted, observed, and studied. The research team has conducted numerous professional development sessions and has more than 100 Group Scribbles lesson discussions with teachers. To help teachers design Group Scribbles lessons, the following design principles were developed: (1) make everybody think, as individuals and in teams; (2) the class accepts new ideas and constantly improves ideas; (3) explore many ideas and from different angles; (4) students take initiative for their own learning; (5) everybody participates actively and contributes knowledge; and (6) students organize their ideas and are self-reflective.

Developing Teachers' Capacity in Knowledge Building

In addition to engaging teachers in codesign, there were also research studies on developing teachers' knowledge building capacity through formal courses. In one study, the researcher engaged seven teacher participants as co-constructors of knowledge in a knowledge building community over three consecutive courses (see Chai and Tan 2009). The teachers' discourse in Knowledge Forum was analyzed using social network analysis and the interaction analysis model (IAM). The results showed that the participants were well connected to one another, and they participated actively, contributing to the advancement of knowledge of the community. In addition, several factors seemed to have facilitated the knowledge building activities: (1) the commitment of the participants toward the community goals, (2) the participants work on authentic problems they faced in schools, (3) high degree of empowerment of the participants to solve the problems and to reflect on their learning, (4) sufficient time provided for the participants to understand the theories and to translate the theories into practice, and (5) a facilitator who is experienced in facilitating knowledge building activities and in using a pedagogical model that is built on appropriate learning theories.

In another study, Tan (2012) examined how cogenerative dialogues (Tobin 2006) – reflective dialogues, involving both teachers and students, at the end of each lesson directing at improving the learning environment – might facilitate the development of teachers' epistemic agency. The 18 participants were learning about knowledge building pedagogy by participating in a knowledge building community. Various knowledge building principles were used to design the lessons (Tan 2010). Cogenerative dialogue sessions were conducted at the end of lessons, asking the participants specifically about what went well in the lesson and what else could be done to improve the subsequent lessons. The participants' dialogues were analyzed. Two broad categories of actions related to epistemic agency were found: knowledge actions and community actions. Talks that aimed at producing knowledge actions were directly related to knowledge building, for example, talks to determine the nature of the community's epistemic artifacts as well as the creation and refinement of such artifacts. These talks are akin to knowledge building discourse (Scardamalia 2002). The second category of talks facilitated community actions that are essential to support the knowledge building process of the community, for example, talks that evaluated the instructor's pedagogical implementation of knowledge building as well as the necessary follow-up actions and talks that addressed the desired etiquette for the participants' community.

2012 and Beyond: Enhancing Teachers' Agency and Expanding Students' Epistemic Repertoire

From the year 2012, we began to have research projects funded under the Edulab initiative, which is targeted at sustaining and scaling up established theoretically informed pedagogical innovations in schools. Edulab is a joint funding agency between the Ministry of Education and the National Institute of Education that aims to surface and spread ICT-enriched pedagogical innovations. It is a key program under the third Masterplan for ICT in Education (mp3). One of the key features of Edulab projects is that practitioners, usually school principals, assume the role of a principal investigator, thus taking on greater responsibility in deepening and spreading good classroom practices to different schools across the system. Below are the outlines of the two Edulab projects.

Building Blocks for Developing Twenty-First-Century Competencies

While the knowledge building pedagogy has been investigated for more than two decades, literature is relatively silent on knowledge building on social studies as the subject matter. Most knowledge building research has focused on science as the subject matter, and even when social studies was mentioned, examples drawn to illustrate students' knowledge building practices were mostly reflecting science content (e.g., Sun et al. 2010). Bereiter and Scardamalia (2012) explicated the differences between building theories about natural phenomena and theories about social historical phenomena – the former attempts to discover generalizable laws or principles, while the latter are theories of the case. From the practitioner's perspective, improving pedagogical practices for social studies, a relatively new subject in the local curriculum, is also an important agenda.

