Education Innovation

Young Hoan Cho
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Authentic Problem Solving and Learning in the 21st Century

Perspectives from Singapore and Beyond

Springer

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Series Editors' Foreword

Foregrounding Authentic Problem Solving and Learning to Rethink and Transform Research, Policy, and Practice for Twenty-First-Century Learners

The twenty-first-century global landscape, where work and life situations are becoming more unpredictable and complex, entails individuals to be equipped with key competencies to help them cope with these rapid changes and thrive as global citizens and workers of the future. Problem solving is regarded as a fundamental competency that is entwined with other twenty-first-century competencies, such as critical thinking and creativity. Students should have greater exposure to solving real-life and nonroutine problems and take part in authentic practices that go beyond acquiring canonical knowledge. Conceptualized and developed with these needs as focal points, this book can help inform and transform research, policy, and practice to better prepare learners to face the challenges of the twenty-first-century knowledge economy.

This book is the eighth in the Springer Education Innovation series. Problem solving has always been recognized as one of the cornerstones of learning and schooling. This book chronicles empirically based perspectives and thought-provoking assertions about authentic problem solving and learning. It provides multifaceted and comprehensive ideas on authentic problem solving by covering various disciplines (e.g., mathematics, science, geography, and teacher education), levels (i.e., primary, secondary, junior college, polytechnic and higher education), and learning contexts (i.e., formal and informal). Utilizing varied frameworks (i.e., cognitive, affective, and sociocultural aspects), it affords wide-ranging insights on various elements of authentic problem solving: the design of problems and environments, implementations of such designs, and evaluation of outcomes. It underscores a wide array of key dispositions and skills relevant to authentic problem solving and learning, such as argumentation, play, thinking through tinkering, modeling, deep processing, invention, critical thinking, goal orientations, and collaboration. The contents of this book present empirical evidence upholding the potential benefits of authentic learning and participation for diverse learners, including low-achieving students (e.g., applying business knowledge and skills learned in school at real workplace environment). Given the broad lens that this volume applies to describe the nature of authentic problem solving and learning, it thus serves as an invaluable resource for educators and policymakers to develop approaches and design environments that prime learners for tackling diverse types of problems—be it structured or ill-structured, routine or nonroutine, and familiar or unfamiliar—which resemble those that they (learners) would encounter in navigating their future workplace.

Moreover, this book also offers a distinct contribution to the extant literature on real-world problem solving by presenting contributions from Singapore-based researchers. In the recently released results of the 2012 Programme for International Student Assessment, Singapore emerged as the top performer among 44 countries and economies in terms of tackling real-life problems. Singapore's 15-year-old students were found to be strongest in dealing with problems that necessitate understanding and formulation or representation of new ideas. Singapore's strong performance on creative problem solving internationally in spite of her emphasis on high-stake assessment could be a testament to the possibility that development of high authentic problem solving proficiencies can be achieved within such educational culture. Gaining leverage from this positive development, this book allows researchers and educators from other parts of the world to glean on the nature of authentic problem solving and learning processes that take place in Singapore classrooms and potentially exemplify key elements of practice that propelled Singapore students' outstanding performance in international assessments, such as those in the realm of problem solving. These scholars can extract useful information, new insights, successful stories, and practical guides that they can apply in their respective educational settings.

Concerning policymakers and curriculum developers who are at the helm of education systems, they can acquire a better understanding of the benefits and challenges of enacting authentic problem solving activities and how authentic learning practices can run counter to other aspects of the traditional school systems, such as teachers' and students' beliefs, curriculum designs and assessment modes, and school culture. Although these contradictions may seed negative reactions from some sectors, they can create the impetus for reflections and changes in education policies and practices. This book presents diverse frameworks and multiple scenarios that can be used in identifying potential bridging strategies to analyze and reconcile such contradictions and streamline the process of adapting school systems to the needs of twenty-first-century learners.

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Foreword

Learning cannot be detached from problem solving. Learning in schools must prepare students for life in the real world that is filled with ambiguities and complexities, a world that is enmeshed with problems that lack the structure and elegance of archetypal classroom tasks. Problem solving skills are part and parcel of one's survival kit in the competitive and dynamic life arena that is continually shaped and transformed by rapid social, technological, and cultural advancements in the twenty-first century. This new world creates a multitude of difficulties for those who are ill-equipped, but brings rewards and a better quality of life for those who possess the necessary competencies.

This book serves as a comprehensive resource for readers who value the promotion of learning that is transferrable to real-world practice and who recognize the importance of authentic problem solving as a key twenty-first-century competency. The various chapters show diverse aspects of authentic problem solving and learning in different learning contexts across K-12 schools and higher education. A wide range of domains, including science, mathematics, geography, and teacher education are given attention by the contributors. The book focuses not only on authentic learning in school but also on participation in informal learning contexts. Although there are a few books about authentic learning or problem-based learning in school, they rarely involved both simulation and participation models for authentic learning focused on both formal and informal learning spaces.

Contributions from authors coming from different educational systems or instructional settings provide both theoretical and empirical perspectives on authentic learning, so as to guide teaching and learning innovations. The book describes innovative school practices in the design of problems, learning processes, environments, and ICT tools for authentic problem solving and learning. In addition, the book not only highlights key components of authentic learning activities but also describes how the components interact with each other in a dynamic system.

This book offers to provide the Asian perspective that is lacking in the current publications on authentic learning or problem solving that have been dominated by Western views. It highlights authentic learning theories initiated by Singaporean researchers (e.g., productive failure, cognitive function) and practices unique in

Singapore (e.g., retail experience for active learning, problem-based learning curriculum in Republic Polytechnic). Those who are interested in reforming school curricula and improving classroom practices, particularly for Asian learners, can identify success stories that bear some semblance to their own instructional settings. Moreover, this book describes possible challenges that educators may face when authentic activities are conducted in Asian classrooms. To reduce the gap between planned and enacted authentic learning activities, the book suggests professional development of teachers and coevolution of learners and authentic tasks.

Being a compendium of articles that focus on the confluence of theory, research, and practice, the book serves as an up-to-date and comprehensive resource on authentic problem solving and learning. It addresses a wide range of readers who are interested in developing and promoting instructional practices and learning environments that are essential for fostering the competencies to solve problems in real-world contexts. In particular, graduate students and researchers in Learning Sciences and Educational Technology will find the book beneficial in understanding both theoretical and practical aspects of authentic problem solving and learning. For teachers and school leaders, the book provides insights on developing school curricula, improving pedagogies, and planning professional development programs. The empirically based insights and thought-provoking propositions presented can help inform and transform practice to better prepare learners and teachers to face the challenges of the twenty-first century.

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Part I
Introduction and Overview

Chapter 1
Authentic Problem Solving and Learning for Twenty-First Century Learners

Young Hoan Cho, Imelda S. Caleon, and Manu Kapur

Abstract In line with the goal of developing learners for the twenty-first century, which is characterized by the emergence of knowledge-based economies, educators have strived to cultivate students' competence in authentic problem solving. This book documents innovative practices of authentic problem solving and learning in Singapore and other countries with regard to three main approaches: *authentic problem*, *authentic practice*, and *authentic participation*. Concerning authentic problems, this book introduces the role and design of authentic problems and problem-based learning environments. The discussions on authentic practice emphasize authentic experience, tool-mediated action, and culture more than realistic problems themselves. The last key theme in the book, authentic participation, elucidates informal learning out of school and learners' interaction with practitioners in a community of practice. Throughout this book, the dynamic interaction and tensions of authentic problems, learners, tools, and learning environments are discussed along with successful cases of authentic learning in K-12 school, higher education, and professional development. Blending contributions from Singapore-based and international authors, this book provides useful information, new insights, successful stories, and practical guides to school leaders, parents, teachers, and researchers who are willing to develop authentic learning environments for twenty-first century learners.

Keywords Authentic problem solving • Authentic learning • Twenty-first century competencies • Authentic practice • Authentic problem • Community of practice

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Authentic Learning for Twenty-First Century Learners

With the rapid changes in the social, political economic, and technological landscape around the world, learners face a more globally competitive job market after leaving school. The twenty-first century, which is characterized by the emergence of knowledge-based societies, necessitates learners to be comfortable in dealing with ambiguities and complexities in the real world and competent in using knowledge as a tool in their workplace. Despite complex demands of a new society, school education has emphasized acquiring knowledge for standardized tests that are usually separated from real-world activities and contexts. In addition, school tests usually include well-structured problems with all elements required for a single right answer (Jonassen 1997). Students can solve well-structured problems by applying prescribed processes and a limited number of concepts or rules without critical and creative thinking. To ensure high achievement of students in high-stakes tests, teachers tend to provide direct instruction of problem-solving processes with worked examples and have students solve practice problems in a textbook. However, these conventional problem solving and instructional practices have limitations in the twenty-first century in which people should flexibly solve novel problems with no single right answer and adjust themselves to a world of constant change (Thomas and Brown 2011).

Literature in the learning sciences and educational psychology has indicated the existence or proliferation of *inert knowledge* problem; that is, learners cannot recall and use their prior knowledge and problem-solving experiences while solving a new problem due to the change of contexts and surface features (Gentner et al. 2003; Novick and Holyoak 1991). For instance, people often fail in using knowledge of fractions they have learned in school when figuring out how much cottage cheese they need to have three-quarters of the two-thirds cup of cottage cheese in a diet program (Lave 1988). Brown and his colleagues (1989) also pointed out a common limitation of contemporary school systems: “Students may pass exams (a distinctive part of school cultures) but still not be able to use a domain’s conceptual tools in authentic practice” (p. 34).

This inert knowledge problem is a critical issue in educational communities that seek for the development of twenty-first century competencies. Authentic learning models can provide a fertile ground to nurture key competencies identified as essential for learners of the twenty-first century, as well as help in tackling the inert knowledge problem. The United States National Research Council (NRC 2012) suggested three domains of twenty-first century competencies: cognitive (e.g., critical thinking, problem solving, argumentation), intrapersonal (e.g., self-regulation, adaptability, metacognition), and interpersonal (e.g., collaboration, leadership, conflict solution). In traditional classroom practice, students may not be able to sufficiently develop the twenty-first century competencies due to the lack of learning opportunities for making arguments to solve ill-structured problems, self-regulate learning processes, and collaboratively build knowledge with classmates. By contrast, it is highly plausible that authentic learning approaches help students to develop the twenty-first century competencies. By working collaboratively to solve problems in an authentic situation, students are likely to engage in critical thinking, collaborative knowledge building, self-regulation, and developing knowledge and skills that are transferrable to a new situation (Hmelo-Silver and Barrows 2008; Kapur and Rummel 2012; Yew and Schmidt 2009). For instance, Hmelo-Silver et al. (2007) found that problem-based learning and inquiry learning are beneficial not only for knowledge acquisition and application but also for the development of problem-solving skills, reasoning skills, self-directed learning skills, and future learning. Thus, to help learners to develop twenty-first century competencies, it is imperative for educators to consider the utilization of authentic learning models.

In authentic learning models, learning occurs while people solve problems in authentic contexts and participate in the practice of a community. That is, authentic learning is closely related to problem solving and other practices in a community. Students learn by engaging in authentic activities defined as "ordinary practices of the culture" (Brown et al. 1989, p. 34) including interaction with practitioners, collaborative problem solving, negotiation of meanings, and reflection. Through these learning activities, students can develop knowledge, skills, and values in authentic contexts as practitioners like mathematicians, scientists, writers, and historians do (Cho and Hong 2015). Thus, authentic learning can help students to become a member of the culture and participate in meaningful practices.

Authentic Learning Models

Although there are a number of barriers in school (e.g., curriculum, examination, school culture) to authentic learning, several instructional models aligned with the principles of authentic learning such as anchored instruction (Cognition and Technology Group at Vanderbilt 1990), cognitive apprenticeship (Barab and Hay 2001; Collins et al. 1989), problem-based learning (Hmelo-Silver 2004), learning by design (Kolodner et al. 2003), and productive failure (Kapur 2012, 2013) have been developed and successfully implemented in K-12 and higher education. These models consider problem solving as a key learning activity in which learners collaboratively solve complex, ill-structured problems that are similar with those that practitioners encounter in the community of practice (i.e., authentic problems). While solving the authentic problem, learners may engage in the epistemic practices of using concepts, principles, rules, tools, and resources that have been iteratively developed in the culture (Bielaczyc and Kapur 2010). These instructional models are based on the epistemological assumption that learning cannot be separated from problem solving, which is an essential part of the practice in a community. Wenger (1998, p. 8) emphasized the integration of learning and practice: "Learning is an integral part of our everyday lives. It is part of our participation in our communities and organization."

Existing literature on authentic learning has indicated that authentic learning environments can be designed based on the simulation and participation models of authenticity (Barab et al. 2000), although there is considerable debate about how best to structure and scaffold such environment (Kapur and Rummel 2009). In the simulation model of authenticity, learners are engaged in classroom activities that resemble real-world practices, and contexts. The participation model for authentic learning emphasizes ecological authenticity where learners participate in the practices of out-of-school communities and develop an identity as a community member.

Simulation Model for Authentic Learning

Instructional models with the simulation perspective involve problem-based learning, cognitive apprenticeship, and inquiry-based learning. In a simulation experience, an authentic learning environment serves as a context that mirrors the process of the utilization of knowledge and skills in real-world situations (Gulikers et al. 2005; Herrington and Oliver 2000). This environment resembles real-world complexity and offers myriad resources that enable analysis from various angles (Herrington and Oliver 2000). The degree to which the processes involved in these environments mirror those performed in real-world settings may be regarded as procedural authenticity. The authenticity of the tasks provided by these learning environments is associated with some key features (as summarized by Herrington and Oliver 2000): The tasks need to be ill-defined and complex, require a sustained period to resolve, afford an opportunity for learners to collaborate, and integrate various domains.

