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

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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)	
Phase 1	Type(s)	Description*
Aim: To elicit students' concepts about energy and energy source/fuel, relationship between fuel & energy.	CK	• Knowledge of the topic • The discussion questions selected are on core scientific concepts
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?	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
Student engagement: 1. Read notes on KF at least twice a week, and post at least two notes by mid-Feb. 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. • Students write weekly learning diary on KF to reflect on the learning process.	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
• 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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