A project, titled "Building epistemic repertoire through computer-supported knowledge creation among primary school students," won the funding by Edulab. This project focused on two design principles: working on authentic ideas and developing collective cognitive responsibilities. These design principles are aligned to the current ICT Masterplan goals that aim to engage students in collaborative learning and self-directed learning with the use of technologies. The intervention started with both grades 3 and 4 students. Grade 3 students were tasked to investigate questions they had about Singapore and to decide whether Singapore is a good country; grade 4 students were given a design problem of building a laborer house for 500 immigrants in the context of the early nineteenth centuries. Both topics are linked to the social studies syllabi of the respective levels. One of the key goals is to build students' epistemic repertoire, which is regarded as a range of skills and beliefs and/or dispositions that students need to be engaged in collaborative knowledge co-construction. These skills include question asking, Internet-based research, collaborative sensemaking, and refining ideas.

To assess students' use of ICT for collaborative knowledge construction and self-directed learning, mixed-method approach was employed. The preliminary findings show that the students were able to engage in online collaborative sensemaking after a prolonged period of teachers' scaffolding and modeling. They acquired some skills in asking deeper questions and were able to work on deep concepts such as "what is a country?" In addition, the quantitative data from survey reveal significant differences in their perception of using ICT for collaborative and self-directed learning and their perception about working with ideas and knowledge co-construction, when they were compared to classes that were not engaged in knowledge building. These initial findings provide strong backing for the pedagogy to be scaled up to the whole level of students and other schools. To further enhance the pedagogy, we are also developing a platform (see Chap. 5) and experimenting with paper-based scaffold to enhance the quality of collaborative talks among students.

Teachers' Knowledge Creation Community

Another Edulab project is titled "Designing Knowledge Building Environment (with technologies) Through Teachers' Collective Discourse." It focuses on sustaining and deepening knowledge building practice in Singapore classrooms through collective effort within teachers' community. Each week, teachers meet to systematically analyze students' ideas and to figure out how to use them to shape the class' problem of understanding and the design of next lesson. This project started with one secondary and two primary schools and is spreading to other school sites.

Within the three lead schools, knowledge building practice has both sustained within departments and scaled across departments. For example, knowledge building practice in one secondary school has scaled up from the science department to the humanities department, as well from the Express classes to the Normal Academic classes. (In Singapore, Express and Normal streams cater to students with different academic inclinations.) In another primary school, several science teachers in the knowledge building community have embarked on knowledge building in English and mathematics. This has provided a fertile ground for the researcher to tackle the disciplinary challenge in knowledge building practice. Each of these teachers' communities is facilitated by a senior teacher whose role is to share his or her knowledge building practices and students' artifacts (e.g., notes on Knowledge Forum) back to the community for collective analysis and exploration. The rest of the team has to pick up these ideas on creating a knowledge building environment and try it out in their own class. They then have to bring their enactment and students' artifacts back to the community, be it the Knowledge Forum views for the week, students' post-its or journals, or any form of learning artifacts. This seemingly simple design that serves to bring students' thinking to the center of the discourse has worked to keep the teachers' focus on idea-centered practice. Week after week, the teachers continued to be inspired by their own students' ideas and work.

Teachers from different school sites also meet in an interschool professional learning community to exchange ideas within a larger community. Starting from March 2013, the research team and the teachers began connecting with Hong Kong and Toronto teachers and researchers to forge diversity of ideas on knowledge building practice. These extended connections have been most precious in their communities as they see the richness of ideas growing exponentially and their understanding of knowledge building advancing; such beneficial effects were also felt by the counterparts. This symmetry in advancement is critical for the growth of teachers' knowledge building community. The distinctive nature of knowledge building community requires each member of the team with particular expertise and duties to be able to build on one another's ideas and to share distributed leadership. Constant refreshment and expansion of this connectivity provides a flexibility that removes the reliance on localized expertise to grow the group effort to succeed despite unexpected complications. Along with this capability is an increased commitment on the part of each member to do whatever is necessary to make the team effort succeed.