The simulation models feature a learning environment in which students can develop knowledge, skills, and values while solving authentic problems and carrying out authentic tasks. The problems and tasks usually do not present all the information needed to solve them, can be solved in multiple ways, often require the use of multidisciplinary approaches, evolve into different forms as more information is collected, and do not have an absolutely correct solution (Gallagher et al. 1995; Jonassen 1997). The benefits of authentic learning environments based on the simulation model have been well-documented in previous studies. For example, research on productive failure has shown how engaging students in the authentic mathematical practice of generating and exploring diverse solutions to a complex problem before learning the canonical concepts helps develop deep conceptual knowledge that can be transferred to novel contexts (Kapur 2014, 2015; Kapur and Bielaczyc 2012). This research also shows how collaborative discussions may initially diverge while exploring multiple representations and solutions when students do not know the correct solutions; yet, this process is key to deep learning (Kapur et al. 2006). Roth and Roychoudburry (1993) found that using authentic contexts for collaborative inquiry activities can facilitate the development of students' higher-order inquiry skills. In consonance with these results, Kuhn and Pease (2008) reported that prolonged engagement in collaborative inquiry activities, which were set in real-world contexts and supplemented with computer-based scaffolds, helped in developing students' fundamental process skills such as interpretation of evidence, formulating appropriate causal conclusions, problem identification, and communicating findings. The problem-based learning (PBL) approach, which emerged from the experiential learning tradition, offers learners a rich opportunity to develop knowledge and life skills by engaging in guided collaborative problem solving (Hmelo-Silver 2004). Empirical studies, mostly involving mature learners, provide converging evidence that the PBL approach can cultivate flexible understanding, transferrable problem-solving skills, self-directed learning strategies, and effective collaboration skills (Hmelo-Silver 2004). A meta-analysis of 43 articles that focused on (PBL) as applied in tertiary education indicated consistent positive effects, especially on skills-related outcomes (Dochy et al. 2003). Although more studies are needed to ascertain the effectiveness of PBL in younger learners, existing evidence provide a strong support for the potential of PBL to foster competencies that are essential for current learners to adapt in a rapidly evolving technology-driven world.

Participation Model for Authentic Learning

The participation approach for authentic learning underscores the provision of opportunities for learners to directly interact with real practitioners in the context of their actual field of practice (Radinsky et al. 2001). Aside from factual, process, and task authenticity, participatory experiences also feature *ecological authenticity*: that is, the learner tackles real-life tasks within the actual context in which the task has meaning (Barab and Dodge 2007; Barab et al. 2000). The learner may assume the role of an apprentice who is being guided by a mentor engaged in professional practice. Using Lave and Wenger's (1991) perspective, the learner may learn through *legitimate peripheral participation*, which allows him or her to take part in simple low-risk activities and then gradually work on tasks with increasing significance in the community. This participatory experience, which physically brings learners into the real world, provides learners with optimum opportunities to learn about aspects of practice that cannot be acquired from and captured by simulation experiences (Radinsky et al. 2001). In Barab and Hay's study (2001), middle-school students took part in a short camp with real scientists. The students were given an opportunity to participate in real scientific projects that entailed them to "do science where scientists do science" and alongside practitioners of science (Barab and Hay 2001, p. 76). The students experienced authentic science practices and discourse in connection with domain-related dilemmas. They perceived themselves as doing legitimate science and contributing to the making of science. Lambson (2010) found that new teachers shifted from peripheral to more central participation in a teacher study group and took on the culture, practices, and language of the teacher community through regular discourse with more experienced teachers. These studies show that authentic learning emerges within participatory experiences which enable novices to interact with practicing professionals and make meaning in a collaborative activity (Bielaczyc, Kapur, and Collins 2013; Rahm et al. 2003).

Authentic Problem, Authentic Practice, and Authentic Participation

We considered both the simulation and participation models for authentic learning in framing this book. Within the simulation model, we further distinguished an authentic problem approach from an authentic practice approach. The authentic problem approach focuses on complex, ill-structured, and realistic problems that may lead to learning through authentic problem solving. In PBL, for instance, all learning activities are organized around complex and realistic problems (Hmelo-Silver 2004). As an illustration of this point, Hmelo-Silver and Barrows (2008) engaged a group of students in a PBL activity which required the diagnosis and treatment of a medical problem involving a real patient afflicted with pernicious anemia. Initially, limited information from the patients' medical record was provided to the students. The students were allowed to ask questions and request for laboratory test results and were given the freedom to identify and research on the concepts that they need to learn to address the problem. They were also asked to generate hypotheses and reflect on them. To guide the problem-solving process, the students wrote facts, ideas, learning issues, and action plans on a whiteboard, which subsequently served as the focal points of the group discussions. After solving the problem, the students reflected on the lessons learned from the activity.

In contrast, the authentic practice approach emphasizes authentic experience, tool-mediated action, and culture more than realistic problems themselves. Within the authentic practice realm, even a simple problem can be useful for understanding how practitioners see the world, use tools, and take part in activities. For instance, Schoenfeld (1991) used a magic square problem (i.e., placing digits from 1 to 9 in a square box with 9 cells so as to make the sum of digits same along each row, each column, and each diagonal), which enables students to take part in mathematical practice and look at a problem as mathematicians do.

The authentic participation approach is divided into two subthemes. The first subtheme, which was described earlier, elucidates learners' interaction with practitioners in the context of their place of practice. The second subtheme focuses on the interaction among members of a community of practice as they engage in collaborative identification and solving of real problems that are present within their community. Illustrative examples of the second subtheme were mentioned by Darling-Hammond (1998) in relation to teacher learning and professional development: Teachers were engaged in collaborative research activities in which they identified and addressed classroom-based problems and issues, such as those pertaining to assessment practices and effective teaching approaches.

Therefore, this book is structured in regard to the three approaches – authentic problem, authentic practice, and authentic participation approaches– toward authentic problem solving and learning.

Authentic Problem Solving and Learning in Singapore

A key purpose of this book is to introduce authentic problem solving and learning practices for school stakeholders who are interested in reforming a school curriculum and improving classroom practices, particularly in Asian settings. Although the simulation and participation models of authentic learning environments have been examined in a number of studies, few books and articles have discussed authentic learning and authentic problem solving in the context of Asian countries. According to Barab et al. (2000, p. 42), “Authenticity emerges through meaningful relations among individual, community, and task.” Authentic learning activities may be designed and implemented differently and have various meanings depending on learners and communities. For example, a group of teachers set up a classroom to resemble a bank, where there are tellers to attend to the withdrawals and deposits of existing depositors and account managers who are meant to entertain those who would open new accounts. If the students are not familiar with banks, the simulated environment may not appear as authentic to them. When educators design and build authentic learning environments in Asian countries, they should fully understand the dynamic interaction or tensions among authentic tasks, Asian learners, and culture of Asian communities. However, there are few design principles, cases, and empirical studies on authentic problem solving and learning for Asian learners who lack experience in student-centered learning. To fill the gap in the literature of authentic learning, this book aims to introduce innovative practices of authentic problem solving and learning in Singapore schools and learning communities. Singapore serves as a worthy example of an education system that is working toward the promotion of authentic learning experiences for students.

During the early 2000s, authentic problem solving was not explicitly utilized as a key learning activity in Singapore classrooms. Hogan and Gopinathan (2008) found that primary and secondary classroom practices mainly consisted of whole class lecture, whole class answer checking, and individual seatwork in their classroom observations during 2004 and 2005. They pointed out the following issues in Singaporean classroom practices:

> The enacted curriculum in Singaporean classrooms is characterized by limited disciplinarity as indicated by a limited focus on advanced concepts, knowledge application, validation of knowledge claims, and generation of knowledge that is new to students … Teacher-dominated instructional practices prevail within classrooms. (p. 370)

In order to overcome the limitation, the Singapore government has introduced educational policies guided by the vision of “a nation of thinking and committed citizens capable of meeting the challenges of the future, and an education system geared to the needs of the twenty-first century” (Ministry of Education 2008). In addition, the Ministry launched a new initiative, referred to as *Teach Less Learn More*, to de-emphasize instruction that is focused on tests and examinations and focus on the quality of learning and engagement of students. As results of the initiatives, Singapore schools began to increase student-centered learning practices and pedagogies to foster the development of twenty-first century competencies. Singapore’s education efforts seem to have paid off as the city-state has shown indications of achievement in line with fostering authentic learning and problem solving. According to the results of the Programme for International Assessment (PISA) survey, which was conducted under the auspices of the Organisation for Economic Cooperation and Development (OECD), Singapore students have fared very well when compared to their counterparts in 64 other countries: They ranked second in mathematics, fourth in science, and fifth in reading (OECD 2010). PISA, with its focus on "the extent to which students can apply the knowledge and skills they have learned and practised at school when confronted with situations and challenges for which that knowledge may be relevant," utilized assessment tasks framed in real-life situations (OECD 2012, p. 22).

Another development that is aligned with the Ministry's vision is the growing research efforts to explore the integration of authentic problem-solving activities as parts of learning activities in Singapore classrooms. Working under the purview of the Office of Education Research at the National Institute of Education, a number of researchers and teachers have collaborated to address this research agenda, with a particular focus on PBL, inquiry learning, productive failure practice, and participation in a learning community. We deem that the current compendium of studies carried out by Singapore researchers over the course of almost a decade is a valuable educational resource that warrants attention from educators, as well as researchers and curriculum developers, from other parts of the world. Information on authentic learning pedagogy coming from high-performing education systems, such as that of Singapore (OECD 2010), will provide fertile insights that can enrich extant knowledge of educators from other education systems around the world. This book also intends to explore how the innovative practices of authentic learning and problem solving have changed Singapore classroom practices and what kinds of challenges are are yet to be overcome in Singapore contexts. This book includes authentic problem solving and learning practices in diverse domains, educational levels, and learning contexts. Readers will easily identify successful stories that can be applied to their own contexts of practice and gain new insights into how to improve instructional practices and design school curriculum innovations.

Overview of the Book

Our hope is that this book will help readers understand authentic problem solving and learning and how it can be used to make a difference in their school or learning communities for the development of twenty-first century competencies. It describes innovative school practices on the design of problems, learning process, environments, and ICT tools for authentic problem solving and learning. In addition to the innovative practices, this book also aims to provide readers with theoretical explanation of authentic learning process and outcomes. For an in-depth understanding of authentic problem solving and learning, this book presents how students learn from generating and exploring solutions to complex problems and what cognitive functions are needed at different stages of problem-based learning.

Comprising 20 chapters, this book presents the three approaches (authentic problem, authentic practice, and authentic participation) about authentic learning along with theoretical explanation, successful cases, instructional design principles, and challenges encountered in K-12 schools and learning communities (see Fig. 1.1). The three approaches, which are presented in the core parts (II to VI) of the book, are embedded in between Part I ("Introduction and Overview") and Part VII ("Conclusion and Future Direction"). We describe our purpose and the overarching structure of this book in Chap. 1 ("Authentic Problem Solving and Learning for Twenty-First Century Learners") of Part I. Parts II and III focus on authentic problems. Parts IV and V include chapters that deal with authentic practice. Chapters under Part VI report studies on authentic participation. Part VII ("Conclusion and Future Direction"), which contains the last chapters provides a synthesis of the key learning points from the previous chapters and meaningful insights for future research on authentic problem solving and learning.

Part II, "Authentic Problems and Tasks," contains three chapters detailing how instructors can design and use ill-structured real-world problems and describing the role of authentic tasks for meaningful learning in school. Chapter 2, "The Role of Authentic Tasks in Promoting Twenty-First Century Learning Dispositions," shows that authentic tasks play a significant role in determining secondary school students' beliefs, motivational dispositions, and individual engagement when it comes to mathematics learning. To enhance the benefits of authentic tasks, teachers need to understand the nature of authentic problems and design them effectively based on theories and classroom contexts. Chapter 3, "A Design Model for Problem-Based Learning," introduces theories and empirical studies on designing real-world

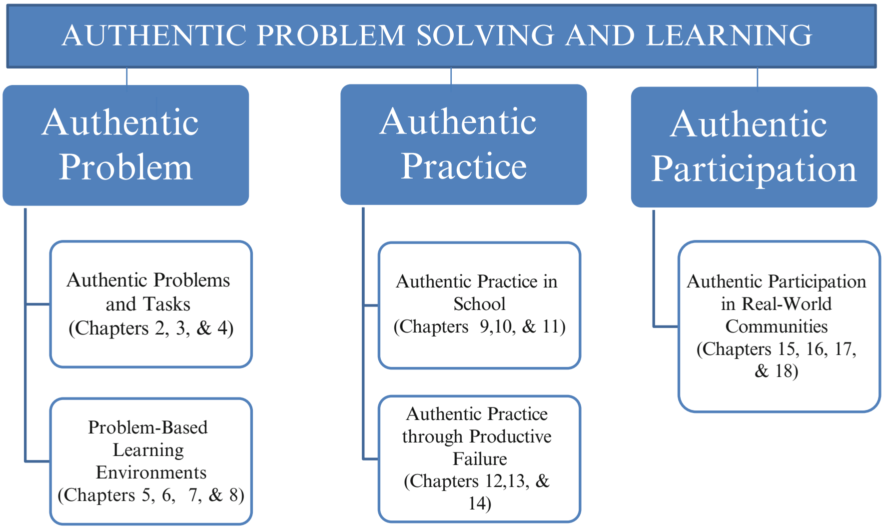

Fig. 1.1 Organization of the book in accordance with three approaches in authentic problem solving and learning

problems for PBL as well as practical approaches to designing and evaluating the problems. In addition, Chap. 4, “Mathematical Problem Solving Using Real-World Problems,” shows the affordances and challenges of using authentic problems with young children in a primary school in Singapore. These chapters can be helpful for readers who want to understand the role of authentic tasks and design them for meaningful learning.

