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

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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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S.C. Tan et al. (eds.), *Knowledge Creation in Education*, Education Innovation Series,
DOI 10.1007/978-981-287-047-6_8,

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.

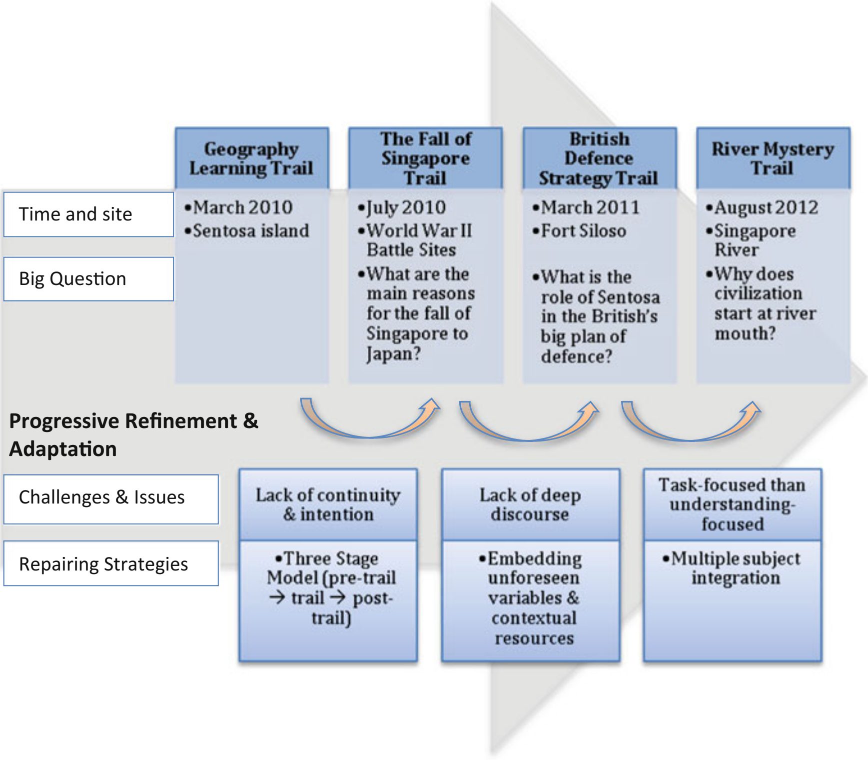

Fig. 8.1 Design progression of the mobile learning trails

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

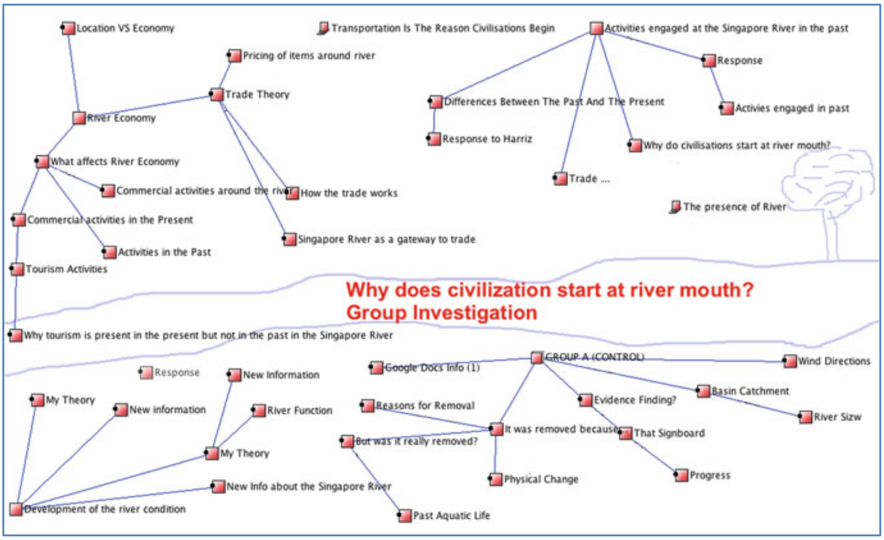

Fig. 8.2 Student-generated inquiry in Knowledge Forum. *Student names were removed for confidentiality

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.

Acknowledgments This research is supported by the FutureSchools@Singapore project under the National Research Foundation's (NRF) Interactive and Digital Media (IDM) in Education Research and Development (R&D) Programme. Portions of this paper were presented at the ICCE 2012 workshop. This research was conducted when the first author was with Nanyang Technological University, Singapore. We are thankful to the teachers, students, and researchers who supported this research.

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