Joining the Dots: Looking Back

The above account of the key research projects suggests the changes in the main foci of our research effort on knowledge creation in education: from an exploration phase, to deepening of knowledge building practices, and to the current effort in expanding students' epistemic agency and building teachers' knowledge creation community. Through this reflection, some other trends had also become more apparent to us. Table 16.1 summarizes some of the key changes over the past 12 years.

When we first started our journey, knowledge building pedagogy (Scardamalia and Bereiter 2006) was a natural choice of model as it has established a strong base in its implementation in K–12 schools. Knowledge building continues to be a prominent model guiding our lesson design and research. The inclusion of expansive learning perspective evolved as researchers like Yeo (see Chap. 9) started adopting a cultural-historical activity theory as a lens to analyze the class as an activity system. This, coupled with the design experiment method, resulted in iterative improvement of the intervention. In other words, two perspectives of knowledge creation were in operation. While the researchers were working with teachers to integrate knowledge building pedagogy with problem-based learning, their iterative improvement act was expansive learning effectively. Lee and Yeo also led another project that extended a nature learning camp with knowledge building. Lee (see Chap. 10) elaborated on understanding knowledge creation through the lens of cultural-historical activity theory. At the same time, Chen and Looi (Looi et al. 2010) began to work on collaborative ideation among students supported by synchronous technology (interactive whiteboard). Due to the nature of the synchronous discussion, a theory of rapid knowledge building was proposed. This rapid collaborative knowledge building focuses on synchronous face-to-face idea generation and organization that creates knowledge artifacts that mediate further knowledge building. In a recent project, Chai (see Chap. 5) proposed an approach that integrated the SECI model (Nonaka and Takeuchi 1995) with knowledge building so as to rationalize technologies that could support knowledge creation in education.

In terms of supportive technologies, we have been using Knowledge Forum, a computer-supported collaborative learning platform that has been developed to

Table 16.1 Trajectory of research on knowledge creation pedagogy in Singapore schools

Years	2001–2004	2005–2012	From 2012
Focus	Exploration	Deepening school practices	Epistemic repertoire Teachers' knowledge
KC perspectives	Knowledge building	Knowledge building Expansive learning (cultural-historical activity theory) Rapid knowledge building	Knowledge building Expansive learning (cultural-historical activity theory) SECI model
Technologies	Online forum (Knowledge Forum)	Online forum Interactive whiteboard Mobile devices	Online forum Other emerging tools
Methodology	Experimental	Design experiments	Multiple
Research sites	Secondary school	Primary school Secondary school High School Teacher education	Primary schools and secondary schools Cross-school community
Transfer and diffusion	Appropriation and dissemination	Collaborative	Knowledge creation
Roles of researchers and teachers	Researchers, as principal investigator, introduce knowledge building pedagogy and design and conduct research	Researchers, as principal investigator, codesign lessons with teachers iteratively	School principals and teachers as the principal investigators Researchers help to build teacher's communities
Facilitating factors	Research funding	Research funding Research Lab R&D culture ICT Masterplan	Research funding Research Lab R&D culture (agency) ICT Masterplan Knowledge creation center

support the knowledge building principles. Nevertheless, a concomitant change to the knowledge creation perspective is the gradual inclusion of more variety of technologies beyond the online discussion forum. In one case, the stakeholders (e.g., the project leader in a school) requested for a different technology design (e.g., Knowledge Constructor in Chap. 10) that still retained the key features of an asynchronous online forum. In another case, the use of technologies is associated with a different theoretical perspective of knowledge creation. For example, rapid knowledge building is associated with synchronous interactions. Yet, in other cases, technologies (such as mobile devices) are necessary to support complementary learning activities (such as learning trails).

In the initial exploratory years, guiding the research design was the tested experimental design. It also reflected the focus on investigating the outcomes of the intervention (rather than process), which was partly the need to prove that the knowledge building pedagogy could work in local schools. With the establishment of the Learning Sciences Lab in 2005, there was a strong advocate for the use of design experiment for studying learning in authentic environments (Brown 1992; Cobb et al. 2003). It involves iterative improvement in the design of learning environments guided by theory and informed by empirical evidence. Examples include the Ideas First project (Bielaczyc and Ow 2007) and the project by Yeo (Chap. 9). At the same time, the research sites were extended to various grade levels to establish the ecological applicability of the instructional approach.