Authentic problems are essential in problem-based learning environments like PBL and inquiry-based learning. These learning environments provide instructional supports, resources, and tools that help learners to collaboratively solve authentic problems. Part III, “Problem-Based Learning Environments,” includes four chapters that present a conceptual framework of PBL and classroom practices in Singapore. Chapter 5, “Problem-Based Learning: Conception, Practice, and Future,” introduces PBL as a student-centered, problem-driven, and situated learning approach that is implemented in a variety of disciplines. The theoretical conception and design issues of PBL are discussed along with suggestions for future research. Chapter 6, “Using Problems to Learn in a Polytechnic Context,” shows how problem-based learning environments have been effectively developed and implemented at a polytechnic in Singapore. The school not only modified its curriculum, assessment, and academic policies for PBL but also made efforts for professional development of teachers. Two chapters in this section show different approaches toward how students learn in problem-based learning environments. Chapter 7, “Pedagogical Interfaces in a Problem-Based Learning (PBL) Environment: Cognitive Functioning at PBL Stages,” reveals cognitive functions at each PBL stage, whereas Chap. 8, “Finding Common Ground During Collaborative Problem Solving: Pupils’ Engagement in Scenario-Based Inquiry,” focuses on the sociocultural aspects of collaborative inquiry learning.

The discussion on authentic practice emphasizes authentic learning activities and experiences more than authentic problems. Parts IV and V both focus on the authentic practice. Although both sections underscore theory and practice to enculturate learners into the culture of real-life practitioners through authentic activities, the latter section focuses mainly on the practice of productive failure (see discussion in succeeding paragraph). The former section, “Authentic Practice in School,” includes three chapters that show different conceptual frameworks and practices for authentic learning activities. The authors of Chap. 9, “Cultivating a Remix Movement in an East Asian Culture,” argue that the activities of play, tinkering, and remix should be fostered to overcome the limitations of examination-oriented education in East Asian cultures. In addition, Chap. 10, “Authentic Thinking with Argumentation: Putting on the Thinking Caps of Scientists and Designers,” provides a conceptual framework for authentic thinking with argumentation that is essential in the practices of both scientists and designers. Lastly, Chap. 11, “Using an Immersive Environment to Address Problems Associated with the Learning of Geography,” presents a curricular intervention in which secondary school students develop geographical intuition and knowledge through experience in immersive learning environments. This section helps to understand emerging practices for authentic learning, which can be applied to K-12 education.

The next section, "Authentic Practice Through Productive Failure," focuses on research that revolves around productive failure. The productive failure learning design provides students with opportunities to engage in the practices of mathematicians by formulating and exploring solutions to novel problems in small groups before receiving formal instruction of canonical solutions. This section includes three chapters that introduce productive failure as authentic practice and explain what makes it effective for meaningful learning. Chapter 12, "Learning from Productive Failure," provides a conceptual framework of productive failure and key learning mechanisms in productive failure on the basis of empirical studies in Singapore schools. A growing number of studies have shown that learning through productive failure is more effective than that achieved through traditional direct instruction. Based on a quasi-experimental study, the authors of Chap. 13, "Discussing Student Solutions is Germane for Learning when Providing or Delaying Instruction," argue that productive failure is effective because learners can pay attention to key components of a canonical solution when it is compared and contrasted with their own solutions. In addition, Chap. 14, "Mathematical Skills and Learning-by-Invention in Small Groups," shows that the effectiveness of invention activities is, in part, determined by the composition of small groups. Group composition plays an important role in productive failure practice, which is usually carried out through collaborative, not individual, work. The authors underscored the findings that groups including both students with high and low math skills are likely to explore a broader range of solutions and higher-quality solutions, which is important for learning from productive failure.

The penultimate section, "Authentic Participation in Real-World Communities," includes four chapters that showcase specific cases and provide insights about how people learn by participating in informal learning activities and community practices. The section zeroes in on authentic participation, which assumes learners' direct interaction with real-world communities. Chapter 15, "Retail Experience for Active Learning (REAL) Experience," shows an innovative program in which secondary school students develop their business knowledge and skills by participating in an internship at local retailers in Singapore. In addition, Chap. 16, "Authentic Learning Experiences in Informal Science Learning: A Case Study of Singapore's Prospective Teachers," shows design-based research in which preservice teachers codeveloped an informal astronomy workshop and interacted with their expert mentors. Chapter 17 and 18 report on authentic participation of in-service teachers for the development of their competencies in a professional learning community ("Exploring the Process of Problem Finding in Professional Learning Communities Through a Learning Study Approach") and in a wiki-based learning community ("Problem Solving of Teacher-Generated Classroom Management Cases in Wiki-Based Environment: An Analysis of Peers' Influences"). The former chapter explores how biology teachers identify and define a problem that would be addressed in a professional learning community, and the latter investigates how secondary school teachers collaboratively solve their own classroom management issues in an online learning community. Teachers can develop their identity and professional competencies necessary in twenty-first century classrooms by actively participating in the process of collaboratively identifying, analyzing, and solving real problems in their community.

The last section (Chap. 19, "Authentic Problem Solving and Learning: Lessons Learned and Moving Forward", and Chap. 20, "Authentic Learning Research and Practice: Issues, Challenges, and Future Directions") presents an integration and reflections on the key ideas that were underscored in the previous chapters and provides the readers with recommendations to transform current practices and advance research in authentic problem solving and learning.

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Part II
Authentic Problems and Tasks

Chapter 2
The Role of Authentic Tasks in Promoting Twenty-First Century Learning Dispositions

Jennifer Pei-Ling Tan and Youyan Nie

Abstract Authentic tasks are widely acknowledged by educators to foster desirable twenty-first century (21C) learning dispositions in students, particularly in terms of motivated and engaged learning. In mathematics education specifically, authentic tasks are commonly upheld as essential to the development of positive student affect towards mathematics, as well as mathematical problem-solving competencies and its encompassing socio-cognitive processes—reasoning, communication and connections—among learners (Beswick K, Int J Sci Math Educ, 9(2):367–390, 2011). Despite this widespread belief in the value of authentic tasks, there is surprisingly limited empirical evidence on the relationship between the use of authentic tasks in classrooms and productive learning dispositions (Pellegrino and Hilton (eds) Education for life and work: developing transferable knowledge and skills in the 21st century. National Academies Press, Washington, DC, 2013), particularly from the perspective of students as a critical stakeholder group. This chapter attempts to address this knowledge gap.

Drawing from a comprehensive study involving more than 4,000 students across 129 classrooms from 39 secondary schools in Singapore, this chapter foregrounds the extent to which the use of authentic tasks predict a suite of productive 21C learning dispositions. These comprise positive beliefs, attitudes and motivational dispositions that lend themselves towards deeper learning, namely, mastery-approach and performance-approach goal orientations, self-efficacy and task value and individual and collaborative learning engagement. Hierarchical linear modelling results underscore the significance of authentic tasks in predicting students' individual engagement levels and mastery-approach and performance-approach goal orientations, as well as the extent to which they consider mathematics to be interesting, useful and important. Authentic tasks, however, were not a significant predictor of students' collaborative engagement and self-efficacy in learning mathematics. The implications of these results are discussed, particularly in light of current understandings of Singapore secondary school students' self-reported dispositions towards learning mathematics and their strong global performance in international mathematics achievement tests.

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Introduction

Social commentators and futurists have produced a variety of characterisations of our current millennium. These include the Digital Age (Brown 2006; Thomas and Brown 2011), the Creative Age (Florida 2002) and the Conceptual Age (Pink 2005), just to name a few. Despite semantic differences, all of these labels acknowledge that our twenty-first century (21C) social and economic landscape has distinctive features that set it apart from preceding historical periods. Where standardisation and mass production used to be primary generators of economic wealth in the Industrial Age, the current 'digital revolution'—embodied in personal, mobile and networked technologies—has replaced manual and routine mental labour with personalised services, ideas and innovation. These are in turn argued to be key commodities that drive new economic growth (Freeman 2004; Perez 2002).

This significant epistemological and sociological shift is exerting substantial pressure on the social institution of schooling worldwide to evolve and respond in terms of what Harvard Professor Richard Elmore (1996) terms the 'core of educational practice', that is, 'how teachers understand the nature of knowledge and the student's role in learning, and how these ideas about knowledge and learning are manifested in teaching and classwork' (p. 2). While the specifics of school curriculum may remain contested, there now appears to be some convergence among global educational scholars, policymakers and practitioners around what constitutes 21C literacies and dispositions and the enabling pedagogical approaches that are likely to foster them (Hanna et al. 2010). The use of authentic tasks is widely acknowledged to be one such pedagogical approach. While commonly referenced '21C literacies and dispositions'—such as digital, creative and critical literacies, collaboration and lifelong learning aptitudes such as engagement, interest and self-efficacy—have always played important roles in the progress of human history, they have traditionally been viewed as 'expressive affordances' (Bernstein 2000). In a knowledge-centred economy, characterised by complexity and rapid change, exponential technological advancements, multiplying bandwidth and increasing global consumer demand, these individual and collective attributes come to play a more central role in determining access to and productive participation in local, global and virtual societies.

As highlighted earlier, however, a review of extant literature appears to indicate an incommensurate gap between (a) the advocacy of authentic tasks as a means to motivate and engage students towards deeper learning and (b) the availability of empirical evidence beyond assorted qualitative small-scale research examples that can provide robust insights into the relationships between authentic tasks and productive student learning dispositions, including engagement and motivation. While the authors recognise the value of qualitative research studies that provide highly contextualised understandings on the use and efficacy of authentic tasks in classrooms, there undoubtedly remains an empirical knowledge gap in the literature that warrants further attention. This serves as the primary focus of our chapter—to contribute robust empirical understandings on the extent to which the use of authentic tasks statistically predict a suite of productive learning beliefs and motivational dispositions that are essential in the current 21C knowledge economy.

While a comprehensive treatise on authentic learning, 21C literacies and learning is beyond the scope of this chapter, the following section provides a brief outline of what constitutes authentic tasks and the 21C learning dispositions of pertinent interest to this study, namely, adaptive achievement goals, individual and collaborative learning engagement, self-efficacy and task value. Collectively, these will serve as both a conceptual and contextual frame for the results and discussion that follows.

Authentic Tasks and Productive 21C Learning Dispositions

Authentic Tasks

The roots of authentic tasks can arguably be traced back to the several decades leading up and into the 1940s known as the 'progressive period' of educational reform in the West, particularly the United States. A priority agenda of this period, led by influential intellectuals such as John Dewey, among others, was that of changing the pedagogical core of schooling, from 'a teacher-centred, fact-centred, recitation-based pedagogy' to one 'based on an understanding of children's thought processes and their capacities to learn and use ideas in the context of real-life problems' (Elmore 1996, p. 7). This pedagogical intention and 'red thread' carried through the following periods of large-scale educational reforms, in the United States and other parts of the world, which saw an intensifying paradigmatic shift away from a *Cartesian* approach towards more *ecological* understandings of the nature of knowledge and learning.

The Cartesian model of learning paradigm lies at the root of conventional transmissionist-oriented instructional approaches, which tends to produce passive or inert knowledge. In sharp contrast, a key premise of the ecological learning paradigm is that of situating the learner within the learning context, which bears 'real-world' relevance and is community based rather than individual based (Barab and Plucker 2002; Brown 2006; Vygotsky 1978). As a study of knowledge, it shifts from focusing on individual forms of cognition and rationality to multiple social forms of knowing, being and doing, where situated cognition and active learning take place within communities of learners as they engage in meaning-making through experiential activities that are relevant and connected to the learners' lives beyond the staid classroom and textbook exercises (Dawson and Siemens 2014; Tan and McWilliam 2008). It is within this 'pedagogical common sense' that authentic tasks are situated.

Authentic tasks, sometimes referred to also as ‘situated learning’ in new literacy studies (Tan 2008; The New London Group 2000) or ‘context problems’ in mathematics education, bear several definitions and understandings in varying degrees of specificity. For instance, Brophy and Alleman (1991) provided a general definition of authentic tasks as ‘anything students are expected to do, beyond getting input through reading or listening, in order to learn, practice, apply, evaluate or in any other way respond to curricular content’ (p. 10). Reeves et al. (2002), on the other hand, identified ten specific attributes of authentic tasks as: (1) relating to real life, (2) encompassing ill-defined problems as complex as real life, (3) providing opportunities to relate/connect various subject areas in fulfilling the task, (4) consisting of complex goals that students pursue over a period of time, (5) providing opportunities to define a problem from various viewpoints using various resources, (6) providing opportunities for collaboration which is essential in classrooms as well as in real life, (7) providing opportunities for self-expression, (8) allowing for different products to emerge at the end of process, (9) encompassing both process and product evaluations and (10) giving way to multiple interpretations and products.

Particular to mathematics education, Kramarski et al. (2002) specifically defined authentic tasks as conveying common contexts ‘for which there is no ready-made algorithm’ (p. 226). In contrast, Jurdak (2006) provided a more general definition that did not specify exclusions but described authentic tasks as ‘meaningful, purposeful and goal-directed’ tasks that simulated real-world problem-solving (cited in Beswick 2011, p. 369).

Regardless of subject domains and the specificity or generality of the definition, a key point of convergence is that authentic tasks require a ‘real-world’ element—whether in terms of meaningfulness, relevance and/or application to the personal lifeworlds of learners, as well as an element of connectedness to other subject domains and contexts beyond the textbook and school. In similar vein, for the purpose of this study, we described and operationalised authentic tasks as the frequency to which students consider their teacher to have:

1. Provided opportunities for pupils to apply ideas to everyday nonschool-related situations
2. Focused the lesson on what is personally meaningful rather than what is in the syllabus
3. Attempted to link subject knowledge to their personal experiences
4. Provided opportunities for them to apply ideas learnt in class to other subjects

Productive 21C Learning Dispositions

By 21C learning dispositions in the context of this chapter, we are referring to a suite of productive beliefs and motivational inclinations towards learning. Specifically, these include (1) two achievement goal orientations—mastery approach and performance approach—that are largely understood to be strongly associated with adaptive learning, (2) self-efficacy and task values and (3) engagement in learning, both individual and collaborative.

Before we further elaborate on our conceptualisation and operationalisation of these dispositions, it is important to highlight that we refer to these productive beliefs and motivational inclinations as essential 21C learning dispositions not because they only emerged or became important to learning in the 21C. Rather, understandings about these learning constructs and their positive impact on learning started coming to the fore since the mid- to late 1990s, primarily through the theoretical and empirical work of educational motivational psychologists and social psychologists. Some outstanding contributors include: John Nicholls (1984) and Carol Dweck (1986, 2000, 2006) on self-theories and achievement goal orientations, Albert Bandura (1982, 1997) on self-efficacy and Jacquelynne Eccles and Allan Wigfield (1983, 2000) on expectancy-value theory of achievement motivation and the impact of subjective task value on learning outcomes.

It was, however, not until the most recent wave of national and international curricular reforms attempting to specify the teaching and learning of 21C competencies that these critical learning dispositions have been explicitly acknowledged in curricular frameworks as an important, even foundational component in the development of 21C skills among learners. A most recent '21C curricular framework' published by the National Academy of Sciences in the United States entitled *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century* (Pellegrino and Hilton 2013) identified 'positive dispositions towards learning'—comprising productive beliefs and motivation towards learning—as one of five core pillars of knowledge that together fostered 21C skills, deeper learning and transfer. In similar vein, the International Baccalaureate's (IB) suite of K-12 educational programmes—which are seeing increasing uptake worldwide by both private and government schools not only for its academic rigour but also pedagogical and assessment approaches, deemed to be highly relevant for nurturing 21C global capacities in learners—are connected through ten explicitly stated 'Learner Profile' dispositions that together serve as flagship learner outcomes for the programmes. At the heart of many of these Learner Profile attributes as conceptualised by the IB (IBO 2006) lie positive beliefs and intrinsic motivations towards learning that are essential to continuous personal growth and development during and beyond formal schooling throughout one's lifetime. The Partnership for 21st Century Skills (2011) proposed the framework for 21C learning. Singapore Ministry of Education (2010) defined desired educational outcomes (i.e. a confident person, a self-directed learner, a concerned citizen, an active contributor) and 21C learning competencies (e.g. critical and inventive thinking, communication skills, social emotional learning) in Singapore education. The dispositions examined in this study are either listed as important values and skills or considered as important factor to enhance this skills and competencies in 21C learning nationally (Singapore) and internationally.

It is within this advancement in educational theory and practice that we frame the following adaptive motivational beliefs and behaviours as essential 21C learning dispositions pertinent to this study.

Mastery and Performance Achievement Goal Orientations

Achievement goal theory purports that the underlying intentions for engaging in particular learning tasks, that is, their achievement goals, tend to drive individuals' learning processes and outcomes (Dweck 2000; Nicholls 1989). Broadly, there are four forms of achievement goals: mastery, performance, mastery avoidance and performance avoidance, with the first two being recognised as more adaptive in nature and generally conducive to learning, whereas the latter two are associated with maladaptive and unconstructive learning behaviours (Liem et al. 2008; Nie and Lau 2009).

This chapter focuses on the first two forms of achievement goals. According to Dweck (2000), learners driven by *mastery goals* are focused on increasing competence, learning new skills, understanding new concepts and 'to get smarter'. These learners tend to exhibit more adaptive responses to complexities and challenges. On the other hand, learners driven more by *performance goals* are primarily focused on 'getting the right answer' and winning positive judgments of their competence and to 'avoid looking dumb'.

While such learners may aspire towards high levels of performance, they concurrently exhibit a higher tendency to experience intellectual paralysis in the face of challenging problems and complexities, as well as feelings of being overwhelmed by the inability to get the right answer. The important thing to note, however, is that current research in the field has raised concerns about a potentially dysfunctional 'mastery-or-performance' binary logic. Rather, productive and sustainable learning are most likely to occur when both mastery and performance goals are present in about a 50/50 ratio (Dweck 2000; Tan and McWilliam 2008).

Self-Efficacy and Task Value

According to the expectancy-value theory posited by Eccles and Wigfield (1983, 2000), two beliefs are most salient in explaining successful learning outcomes: (1) *self-efficacy*, that is, the degree to which one is confident of his/her capability in successfully accomplishing a given task (Bandura 1997), and (2) *task value*, that is, the extent to which one believes the task to be important, valuable and worth pursuing.

Self-efficacy is considered by many to be one of the most important adaptive learning motivation constructs, with numerous empirical studies illustrating its positive relationship with a range of behavioural choices and outcomes, including higher levels of effort and persistence, resilience to adversity and learning engagement (Yeung et al. 2011).

Task value, relative to self-efficacy and achievement goals, has historically received less attention by achievement motivation researchers (Wigfield and Eccles 1992). Empirical findings from various studies, however, have clearly shown that while self-efficacy relates more strongly to task achievement outcomes, task value more strongly predicts learners' intentions and choices to engage with tasks (Greene et al. 2004; Liem et al. 2008). This is particularly important in the context of K-12 formal schooling where early task disengagement, particularly of core subjects such as literacy and numeracy, could lead to sustained disadvantage in terms of academic achievement and therefore future social access and mobility. Through this lens, one might even argue that positive task value bears more significance in sustaining primary and secondary students' ongoing interest and engagement in learning tasks and subjects, such that they become more resilient learners who can productively traverse the ebb and flow of formal success indicators such as test grades.

Individual and Collaborative Engagement

Learning engagement generally refers to students' willingness to participate in routine school activities, such as attending and paying attention in classes, completing assigned tasks and following teachers' explanations and instructions in class (Chapman 2003; Yeung et al. 2011). Students who are engaged in learning have been found to invest greater effort and exhibit more persistence and determination, thereby contributing to higher-quality learning and better learning outcomes (Fredricks et al. 2004; Skinner et al. 2008). Learning engagement has been defined and measured in various ways, but studies generally focus more on individual engagement rather than group or collaborative engagement. Given that collaboration is widely acknowledged to be an increasingly important and essential 21C competency, for the purpose of this study, we extend the engagement construct to include both individual and collaborative engagement because they are closely linked processes in classroom learning.

By individual engagement, we refer to students' self-perception of the extent to which they pay attention and participate in class activities. Collaborative engagement, on the other hand, refers to students' perception of the extent to which they participate in and contribute to group work and discussions.

To recap, authentic tasks and the aforementioned productive learning beliefs and behaviours present as important pedagogical and dispositional constructs essential to quality learning in the 21C. To date, however, there exists limited empirical evidence on the relationship between the use of authentic tasks in classrooms and these productive learning dispositions, particularly from the perspective of students as a critical stakeholder group. This chapter aims specifically to address this gap.

To this end, it asks the question: to what extent does the use of authentic tasks predict (1) mastery and performance achievement goals, (2) self-efficacy, (3) task value and (4) individual and collaborative learning engagement in students? The following sections present the method and results of this empirical inquiry.

Method

Sampling, Design and Participants

The sample was drawn by a stratified random sampling technique. The participants in this study were 4,164 Grade 9 students from 129 classrooms in 39 secondary schools in Singapore. The secondary schools in Singapore were first divided into three strata based on their prior aggregate school achievement. Thirteen schools were randomly selected from each stratum. About half of the Grade 9 classrooms in each participating school were randomly selected.

The ethnic distribution of the participants was as follows: 71 % of the participants were Chinese, 20 % were Malay, 7 % were Indian, and 2 % were of other ethnic groups. The gender distribution of the sample was about even (53 % girls and 47 % boys). The mean age of the students was 15.5 years (SD = .61).

Procedure

An online survey was conducted. Half of the students within each class were randomly selected to complete Form 1 in which students reported their motivation related to learning mathematics (student-level data). The other half of the students in the same class completed Form 2 in which students reported the frequency of authentic tasks that their mathematics teachers gave to them (class-level data). Although different groups of students provided student-level and class-level data, these multilevel data could be linked through common class identifications.

Measures

All items on the questionnaires were rated on 5-point Likert scales ranging from 1 (never) to 5 (always) or from 1 (strongly disagree) to 5 (strongly agree). These items are presented in Appendix A. Factor analysis results are not reported in this paper due to space constraints but can be made available to interested readers upon request.

Use of Authentic Tasks

The measure of use of authentic tasks included four items. This scale measures the frequency of using authentic tasks in the classrooms. All items on the questionnaires were rated on 5-point Likert scales ranging from 1 to 5. 5 means ‘always’, 4 means ‘often’, 3 means ‘sometimes’, 2 means ‘seldom’ and 1 means ‘never’. A one-factor structure provided a good fit for the data, $\chi 2$ (1, $N = 2{,}070$) = 10.15, TLI = .979, CFI = .998, RMSEA = .066, internal consistency reliability, and Cronbach’s alpha

Table 2.1 Descriptive statistics and zero-order correlations among motivational variables

	M	SD	1	2	3	4	5	6
1. Individual engagement	3.64	.86	–					
2. Group engagement	3.81	.77	.48**	–				
3. Mastery-approach goal	3.55	.79	.54**	.35**	–			
4. Performance-approach goal	3.09	.99	.13**	.17**	.26**	–		
5. Efficacy	3.74	.72	.47**	.31**	.64**	.26**	–	
6. Task value	3.77	.77	.44**	.26**	.72**	.18**	.56**	–

**$p < .01$

was .87. The mean of authentic task at class level was 3.06 and standard deviation was .45. The mean 3.06 showed that teachers not very frequently used authentic task in classroom teaching and learning.

Productive 21C Learning Dispositions

Six productive 21C learning dispositions were measured in the current study. The scales were adapted from the Motivated Strategies and Learning Questionnaire (MSLQ, Pintrich et al. 1993) and Patterns of Adaptive Learning Scales (PALS, Midgley et al. 2000). All items on the questionnaires were rated on 5-point Likert scales ranging from 1 to 5. 5 means 'strongly agree', 4 means 'agree', 3 means 'partly agree and partly disagree', 2 means 'disagree' and 1 means 'strongly disagree'. The mastery goal orientation scale consisted of five items (Cronbach's $\alpha = .89$). The performance goal orientation scale consisted of four items (Cronbach's $\alpha = .88$). The self-efficacy scale consisted of five items (Cronbach's $\alpha = .86$). The task value scale consisted of five items (Cronbach's $\alpha = .88$). The individual engagement and collaborative group engagement scales consisted of four items (Cronbach's $\alpha = .87$ and .90). The higher score means higher mastery goal orientation, higher performance goal orientation, higher self-efficacy, higher task value, higher individual engagement and higher collaborative group engagement.

Confirmatory factor analysis was conducted to examine the factor structure of the six constructs. A six-factor structure provided a good fit for the data, $\chi 2$ (305, $N = 2{,}094$) = 1809.25, TLI = .946, CFI = .957, RMSEA = .049. The inter-factor correlations ranged from .13 to .72 (see Table 2.1 for details).

Results

Analytic Approach to Modelling Student Outcomes

All predictors and outcome variables were standardised before running hierarchical linear modelling (HLM) analyses. The unconditional model (model 0, no predictor variables) was used to estimate the proportion of variance within classroom and among classrooms (Raudenbush and Bryk 2002). The next set of HLM analyses (model 1) was performed to evaluate the predictive relations between the use of authentic task and student motivational outcomes. Furthermore, we estimated the proportion of variance reduction as a result of adding authentic tasks in model 1, that is, comparisons of level 2 variances between model 1 and model 0.

Authentic Tasks Predicting Dispositional Outcomes

The results from HLM analyses predicting students' dispositional outcomes are presented in Tables 2.2, 2.3, 2.4, 2.5, 2.6, and 2.7. The results showed that the use of authentic task was a positive predictor of mastery goal orientation ($\gamma = .161, p < .001$), performance goal orientation ($\gamma = .065, p < .01$) and task values ($\gamma = .112, p < .001$) and individual engagement ($\gamma = .103, p < .01$). Comparison between, model 1 and model 0 yielded 11–28 % reduction in between-class variance in the above motivational outcomes (please refer to Tables 2.2, 2.3, 2.4, 2.5, 2.6, and 2.7 for detailed results).

On the other hand, the use of authentic tasks was not a significant predictor of self-efficacy ($\gamma = .025, p = .377$) and collaborative engagement ($\gamma = .022, p = .458$).

Discussion

The results of this study bear important implications for our understandings related to 21C pedagogy and learning in general and mathematics education specifically. We discuss these in turn.