One of the key trends is the change in approach in transferring and scaling up the innovative practices that have been reported by Tan (2014). In essence, we started with an appropriability approach characterized by the adoption of a practice by the receiving end. In our case, a researcher was attracted to the knowledge building pedagogy and was motivated to introduce it to local classrooms. The researcher then introduced the pedagogy to some classrooms through a dissemination approach, which is a unidirectional approach led by the researcher. From 2005 to 2012, we saw a collaborative approach that featured strong partnerships between researchers and practitioners (school teachers) in codesigning lessons and iteratively improving the implementation. In the current phase, a situative knowledge building community is emerging that highlighted strong epistemic agency by the practitioners (school teachers and leaders) in leading the project and engaging in creating new knowledge about their practices. This journey reflects a gradual adjustment in the power differential between the researchers and the teachers. The teachers assume greater agency in improving their practices and exerting their influences to other teachers; at the same time, the researchers become partners in codesigning lessons and in developing teachers' knowledge creation community.

Related to the transferring and scaling approaches are some contextual factors and environment conditions that facilitated the research studies. Nevertheless, there are also challenges to overcome. According to Rogers (2005), facilitating factors for adoption of an innovation include relative advantage, compatibility, complexity, triability, and observability. In our case, at least one of the schools saw the fit of knowledge building pedagogy to their program. In addition, there are other facilitating factors, for example, the availability of the research fund and a motivated researcher. There are numerous challenges in this phase of research. For example, the predominant practices in the school, which partly reflect the culture and beliefs of the participants, were teacher-led approaches that could help students achieve good results in typical examination. The client-server technology of Knowledge Forum also posted challenges, particularly in school networks that were firewalled for security. Most critically, the research team was small; there was a dire lack of community support in the knowledge creation effort by the researchers. Fortunately, the situation improved in 2005 with the establishment of the Learning Sciences Lab in the National Institute of Education (Singapore). With the establishment of the Learning Sciences Lab, the amount of research fund available increased, and at the same time, more researchers could be engaged in the projects. This explains the dramatic increase in the research activities from 2005 to 2012. It provides a fertile environment where diversity of ideas and views among researchers help to generate a productive and vibrant research culture. New researchers (e.g., Kate Bielaczyc) also introduced novel ideas like the use of design experiments. The larger educational context was also favorable to the research as the Second IT Masterplan for Education (mp2) was launched; research and development was a specific strategy identified by the Ministry of Education to help advance the practices of using technologies to support teaching and learning in schools. In 2013, the Knowledge Creation and Innovation Design Center was set up in the National Institute of Education (Singapore). This center acts as a hub to develop a community of practitioners and researchers who could lead research on knowledge creation in education and advance such practices in schools. The researchers responsible for the latest two projects, for example, are all key members of this center.

Looking Forward

Knowledge creation is a more inclusive and expansive perspective of knowledge building. It is used to extend knowledge building beyond the confines of the classrooms to other contexts, include other actors in addition to students, and, most importantly, convey a sense of a lifelong knowledge creation trajectory. Moving forward, we are developing a programmatic approach for knowledge creation in Singapore. This program will be a key tool for bringing together researchers and educators from diverse disciplines and settings to build on the knowledge base for knowledge building.