Table 2.2 Results from HLM analyses predicting *individual engagement*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	−.004	.034	−.001	.032
Authentic task (γ_{01})			.103**	.031
Random effect	Variance		Variance	
u_{0j}	.090		.080	
r_{ij}	.912		.912	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.089		11 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance
$^{**}p < .01$

Table 2.3 Results from HLM analyses predicting *group engagement*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	−.007	.031	−.006	.031
Authentic task (γ_{01})			.022	.030
Random effect	Variance		Variance	
u_{0j}	.068		.068	
r_{ij}	.935		.935	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.067		0 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance

Table 2.4 Results from HLM analyses predicting *mastery-approach goal*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	.001	.034	.005	.030
Authentic task (γ_{01})			.161**	.030
Random effect	Variance		Variance	
u_{0j}	.088		.063	
r_{ij}	.913		.913	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.088		28 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance
**$p < .001$

Implications for Twenty-First Century Pedagogy and Learning in General

First, the results show that the use of authentic tasks is a significant predictor of adaptive mastery and performance achievement goal orientations, task value and individual engagement. This makes a strong quantitative empirical contribution to extant literature that advocates the potential of authentic tasks for enhancing positive learning dispositions—particularly motivation and engagement—in students (e.g. Jurdak 2006; Kocyigit and Zembat 2013; Norton 2006). As highlighted earlier, studies to date advocating for authentic tasks have largely been found to be more

Table 2.5 Results from HLM analyses predicting *performance-approach goal*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	.000	.025	.003	.024
Authentic task (γ_{01})			.065**	.022
Random effect	Variance		Variance	
u_{0j}	.018		.015	
r_{ij}	.982		.981	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.018		17 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance
$^{**}p<.01$

Table 2.6 Results from HLM analyses predicting *efficacy*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	−.007	.030	−.006	.030
Authentic task (γ_{01})	.11121		.025	.029
Random effect	Variance		Variance	
u_{0j}	.061		.061	
r_{ij}	.941		.941	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.061		0 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance

speculative in nature or comprise generally small-scale case studies based on small number of participants and classrooms (Beswick 2011). Given that the use of authentic tasks are often explicitly recommended in numerous published 21C skills curricular frameworks as a desirable pedagogical approach, the results of this study go some length to empirically validate this theoretical stance. The significance of this empirical contribution is further underscored by the pertinence of adaptive achievement goal orientations, task value and individual engagement as salient dispositional predictors of learning quality and schooling outcomes.

On the other hand, the results show that authentic tasks do not significantly predict self-efficacy and collaborative engagement in learners. This finding is somewhat surprising and of great interest to the authors, as it appears to run against the grain

Table 2.7 Results from HLM analyses predicting *task value*

Variable	Model 0		Model 1	
The use of authentic tasks				
Fixed effect	γ	SE	γ	SE
Intercept				
γ_{00}	−.001	.033	.002	.031
Authentic task (γ_{01})			.112***	.032
Random effect	Variance		Variance	
u_{0j}	.080		.069	
r_{ij}	.921		.921	
			Proportion reduction in variance	
	ICC		M1 vs. M0 (L2)	
	.080		14 %	

Note: *ICC* intraclass correlation coefficient, L2 indicates that the calculation of proportion reduction in variance is based on level 2 variance

$^{***}p < .001$

of popular beliefs about the use of authentic tasks. A clear implication of this finding is that we should be cautious in accepting general claims extrapolating the efficacy of authentic tasks in fostering learners' motivational dispositions in all its forms. Rather, as aptly pointed out by Rahim et al. (2012), the nature and quality of tasks may differ substantially even within the umbrella of what is considered to be 'authentic tasks'. As such, in-depth consideration must be given to the design of tasks and what counts as 'authentic' for the purposes at hand.

Authentic tasks, as operationalised in this study, refer to the extent that students perceived their teachers to have provided opportunities for them to learn and apply ideas in personally meaningful ways beyond the school and in connection to other subjects. This operationalisation does not specifically include aspects of collaborative learning. This may account for why no significant relationship emerged between authentic tasks and collaborative engagement in this study. This is, however, an educated inference at best. Further research is warranted to shed robust insights on this finding.

In similar vein, more investigation is needed to better understand the relationship between authentic tasks and self-efficacy. The findings of this study suggest that the 'real-world' relevance, personal meaningfulness and connectedness elements of an 'authentic' learning task have limited influence on raising learners' self-perceived competency levels associated with successfully accomplishing a given task and/or subject domain. Nie and Lau's (2010) research found that constructivist instruction was positively related to self-efficacy in English learning. In their definition, constructivist instruction included three key elements, i.e. deep thinking, communication and real-life experiences. Taken together, the results of that study suggest that instruction which draws on students' real-life experiences on their own might not foster self-efficacy, especially in the learning of multiple subject domains; but if combined with deep thinking and communication in learning as a whole package in pedagogy, it may then be effective. Given that authentic tasks may be defined and operationalised to varying degrees of context specificity, more comparative research on authentic tasks across different subject domains will likely yield meaningful and insightful contributions to our current understandings in the area.

Implications for Mathematics Education: Singapore in Global Context

We now move more specifically to discussing the results within the context of mathematics education. Mathematical tasks, defined as a set of problems or a single complex problem that focuses students' attention on particular mathematical ideas, are central to mathematics lessons (Kaur and Toh 2012). In fact, according to the results of a large-scale transnational video survey research of Grade 8 mathematics and science teaching across seven countries, conducted by International Association for the Evaluation of Educational Achievement and the US National Center for Education Statistics, more than 80% of the time in mathematics class were spent on mathematical tasks (Hiebert, 2003). Given the significant amount of time accorded to mathematical tasks, the nature and quality of tasks, as well as their impact on learning dispositions and outcomes, become paramount.

This is further underscored by growing concerns, especially in developed countries, over what appears to be waning participation in mathematics and related fields in post-compulsory schooling—a trend that if left unattended could possibly represent a threat to national economies resulting from an undersupply of qualified mathematicians, statisticians, economists and engineers (Australian Academy of Science 2006; Beswick 2011).

Mathematics researchers have found that many students disengage with mathematics learning as early as in middle school (Sullivan et al. 2006). To this end, authentic tasks or context problems, as they are sometimes referred to in mathematics education, are often enrolled on the premise that they are more likely to interest and engage learners. However, a common critique that follows within the field is that evidence for the efficacy of such tasks is wanting, particularly in relation to raising student affect towards mathematics, and therefore, the premise is more a claim than actuality (Beswick 2011). In this regard, the findings reported in this chapter go some length to address this significant knowledge gap, especially from the invaluable perspectives of Grade 9 students as a critical stakeholder group.

More specific to Singapore and its high-performing East Asian peers who consistently top the Trends in International Mathematics and Science Study (TIMSS) results, the findings reported here bear some pertinent implications. Frederick Leung (2008) in his analysis of East Asian mathematics classrooms and students using the 1999 and 2003 TIMSS results and video studies highlights two important trends:

1. East Asian students (Korea, Japan, Hong Kong, Taipei), other than Singaporean students, neither valued mathematics highly (*task value*) nor enjoyed studying

the subject (*engagement*). This is despite achieving high scores on the international mathematics test. It is important to note that although Singaporean students' reported higher levels of task value and enjoyment of mathematics relative to their East Asian peers, these were still only marginally higher than the international average and noticeably lower than other peers worldwide (see Mullis et al. 2004 for details).

2. East Asian students, including Singaporean students, despite achieving high test scores, consistently reported low levels of self-confidence (*self-efficacy*) with respect to learning mathematics, as compared to their global peers.

Triangulating these results to the video study, Leung (2008) concluded that while mathematics lessons in East Asia exhibited the strengths of engaging with more complex and advanced contents requiring more deductive reasoning, they also had some consistent weaknesses. In particular, mathematical tasks were found to be largely unrelated to real life. Coupled with the highly challenging content, this may explain students' negative beliefs and attitudes towards the subject and ultimately serves to alienate students from sustained and advanced participation in the study of mathematics and related disciplines. An important upshot, therefore, is that high student achievement in mathematics should not blindside teachers to the equally important objective of stimulating students' positive beliefs and motivational learning dispositions towards mathematics.

In light of the above global trends pertaining to mathematics teaching and learning, the results of this study provide empirical support that one productive recourse is the employment of authentic tasks that are specifically designed to provide students with more opportunities to connect the mathematical ideas they learn in class to their personal experiences, lifeworlds as well as other ideas learnt in other subject domains. This has the potential to improve their mastery orientation in learning mathematics (and performance orientation, although this does not appear to be a significant problem in general for East Asian students) as well as foster higher levels of engagement, importance and value they place on the learning the subject.

The results of our study do not shed much light on the concern of East Asian students generally lacking self-efficacy and confidence in the learning of mathematics. As highlighted earlier, our results suggest that the relevance and connectedness of mathematical tasks to real-life contexts and other subjects on their own do not improve students' perceptions of their competency in mathematics. On one hand, this could partially be due to the highly challenging nature of mathematics content taught in East Asian countries (Leung 2008), resulting in students' perceptions that they may not do well even if given more time or effort. More insidious could be the possibility that students hold a 'fixed' rather than 'incremental' belief (Dweck 2006) about their own mathematical intelligence or ability, which could be reinforced in 'ability-driven' education systems such as Singapore where the practice and philosophy of 'ability banding' or differentiated instruction takes on highly institutionalised forms with multiple points of high-stake testing determining future academic 'tracks' and pathways. Such unproductive learning beliefs regarding one's ability may be bridged to some extent by adaptive motivational processes such as mastery goal orientation (Dweck 2006; McWilliam 2008). Given that our results showed authentic tasks to be a positive predictor of mastery goals, one may surmise that they bear potential for inadvertently raising self-efficacy in mathematics. This is however a hopeful conjecture at best, one that future research would do well to address.

Last but not least, our results indicate that authentic tasks did not significantly predict collaborative engagement among students. This suggests the possibility that even though authentic tasks, as they are currently designed in Singapore mathematics classes, may allow opportunities for students to connect their learning to real-world experiences and other subject domains, these tasks may remain largely individualised in nature (Boaler 1994). In similar vein, a local Singapore study conducted by Foo (2007) on the use of authentic performance tasks in mathematics lessons revealed teacher concerns that authentic tasks were carried out at the expense of content, thereby comprising test preparation and performance in semestral examinations, which are largely individual based. To this end, we can logically deduce that mathematic tasks used in mathematics lessons, at least in relation to those experienced by the participants of our study, even those learning tasks designed to be authentic in nature, tend more towards individualised learning rather than affording significant opportunities for meaningful collaborative learning. This deduction is further validated by a review of the key reference material used in Singapore to guide preservice teachers in designing authentic tasks in their mathematics lessons (e.g. Fan 2011). The exemplar tasks provided in this key reference text were found to be overwhelmingly individual based rather than collaborative in nature. In this regard, further research on ways to enhance the design of authentic tasks to incorporate powerful collaborative learning elements and their impact on group engagement would likely prove invaluable to move the field forward.

Conclusion

In conclusion, we highlight some limitations of the study presented in this chapter. First, like many survey-based research studies, despite our best efforts to ensure that the constructs are conceptualised in a theoretically informed and empirically grounded manner, our operationalisation of authentic tasks are unavoidably limited to a set of attributes. Future research could consider measuring a broader set of instructional elements and practices associated with authentic tasks, given their inherent richness of design. Second, the correlational and cross-sectional design of our study does not allow for causal understandings and is likely to lead to an underestimation of the task effects on students' dispositional outcomes (Nie and Lau 2010; Rowan et al. 2002). The findings of this study could be enhanced by other designs that are experimental and/or longitudinal in nature. These could shed more robust insights into the causality, as well as the cumulative effects of the use of authentic tasks and their impact on students' learning dispositions, and how these may change over time. Third, students' self-reported measures were used as the sole source of data in this study. Multiple data corpuses such as classroom observations, teacher reports, lesson artefacts and qualitative interviews would do well to enhance our understandings of the findings reported here.

Despite these limitations, it is our hope that this chapter goes some length to address a significant empirical gap in extant literature regarding the efficacy of authentic tasks in fostering students' productive learning beliefs and motivational dispositions, in general as well as specific to mathematics education.

As educators, we have an implicit yet unequivocal obligation to ensure that the formal schooling experiences of students amount to much more than accruing high achievement scores in exams. Rather, students should graduate from the formal schooling institution having experienced ample opportunities to develop as literate and responsible citizens armed with the relevant dispositions to contribute productively to the wider economy, workplaces and civic life. This endeavour is a complex one indeed. The mere incorporation of some form of authentic tasks into lessons may be simple enough but hardly sufficient in and of themselves. The true challenge lies in designing lessons, learning tasks and units of work with coherence, continuity and progression such that productive dispositions, values and practices are able to be cultivated and sustained, by being relevant to the culture of the school and the life futures of its most important stakeholders—the students.

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Appendix A

The Use of Authentic Tasks

1. How often does your MATHS teacher provide opportunities for you to apply mathematical ideas learnt in your class to other subjects?
2. How often does your MATHS teacher provide opportunities for pupils to apply mathematical ideas to everyday nonschool-related situations?
3. How often does your MATHS teacher focus the lesson on what is personally meaningful to you, rather than what is in the syllabus?
4. How often does your MATHS teacher attempt to link subject knowledge to your personal experiences?

Individual Engagement

1. I pay attention well.
2. I keep my attention on the work during the entire lesson.
3. I listen carefully when the teacher explains something.
4. I try my best to complete classwork.

Group Engagement

1. I try my best to contribute during small group discussions.
2. I share my ideas during group work.
3. I try my best to get involved in class discussions.
4. I try my best to contribute to group work.

Mastery-Approach Goal Orientation

1. An important reason I do my MATHS work is that I like to learn new things.
2. I like the work in my MATHS class best when it challenges me to think.
3. An important reason I do my work in MATHS class is because I want to get better at it.
4. An important reason I do my MATHS work is that I enjoy it.
5. An important reason I do my MATHS work is that I want to learn challenging ideas well.

Performance-Approach Goal Orientation

1. I want to show pupils in my MATHS class that I am smart.
2. I like to show my teacher that I am smarter than the other pupils in my MATHS class.
3. It is important to me that the other pupils in my MATHS class think I am smart.
4. I feel successful in MATHS if I get better marks than most of the other pupils.

Self-Efficacy

I am sure I can learn the skills taught in MATHS class well.

1. I can do almost all the work in MATHS class if I do not give up.
2. If I have enough time, I can do a good job in all my MATHS work.

3. Even if the work in MATHS is hard, I can learn it.
4. I am sure I can do difficult work in my MATHS class.

Task Values

1. I think learning MATHS is important.
2. I find MATHS interesting.
3. What I learn in MATHS is useful.
4. Compared to other subjects, MATHS is useful.
5. Compared to other subjects, MATHS is important.

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Chapter 3
A Design Model for Problem-Based Learning

Nachamma Sockalingam

Abstract An underpinning tenet of problem-based learning (PBL) is that solving ill-structured, real-world and authentic problems motivates students to engage in the learning process, leading to deeper and meaningful learning. Hence, designing problems is crucial to successfully implementing PBL. This chapter introduces readers to theories and empirical studies on designing PBL problems and provides a practical approach to designing real-world problems. Readers can also look at how they can evaluate the effectiveness of problems. Overall, this chapter will help the readers design and evaluate real-world problems for PBL.

Keywords Design model • Problem • Problem-based learning • Problem characteristics

Why PBL?

Rapid growth in technology, increasing globalization and continuing drive towards a knowledge-based economy demand new skills from students of today (Griffin et al. 2012). It is no longer sufficient for students to excel in just content knowledge and skills. According to Assessment and Teaching of 21st-Century Skills (ATC21S) Consortium, students need to develop new skills, popularly known as twenty-first century skills, to succeed in the fast-changing globalized societies (Binkley et al. 2010). These skill sets include (1) ways of thinking (being curious, critical and analytical), (2) ways of working (working independently and collaboratively), (3) ways of using technology tools and (4) life skills for living in the world (Binkley et al. 2010).

While traditional teaching ensures curriculum coverage and content mastery, it does not sufficiently prepare students for higher education and workforce (Saavedra and Opfer 2012). Several global research findings reveal a gap between what is taught in schools and what is expected as employability skills, especially on the technical

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(real-life application) and noncognitive aspects (e.g. teamwork, communication, problem solving and critical thinking) (Jayaram 2012). What is needed of today's students is not mere acquisition of information but the ability to access and analyse information in order to apply in real-world contexts (Griffin et al. 2012).

To prepare students for today's world, we cannot simply continue with bygone teaching methods; there needs to be a paradigm shift in various aspects of our educational support systems such as (1) curriculum and instruction, (2) standards, (3) learning environment, (4) assessment and (5) professional development of educators (Binkley et al. 2010). To this end, educational institutions are now embracing more learner-centric, authentic instructional methods such as problem-, project- and case-based learning (Weimer 2013).

Authentic instruction refers to teaching that encourages students to learn beyond textbooks and school and move away from mere acquisition of factual knowledge to application of knowledge in real-life contexts. Authentic instruction features ill-structured, real-life contexts to engage students in an inquiry process, which requires them to understand and construct new knowledge that they can apply in such contexts. In doing so, students are likely to recognize the value of why they are learning what they are learning (Lombardi 2007; Newmann et al. 1996). As a result, authentic instruction is considered as an effective means to engage students in active and deep learning (Newmann et al. 1996).

One common approach used in authentic instruction is problem-based learning (PBL). Currently, PBL is used across a wide range of educational levels, starting from lower primary to tertiary education, and in different types of schools. It is also implemented across various content areas such as Languages, Literature, Mathematics, Geography, History, Science and professional disciplines such as Medicine, Engineering, Accounting and Law (Boud and Feletti 1991; Hung et al. 2008; Kim et al. 2006; Torp and Sage 2002).

This widespread use of PBL can be taken to be indicative of its positive impact on student learning. In fact, numerous researchers have established that PBL is on par with traditional teaching in terms of promoting achievement in conventional assessments (Colliver 2000; Newman 2003). Studies also show that PBL is more effective than traditional teaching in facilitating problem-solving skills and self-directed learning (Strobel and van Barneveld 2009; Walker and Leary 2009). However, Hung (2011) warns that adaptation of PBL does not automatically enhance learning; success of PBL depends on its effective implementation. He and his colleagues postulate that "probably the most important research question (in PBL) is that of addressing the nature of problems that are amenable to PBL" (Hung et al. 2008).

This chapter attempts to address this issue by providing a practical guideline for designing and evaluating PBL problems, with a particular focus on supporting primary and secondary school teachers. The first section of the chapter is introductory and explains what problems are and why they are important. The second section provides an overview of the current literature on the characteristics of problems and proposes a three-dimensional framework of problem characteristics. The last section describes a systematic approach to formulating PBL problems based on the three dimensions of problems. Overall, this chapter presents a relatively novel approach to designing real-world problems.

PBL Problems

“Problems” are the fundamental instructional materials that initiate and direct students’ learning process in PBL. According to Hmelo-Silver (2004), PBL problems tend to be complex issues that can be addressed in many possible ways. To tackle such a problem, students work in small collaborative groups, guided by a tutor. Students typically follow a series of steps, such as those specified in the Maastricht seven-step model of the PBL process (Schmidt 1983), in which they (1) clarify the concepts, (2) define the problem, (3) analyse the problem, (4) propose hypotheses, (5) identify learning goals, (6) find information and (7) report and test the newly found information. The role of tutors will be to facilitate students’ learning process by various means such as stimulating discussion amongst team members, raising thought-provoking questions, encouraging collaborative work and providing feedback at appropriate instances to the students (Das et al. 2002; Maudsley 1999). This is in contrast to traditional teaching in which teachers deliver the content materials directly to their students. Such a change in role of tutors requires PBL students to actively seek information and synthesize their own understanding, directed by the given problem. Learning in PBL thus places a greater emphasis on the instructional material (problem) than in traditional teaching.

Overall, the purpose of a problem is to engage students in problem solving, rekindle their prior knowledge, spark discussions, encourage collaborative work, promote self-directed learning skills and result in acquisition of relevant content knowledge (Hmelo-Silver 2004). As problems initiate the learning process in PBL, they are sometimes known as “triggers”. They are also known as “cases” or “scenarios” in the PBL literature (Hmelo-Silver 2004). Frequently, problems are formulated and presented to students in textual format. In some cases, problems utilize visual aids or multimedia such as videos or computer simulations. Box 3.1 shows an example of a problem from Republic Polytechnic, Singapore. This problem is taken from the core module Cognitive Processes and Problem-Solving Skills.

A common dilemma for teachers is differentiating a PBL problem from a direct question. For instance, the PBL problem in Box 3.1 may be considered as similar to this direct question: “What does it mean to receive an education, and what makes a person educated?” The obvious difference is that the former presents an authentic context, while the latter does not. In the given problem, an example of classical conditioning learning theory is presented first. This is then compared with limping as a response to injury, and a point is raised about why this may not be considered as learning. Finally, the concept of learning is used to draw students’ attention to the concept of education and “being educated”, and students are tasked to explain these.

The lack of authentic context in the direct questions means that students may not really understand the relevance and significance of what they are learning. Students

Box 3.1: Example of a PBL Problem from Cognitive Processes and Problem-Solving Skills Module

Education, What Is It?

Ivan Pavlov is a Russian biologist who received the Nobel Prize in 1904 for Medicine. He found out during a study that every time a bell is sounded when a dog is given food, the dog would salivate. Eventually, the dog would salivate even when just the bell rang without food.

Psychologists who had defined learning as what causes a “change in behaviour” concluded that the dog has learned something it could not do before. This happening of “learning” in the dog has since become a famous example of “classical conditioning” in the so-called learning theory.

Sceptics criticize that if we link learning to change in behaviour and then if someone suffered a leg injury and started to limp, it would be acceptable to say that the injured person had learned to limp.

Quite clearly, there is so much confusion about learning. However, the more important question to individuals, communities and taxpayers is about education rather than learning. Some people believe that learning is the same as receiving an education, yet many would be unwilling to consider that Pavlov’s dog got educated to salivate or someone got educated to limp following an injury.

What could be meant by the phrase “receiving an education”? What makes someone “educated”?

are also likely to answer the direct question in a more factual manner, that is, focusing on the answers to the questions, overlooking the process of working out the response and thus omitting any possible additional learning. Thus, the disadvantage with the direct question is that it may not help students to realize all of the learning goals associated with the question.

The purpose of the PBL problem is more than getting students to provide factual answers to questions. It guides students in their information search or formulation of a response by providing keywords such as “learning theory” and clues such as contrasting learning with education in the given example. It is designed to pique students’ interest by highlighting a contradiction on what is considered as “learning”. This is likely to engage students in discussion. It also helps students to value the contextual application of what is being learned. In this manner, the problem is likely more effective than the direct questions in encouraging students to be engaged in self-directed, collaborative and reflective learning. Solving authentic problems is expected to prepare students better for the real world, encourage deeper learning, contribute to knowledge acquisition and provide opportunities for learning problem solving as well as “learning to learn” skills (Errington 2011). Furthermore, it allows for contextualized learning (Schmidt 1983), which results in meaningful learning (Brown et al. 1989).

A large body of evidence supports the notion that authentic problems play an important role in PBL. Schmidt and Gijselaers (1990) and Van Berkel and Schmidt (2000) report that the quality of problems plays a significant role in contributing to the learning process and outcomes than students' prior knowledge and tutor's role. Rotgans and Schmidt (2011) found that students' situational interest is significantly increased upon the initial presentation of a problem. According to Soppe, Schmidt and Bruysten (2005) and Sockalingam and Schmidt (2013), this interest is sustainable throughout the learning process with the use of appropriate problems. For instance, they found that familiar problems piqued students' interest and contributed to improved learning than unfamiliar problems. Similarly, Verkoeijen et al. (2006) report that a goal-free problem encourages students to spend more time in learning than a goal-specified problem.

At the same time, other studies reveal that vague problems that are too generic could result in students going off track and spending much time researching content that are not meaningful (Dolmans et al. 1994; Hung et al. 2008; van den Hurk et al. 1999). While it is desirable that students are more independent and spend time and effort in exploring a wide range of information, it is also important for them to engage in purposeful actions.

The foregoing reports provide strong evidence that the quality of problems is indeed important in PBL. They suggest that (1) a well-designed problem can engage and lead to better learning, (2) a not so well-designed problem can be detrimental to student learning and (3) it is possible to craft well-designed problems. Given these premises, it can be surmised that identifying the characteristics of problems can help in designing problems. Thus, the early attempts in providing guidelines on designing problems have focused on identifying the characteristics of well-designed problems (Des Marchais 1999; Dolmans et al. 1997).

Problem Characteristics

Teachers introduced to PBL are expected to design problems intuitively. They usually do so on their own with the help of a guide comprising principles or characteristics associated with problem design, along with a compilation of examples. Des Marchais (1999) developed one such commonly used guide. He proposed that problems used in medical discipline should stimulate thinking, analysis and reasoning, initiate self-directed learning, relate to basic knowledge, be set in a realistic context, lead to discovery of learning objectives, arouse curiosity and interest, be on topics related to public health, include a global perspective and contain appropriate medical analytical vocabulary. The seven principles suggested by Dolmans and colleagues (1997) state that problems should simulate real life, lead to elaboration, encourage integration of knowledge, encourage self-directed learning, fit in with students' prior knowledge, interest the students, be of an adequate level in terms of complexity and structuredness and reflect the faculty's objectives.

While these guidelines are relevant, it may be difficult to apply them in the actual process of designing a problem. Providing a list of problem characteristics and asking to design a problem are comparable to giving a list of expected qualities of a cake (such as the cake must be creamy, brown in colour, tasty) and asking someone to bake such a cake. Similarly, it is difficult for teachers to conceptualize how to design problems with just a list of characteristics. What seems to be missing are the key elements and procedure on how to design a problem.

To help teachers in conceptualizing a problem, Hung (2006) proposed a conceptual framework called the "3C3R" model. In this model, "C" refers to three core components, and "R" refers to the three process components of a problem. The core components "content", "context" and "connection" reflect students' content and conceptual learning. On the other hand, the process components – "researching", "reasoning" and "reflecting" – represent students' cognitive processes and problem-solving skills.

Sockalingam and Schmidt (2011) also propose a similar model in which they categorize eleven problem characteristics as either "feature" or "function" characteristics. Unlike Hung's conceptual framework, this model stems from empirical data that were drawn from students' views concerning the attributes of a good problem. The feature characteristics that correspond to the design elements of a problem include (1) problem format, (2) clarity, (3) familiarity, (4) difficulty and (5) relevance (application and use). On the other hand, function characteristics refer to the potential outcomes of engaging with or working on a problem. The six functional characteristics refer to the extent to which the problem (1) stimulates critical reasoning, (2) promotes self-directed learning, (3) stimulates elaboration, (4) promotes teamwork, (5) triggers interest and (6) leads to the intended learning issues. In a way, these functional characteristics are reflective of the five principles of constructivist learning and the objectives of PBL (Savery and Duffy 1995). Figure 3.1 shows the classification of the proposed feature and function characteristics.

Hung's "3C3R" (2006) and Sockalingam and Schmidt's (2011) "Feature and Function" models may be expected to provide additional clarity than the list given by Des Marchais (1999) and Dolman's group (1997) since the former groups provide a second-order classification. However, anecdotal information from teachers designing problems indicates some level of difficulty in using these models. This is probably because the components (core and process) and characteristics (feature and function) are not obvious aspects of a problem that can be manipulated.

As such, a different approach in designing problems was considered. Instead of starting with the question of what makes a good problem and the characteristics of a problem, the new approach contemplates how students use a problem. From the author's PBL lesson observations, it became obvious that the "user interface", that is, the structure of a problem, is key to how students approach it. Students tend to analyse every aspect of the problem such as the title, keywords and any clues to identify the learning issues, before they plan how they are going to work on the problem. This notion of the importance of the problem's user interface is also supported by Maastricht's seven-step model of PBL process (Schmidt 1983), especially in the first three steps of clarifying the concepts, defining the problem and analysing the problem.