To compare different perspectives on knowledge creation, Tan and Tan (Chap. 2) brought together the theoretical lenses of organizational knowledge creation (Nonaka and Takeuchi 1995), expansive learning in cultural-historical activity theory (Engeström 2001), epistemic culture in scientific communities (Knorr-Cetina 1999), and knowledge building (Scardamalia and Bereiter 2006). The use of these theoretical lenses brings knowledge creation in other contexts into focus, extending knowledge creation work in classrooms onto possible trajectories for long-term knowledge creation endeavors. By rising above the perspective of knowledge building in classrooms, and pulling together different perspectives, a more expansive view of knowledge creation could emerge. This view of knowledge creation highlights the varied contexts, actors, and driving forces for knowledge creation as well as the different knowledge products of knowledge creation. Despite these differences, there are unifying features of knowledge creation. Central to knowledge creation is social cultural nature of knowledge creation and the critical role of mediating artifacts. Several areas for future research can be drawn from this work. The first area suggests research that supports a lifelong trajectory for knowledge creation. The second area suggests research that looks into transforming schools as knowledge building or more appropriately knowledge-creating organizations. The third area suggests research into the identity of learners as knowledge creators. The fourth area suggests research into the dynamics of knowledge creation in social contexts, specifically the tension between competition and collaboration in knowledge creation. The fifth area suggests research to develop the epistemic practices of learners. Together these research areas contribute to understanding the development of learners along a lifelong knowledge creation trajectory.

Shedding further light on possible research directions for knowledge creation, Tsai et al. (2013) propose a broader conception of personal epistemology – design epistemology – that foregrounds innovation and creativity. Design epistemology has the synthesis of disparate knowledge and information as its central feature (Cross 2006; Pink 2006; Simon 1996). This conception of personal epistemology guides knowledge construction that cuts across disciplines, domains of skills, practices, and dispositions (Tsai et al. 2013). It is suggested that design thinking is likely to thrive in a collaborative environment. A useful segue into the realm of social epistemology (Goldman 2011) surfaces issues and challenges in terms of determining the value of knowledge and ways of knowing in social contexts. These provide indications that the navigation between the realms of personal and social epistemology is not as straightforward as it appears. Collectively, the benefits of thinking about knowledge and ways of knowing from the realms of design epistemology and social epistemology give rise to more creative and social epistemological foundations for knowledge creation. The work on design and social epistemology suggests the foregrounding of research to develop the epistemic practices of learners. To elaborate, research to develop the epistemic practices of learners would involve research into developing learners' *epistemic repertoire* or the range of ways of knowing that enables individuals to develop cognitive artifacts for sensemaking (Tsai et al. 2013).

We are in the process of conceptualizing a knowledge creation research program from which several major streams of research could emanate. These in turn have the potential to give rise to research projects that contribute to the strength of these research streams and the overall research program. The major streams of research are "developing the epistemic repertoire of learners," "developing learners' identity as knowledge creators," "building teacher capacity for knowledge creation," and "building a systemic understanding of knowledge creation in learning institutions."

- *Developing the epistemic repertoire of learners*. This research stream seeks to generate research that investigates ways of knowing and sensemaking in knowledge-creating communities. It includes investigations into the epistemic practices for disciplinary and multidisciplinary learning, learning in collaborative groups, as well as learning in formal school settings and other more informal settings.

- *Developing learners' identity as knowledge creators*. This research stream seeks to generate research that conducts inquiry into the construct of the identity of a knowledge creator. Research within this stream can also take the form of research that explores identity development and transformation of learners in a knowledge-creating community (e.g., tertiary institution).
- *Building teacher capacity for knowledge creation*. This stream of research seeks to generate research that contributes to the knowledge base for teaching in knowledge-creating classrooms, explores pedagogical approaches, and, more importantly, creates professional development models for building teacher capacity for knowledge creation.
- *Building a systemic understanding of knowledge creation in learning institutions*. This stream of research seeks to generate research that investigates and generates frameworks and principles for theorizing and designing for knowledge creation in learning institutions. To provide greater insights into the systemic considerations for knowledge creation, research can explore dimensions within education such as the curriculum and draw implications to inform the theories for transforming schools as knowledge-creating organizations.

In terms of supportive technologies for knowledge creation, we would expect continual development of Knowledge Forum (or other platforms) that might leverage distributed expertise of a larger community. We expect enhanced features of learning analytics that could provide real-time information for both teachers and students, using embedded data to achieve assessment for learning or even moving toward assessment as learning. We are also likely to use a suite of available Web 2.0 tools to support learner's construction of epistemic artifacts, while the forum serves as the integrative platform for the improvement of ideas contained in these artifacts.

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