The structural elements of a problem can be classified as (1) content, (2) context, (3) task and (4) presentation. The c*ontent* of a problem refers to the focus of that

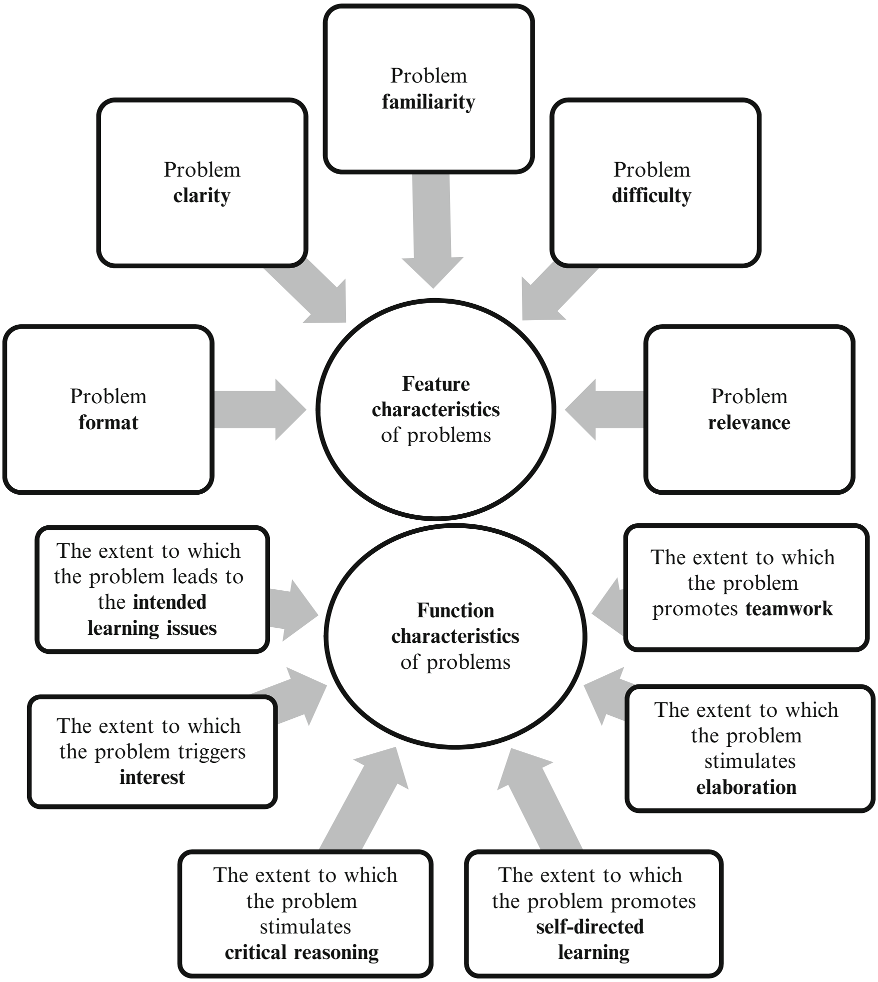

Fig. 3.1 Function and feature characteristics of problems

problem, and it reflects the teacher's intended learning objectives. It is presented such that it generates more driving questions to guide students in their learning. The *context* of a problem refers to the background setting or a scenario in which the problem is embedded. It is often complex, is ill structured and embodies real-life applications of what students are learning. The *task* refers to the expected output from the problem. A *task* is often authentic in nature and can be in the form of (but not limited to) reports, proposals and PowerPoint presentations. The fourth aspect, *presentation*, refers to the plot, characterization and format of the problem, that is, how it is written and conveyed to the students.

Of these four elements, only *presentation* is represented directly in Sockalingam and Schmidt's (2011) feature characteristics as *format*. If the structural elements of a problem are likened to the "ingredients" of a cake, all of the feature characteristics described by Sockalingam and Schmidt (2011) except *format* can be considered as the "nature of these ingredients". The outcomes of assembling these various ingredients together are analogous to the functional characteristics suggested by Sockalingam and Schmidt (2011). Hence, it is best to reclassify Sockalingam and Schmidt's characteristics in three dimensions instead of two (see Table 3.1).

In general, the effectiveness of a problem can be considered to be determined by whether the learning outcomes or functional characteristics are achievable by students (Dolmans et al. 1994). To illustrate how a PBL problem can be designed effectively, the problem in Box 3.1 is a good starting point. While this problem is likely to encourage students to think about what it means by "learning", "receiving an education" and "being educated", it may not necessarily get students to consider the concept of "being educated" across different cultures. To promote such critical thinking, one suggestion could be to modify the task and ask students to explain their understanding of "being educated" across different cultural contexts. To achieve a similar effect, another approach could be to modify the context and include contrasting quotations from different cultures on what it means to be educated.

Clearly, there is more than one right way to design a problem, and it is possible to achieve similar effects through multiple routes. Desired changes in functional characteristics of a problem can be achieved by manipulating the structural elements and/or feature characteristics of a problem. The key is to ensure that the problem is able to drive towards the intended functional characteristics or outcomes. The next section presents the steps in formulating a PBL problem.

Formulating a PBL Problem

Formulating a problem involves five basic steps. It should be noted that these steps are not necessarily linear and tend to be simultaneous and often iterative. They are:

1. Studying learning needs
2. Specifying content
3. Selecting context
4. Setting expectations
5. Synthesizing the problem

Table 3.1 Three dimensions of PBL problems

Structural elements	Feature characteristics	Function characteristics
Content	Relevance	Promote self-directed learning
Context	Familiarity	Encourage teamwork
Task	Difficulty	Encourage elaboration
Presentation/format	Clarity	Stimulate interest
		Stimulate critical reasoning
		Lead to learning issues

These steps are consistent with the "Backward Design" approach described by Wiggins and McTighe (2005). In this approach, learning objectives guide the definition and derivation of a problem. An alternative approach, which can be termed as the "Forward Design" approach, is one in which a context is chosen first and then mapped to learning objectives that is relevant to the educational system.

Although the Forward Design approach may seem easier, firstly, its main drawback is that not all of the intended learning objectives may be captured by the chosen context. Secondly, real-life contexts are often too complex and ill structured, and unless the contexts are modified, it may be overwhelming for students. Thirdly, learning objectives and assessments may be disconnected since the objectives tend to be formulated "by chance". However, in the Backward Design approach, it is possible to map the learning objectives to assessment since teachers would have a clear idea of the objectives they want to focus on. They can select the key learning issues and design an authentic assessment. Hence, it is recommended to start with the Backward Design approach in designing a PBL problem.

Studying Learning Needs

In designing problems, it is important that students' learning needs are considered since students are usually heterogeneous and they may have different prior knowledge. One way to estimate students' learning needs is to refer to students' past year curriculum and achievements. Understanding where students are at the starting point would help to estimate how far students can reach in terms of learning. If required, students need to be supported with additional scaffolds or resources. A more comprehensive explanation on supporting students with additional scaffolds can be found in Vygotsky's work on Zone of Proximal Development (ZPD) (Vygotsky 1978).

Specifying Content

In specifying the content, the learning objectives should be *Specific*, *Measurable*, *Achievable*, *Relevant* and *Time dependent* (SMART). *Specific* learning objectives are objectives that are clear in terms of what students are expected to achieve or demonstrate. To indicate *specific* learning objectives, teachers can use Bloom's categorization of learning and classify the objectives as (1) cognitive, (2) behavioural and (3) affective (Airasian et al. 2001). Such objectives should also include the frequently neglected twenty-first century skills. *Measurable* means that some form of assessment can be used to evaluate if and to what extent the learning objectives have been met. *Achievability* refers to whether the objectives are reachable by students, and this depends on whether students have sufficient prior knowledge. *Relevancy* refers to how suitable the objectives are to the selected course/subject/discipline. *Time dependency* refers to consideration of the time needed in achieving the learning objectives.

Selecting Context

Once the learning objectives are determined, the next step would be to explore various real-life contexts that match these objectives. Sources of real-world contexts could be newspapers, journal articles, research findings and interviews, which depict the real-world application of what is being discussed.

If the real-life context is too complex, it can be made simpler to help students focus on the key issues. For instance, assume that a problem intends to teach students about a specific bacterium (as a causative agent of water-related sickness). A teacher designing the problem may want to use a real-life context such as a news report to describe such a situation. In real-life, water-related sickness may be caused by multiple factors such as bacteria, parasites, algae, virus or even chemicals. Bacteria need not be the sole agent. Hence, if the teacher describes generic symptoms of water-related sickness, students may generate wide-ranging learning issues and may even neglect bacteria. One way to overcome this could be by hinting in the problem that the symptoms are likely due to microorganisms or even indicate that bacterial infection is suspected. In this manner, the problem can be made more specific while keeping it authentic.

Depending on how the problem is contextualized and presented, one can also define the problem as well structured or ill structured (Jonassen 1997). Well-structured problems require specific, prescribed or predictable approach to solving the problem and have clearly defined or limited number of specific outcomes. In contrast, ill-structured problems do not present all of the information and encourage students to search for additional resources to solve the problem in multiple ways (Jonassen 1987).

A general guideline in designing problems is that the complexity and structuredness of the problem should be reduced when students are new to PBL. Additionally, students must be guided or provided with scaffolds to help them learn how to handle the complexity and structuredness of the given problem. If the problem is far beyond students' capabilities such that they cannot handle it even with support, they will feel overwhelmed and become disengaged. The level of authenticity of the problem depends on a number of factors, such as (1) students' experience with PBL, (2) students' prior knowledge of content and context and (3) time available for the problem, to name a few (Mauffette et al. 2004).

Setting Expectations

The next step in formulating a PBL problem is to decide on the task, that is, what students are required to do. The task should provide an avenue for more than one right answer, consideration of multiple perspectives, multiple approaches to solving the problem and discussion. Such tasks are found to engage students and result in better learning (Errington 2011). Since the task provides specific goals, it is likely to help students in identifying the intended learning objectives easily. While task or goal-free problems may be advocated to encourage independent work by students (Verkoeijen et al. 2006), teachers may find it difficult to manage the diverse responses

(Hung 2011). Another advantage with task specification is that students become actively engaged. This is because tasks often require students to visualize themselves as parts of the problem context. Hence, students tend to be more involved in solving the problem. It is also recommended that the tasks given to students are authentic in nature as would be expected in the real world. Examples of authentic tasks are writing a proposal or doing a presentation. Authentic tasks provide an avenue for authentic assessment. Taken together, authentic contexts, tasks and assessments help students to appreciate the value of their learning (Brown et al. 1989).

Synthesizing Problem

Finally, the structural elements of the problem need to be synthesized. The process of writing the problem can be likened to writing a story. The four aspects that need to be considered in writing the problem are the (1) plot, contextual settings and characters, (2) clarity of ideas and language, (3) presentation format and (4) the attention-grabbing title.

In formulating a problem, teachers can start with the contextual setting and introduce the characters to narrate the background setting. To ensure that students can relate to the selected context, care must be taken that the setting, time, place, plot and characters are relevant and familiar to students. While it is important that the context needs to be interesting, it does not mean that students are looking for entertainment (Mauffette et al. 2004). The written format is popular as it gives students a concrete starting point, though it was found that students do not like to read long passages (Sockalingam and Schmidt 2011). Also, Mauffette and colleagues (2004) suggest that the use of short simple sentences makes it more readable. Sockalingam and Schmidt (2011) recommend the deliberate use of selected keywords and embedded clues to direct students' learning.

The inclusion of various formats such as text, video and multimedia is also recommended to cater to multiple learning styles of students and add variety. Hoffmann and Ritchie (1997) recommend the use of multimedia in PBL problems to provide richer, interactive contexts. De Leng et al. (2007) found the use of videos as PBL problems to be beneficial, especially in promoting group work and engaging students. The use of multimedia can also contribute to the clarity of the problem.

Finally, it is always good to include an attention-grabbing title that is relevant to the problem so as to hook students' interest as they start out (Sockalingam and Schmidt 2011). This serves the same purpose as a book or movie title. It provides some information about the problem and builds anticipation.

Evaluating the Problem

Once the problem is completed or even while writing the problem, teachers can attempt to evaluate the problem. To do so, teachers can use the checklist in Box 3.2 or similar evaluation tools (Sockalingam et al. 2012) for assessing the quality of problems.

The fundamental criteria in evaluating the effectiveness of any problem will be to verify the three dimensions of PBL problems (structural elements, feature and function characteristics). Getting the problem reviewed by experienced colleagues is also a useful exercise. Obtaining feedback from students at the end of their experience in solving the problem is also recommended. This allows teachers to understand how to design better problems and review the problem for subsequent use. Formulating a problem is often an iterative process and involves several rounds of evaluation and review of the problem.

Box 3.2: Checklist to Evaluate PBL Problems

Evaluating PBL Problems

- I am clear about my students' difficulties, needs such as learning styles and other stakeholders' needs.
- I have specified clear learning objectives or issues.
- I have considered various contexts and selected a suitable context.
- I have made the expectations clear.
- I have presented the problem in a suitable format such that it is sufficiently clear.
- The problem is sufficiently engaging to students.
- The problem allows students to proceed in multiple paths.
- The problem allows for collaborative work.
- The problem promotes critical reasoning.
- The problem encourages self-directed learning.

Conclusion

Problems play an important role in PBL, and a well-designed problem is a must for PBL to be effective. However, designing PBL problems is not intuitive. While there are guidelines and principles based on problem characteristics, these may not be helpful in guiding teachers. This chapter presents an alternative approach, the Backward Design approach that is potentially useful in designing a problem systematically.

Writing a PBL problem needs a good understanding of the purpose and characteristics of problems. To this end, a third dimension is added to the existing design models that involve both feature and function characteristics of problems (Sockalingam and Schmidt 2011). This chapter also illustrates how to manipulate the feature characteristics and structural elements of a problem to have an impact on function characteristics. To put this in practice, a five-step approach to designing problems, with the consideration of the three dimensions of problem characteristics, is discussed. To further support teachers in designing problems, a checklist to evaluate problems is also provided.

In designing problems, teachers should also take note of the materials that they should prepare. These include (1) learning resources, such as a list of websites or references; (2) scaffolds, such as worksheets to help students analyse and approach the problem; (3) notes for instructors that list out the problem objectives and possible guiding questions to ask students; and (4) assessment questions to test understanding and rubrics to measure self-directed and collaborative learning and critical thinking. Other factors such as the learning environment, role of instructor and preparedness of students should not be neglected. As it is common for teachers to use a set of problems rather than a single problem, they should consider the issue of sequencing problems. The usual practice is to start with less ill-structured problems and move on to more ill-structured problems.

Overall, the design model for problem crafting (and implementation of PBL) should result from our understanding of how students learn rather than focusing on how to deliver the content. By designing real-world problems using the learner-centric approach described in this chapter, teachers are likely to engage students, encourage deeper learning and, at the same time, prepare students for the changing world.

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Chapter 4
Mathematical Problem-Solving Using Real-World Problems

Lu Pien Cheng and Tin Lam Toh

Abstract According to the Singapore primary mathematics curriculum (2006), it is important that students tackle a variety of mathematical problems, including real-world problems, as they apply their mathematical problem-solving skills. This paper examines the challenges and affordances of using real-world problems with young children in a primary school in Singapore. Using the laboratory class cycle, the teachers in the study planned, observed and critiqued a mathematics lesson using real-world problems for primary two children. Data in this study includes the teachers' conversations during the laboratory cycle and the students' responses during the observed mathematics lessons using real-world problems. Our findings show that the real-world problem used in this study generated rich mathematical classroom discussion. The teachers' learning from using real-world problems through the laboratory cycle and the challenges they faced were discussed in this study.

Keywords Primary mathematics • Real-world problems • Mathematical processes • Problem solving

Introduction

Recent education reform efforts have been influenced by the demand of the economy for skilled workers who can apply their knowledge in flexible ways to solve novel problems (Goodman 1995). It is thus not surprising that educators measure *competence* as not only the acquisition of basic skills but also the integration of these skills in solving real-life problems (Fuchs and Fuchs 1996; Fuchs et al. 2005). In line with the above education reform, the call among the mathematics education community throughout the world to introduce mathematical tasks that are related to "real life" and the "real world" in the mathematics curriculum is a natural progression. Such a call could be traced back to as early as 1982 in the Cockcroft Report about the increased concern that adults were not able to apply the mathematics they

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had learned at school in everyday contexts (Boaler 1993). The reasons provided by the advocates of this movement can generally be classified under five main categories: (1) meeting the economic needs of the society, (2) deepening students' understanding of important issues, (3) improving students' understanding of mathematical concepts, (4) enhancing students' appreciation of mathematics and (5) improving student affect in mathematics (Beswick 2011).

The Singapore primary school mathematics curriculum has consistently emphasised the application of mathematics to solve real-world problems (MOE 2000, 2006, 2012). Students must be able to connect mathematics that they have learnt to the real world in order to enhance their understanding of key concepts and to develop mathematical competencies (MOE 2012). This matches the two main reasons proposed by Cooper and Harries (2002) for mathematical applications: (1) applications of mathematics to problems outside of the classroom and (2) improve students' understanding of mathematics concepts.

"Mathematical problem solving includes using and applying mathematics in practical tasks, in real life problems and within mathematics itself" (MOE 2000, p. 5). Central to mathematics learning is mathematical problem-solving which involves the "acquisition and application of mathematics concepts and skills in a wide range of situations, including non-routine, open-ended and real-world problems" (MOE 2006, p. 6).

Teaching Mathematics in the Context of Real-World Problems

In this study, real-life contexts are defined "broadly to include situations that refer (directly or indirectly) to everyday activities or concern mathematical applications" (as cited in Stylianides and Stylianides 2008, p. 860). The terms real life and real world are used interchangeably in this paper. The range of practices under the umbrella of real-world connections includes simple analogies, classic word problems, analysis of real data, discussions of mathematics in society, hands-on representations of mathematics concepts and mathematically modelling real phenomena (Gainsburg 2008, p. 200).

One positive effect of using real-world problems on students is students' increased motivation in mathematics. When children make connections between the real-world and mathematics concepts, the latter becomes relevant to them, thereby motivating students to learn and get more interested in the learning process (Albert and Antos 2000). Hiebert et al. (1996, p. 18) reported that "the problems with which students will become most easily engaged are those that are taken from their everyday lives". Research also suggested that teachers can place problem-solving in real-life contexts as one way to increase their students' motivation in mathematics (Schiefele and Csikszentmihalyi 1995; Stylianides and Stylianides 2008). However, real-world activities intended "to review or enhance previously taught concepts would seem particularly expendable" when the main goal is to impart mathematical concepts and skills rather than to develop "students' ability and disposition to recognize applications and solve real problems" (Gainsburg 2008, p. 215). In our opinion, a real-life task needs to be well designed in order to "stimulate student interest and engagement and the development of a healthy, accurate view of mathematics as a useful discipline" (Trafton et al. 2001, p. 263).

Mathematical Problem-Solving in Singapore: From Story Sums to Real-World Problems

The classification scheme for the types of mathematical problems in Foong (2009) suggests the possible range of problems Singapore primary school students might be exposed. Teachers are generally comfortable with solving problems using problem-solving heuristics and thinking skills (Kaur and Dindyal 2010). In fact, teachers have received extensive preparation on the use of heuristics. Efforts were also made to associate each given type of word problems with a particular heuristics listed in the mathematics curriculum.

Students at the primary level learn most of their mathematics through *word problems* or *story problems* in general (Reusser and Stebler 1997). In Singapore classrooms, word problems can be found in typical textbook problems. These word problems are usually contextualised; students solving these problems are required to understand the context and use appropriate mathematical operations to solve these problems. It could also be seen that these contextualised problems are generally artificial with "very clean and tidy state" (Ang 2009, p. 180). The word problems are unrealistic in nature and they actually teach students to suspend real-world sense making (Greer 1997). Indeed, "many teachers consider the real contexts of word problems irrelevant distractions" (cited in Gainsburg 2008, p. 200) making it difficult to convince students about the real-life applications of mathematics. Furthermore, most of these problems are close-ended; many real-life problems are open-ended and require the solvers to engage in "interpretive activity" (Inoue 2008, p. 39). The open-endedness of such real-life problems suggests fewer constraints in problem goals, thus allowing problem-solvers more opportunities to connect their diverse everyday experiences and the problem and make sound decisions based on assumptions about the real world. Open-ended tasks encourage students to adopt divergent thinking and reasoning and therefore allow students to "respond positively and participate actively in the learning processes" (Kwon et al. 2006, p. 51). Furthermore, it has been shown that open-ended tasks focused on content-specific features are effective in promoting particular concept development and to elicit higher-order thinking (Sullivan et al. 2009).

Efforts were made to expose students to contextual open-ended mathematics problem tasks in Singapore. Foo and Fan (2007) investigated the effects of integrating authentic open-ended tasks in the Singapore mathematics classroom in a secondary school as an assessment strategy. Chan (2005) examined the teacher's and students' experiences and difficulties in using contextual open-ended mathematics problem tasks with primary six students. Results from Chan (2005) showed that the students were actively engaged at high levels of cognitive thinking through scaffolding and meaningful explanations. In the same paper, Chan reported that the authentic nature of the contextual open-ended mathematics problem tasks provided "opportunities for personal values and beliefs to be raised through the discussion". In addition, exposing students to contextual open-ended mathematics problem allowed the students to appreciate the complexity of the real world. Through the problem-solving process, contextual open-ended mathematics problem helps students connect mathematics learning to the real world. However, such tasks require much time to plan and complete.

Challenges in Teaching Using Real-World Problems

Research shows that teachers may face some difficulties in utilising mathematical tasks that are set in real-world context. For example, Rule and Hallagan (2007) noticed that the teachers in their studies had difficulties understanding algebraic generalisations set in an authentic context. This occurrence suggests some inadequacies in teachers' pedagogical content knowledge (PCK), particularly in teaching authentic problem-solving. Shulman (1986b) has highlighted the importance of PCK in order to teach the subject well. This idea was upheld by Charalambous (2008) who has shown that teachers with good PCK were able to maintain the high cognitive demands of the mathematical tasks, while teachers without good PCK generally "proceduralized even the intellectually demanding tasks [he or] she was using and placed more emphasis on students' remembering and applying rules and formulas" (p. 287). The inadequacies in PCK in teaching authentic problem-solving may be due to "teachers mainly get[ting] their ideas for real-world connections from their heads, and many feel hindered by a lack of resources, ideas, or training for making connections" (Gainsburg 2008, p. 215). Another reason could be a wider knowledge base is required to fully utilise such contextualised tasks. In a study with elementary Latina/Latino students in the use of authentic mathematical investigations, students brought "multiple and diverse funds of knowledge to the classroom" (Turner et al. 2009, p. 140). The studies suggest that teachers may require a wider knowledge base which may include a blend of students' "out-" and "in-" school experiences when using mathematics problems embedded in real-life context.

Foong et al. (1996) reported in their study that a number of teachers felt inadequately prepared to teach mathematical problem-solving when the examples had multiple possible solutions. Foong (2005) described how three primary teachers implemented the same open-ended problem-solving activities with varying degrees of success. Only one teacher implemented the tasks successfully. One of the teachers was too procedural in her instruction and the other teacher had limited understanding of the mathematical thinking embedded in the task and the kind of cognitive demands to be made of the students.

The use of contextual open-ended problems may pose challenges to collaborative group work. For example, Chan (2005) reported that "groups with quieter students made it difficult to work as a team" and students who were more vocal within the group appeared to be more engaged in the task. Bennett and Desforges (1989) cautioned that the use of such problems should be built on students' prior knowledge.

Unfamiliar contexts may cause some students to have difficulty proceeding with the problem-solving process (Rogoff and Lave 1984 as cited in Chan 2005). In the same line, Stillman reported that "cue salience and its interaction with prior knowledge are of particular importance" (2000, p. 335) in application tasks. The problem-solver will be less likely to "engage with the context of a task" in which they are unfamiliar in the "same degree" as another person who has been exposed to a similar scenario (Stillman, p. 335).

Amid the challenges faced by the teachers in using real-world problems in the mathematics classroom, much potential is yet to be explored for the problems to enhance teaching and learning of young children. This paper investigates the potential of real-world problems in mathematics by examining its benefits and challenges for teachers and young learners.

This Study

This paper continues the investigation of the potential of real-world problems in mathematics that was previously reported by Cheng (2013). The results presented in this paper were based on a subset of the data that were collected in Cheng's study (2013). The laboratory class cycle served as the platform for the teachers to plan, observe and critique the real-world mathematics problems. The observation stage is also referred to as the research lesson. In the following section, we report the teachers' engagement in one laboratory cycle in a neighbourhood primary school to develop primary two students' decision-making skills through real-world problems in mathematics. Specifically, we aim to address the following research questions:

1. What are the benefits for teachers and young children by using real-world problems?
2. What are the challenges for teachers in using real-world problems with young children?

A total of six consecutive weekly meetings were conducted with the teachers. Each meeting lasted 1 h. The first four meetings were used to plan the mathematics lesson involving the use of real-world problems. The fifth session was the research lesson and the last session was used to critique the research lesson.

Participants

Five teachers from the same school with various backgrounds, ethnicities and varying years of teaching experience participated in the study. The teachers were Mary, Mable, Ginger, Vin and Ivy. Pseudonyms were used for the teachers in this study. The research lesson was taught by Mary to the children in her class. The children were the better students in the primary two cohort in her school and the children were arranged into mixed-ability groups prior to the research lesson. For the rest of this paper, we used the term children instead of students to denote the young children involved in this study.

The Mathematics Lesson

This study utilised an approach that differs from problem-focused teaching approach. The problem-focused teaching (Riedesel et al. 1996) approached teaching mathematics in context in such a way that the real-world problems become the settings in which the mathematics are presented. That is, students were presented a word problem to solve in whatever ways that makes sense to them. The students then shared their methods for solving the problem with the class before the teacher offered a standard algorithm of solving the problem. "Skill in mathematics arises from context", rather than presenting the skills first then the context (Schwartz 2008, p. 8). The teaching approach that was applied in this study differed from problem-focused teaching in that the skills in mathematics were taught to the children first before presenting the problems embedded in real-life contexts. The purpose of the task was to further reinforce the computational skills and provide opportunities for the children to apply those skills in a more open-ended task framed in real-life context.

The task was designed by a group of teachers from a neighbourhood school for primary two children with several principles in mind (Cheng 2013): It was aligned with the 2006 Singapore mathematics curriculum, tapped and extended mastery of mathematical concepts. A pre-task of the school *Bookshop* was used to familiarise the children with the competencies before solving the actual[1] *Restaurant* problem. The pre-task required the children to spend exactly $2 at the scenario of a school bookshop. Small numbers (10¢, 20¢, 30¢, 50¢, 80¢ and $2) were used and the children had to choose from only nine items. The items included, for example, pencil, eraser and ruler.

The *Restaurant* problem required the children to spend close to $30 at a restaurant scenario. Bigger numbers were used ($18, $5.50, $3, $2.50) and the children had to choose from 14 items such that each person in the group had a drink and dessert was optional. The items included, for example, fried chicken wings 1 basket of 12 for $18, orange juice 1 cup for $2.50 and ice cream cones 3 for $4.50.

The *Restaurant* problem and the *Bookshop* pre-task were designed and sequenced in such a way that learning would take place at the anticipated zone of proximal development for the majority of the children in the class where the lesson was to be conducted. Polya's (1957) problem-solving steps were not formally introduced to the children but were used to guide the implementation of the tasks. Mary, one of the participants in this study, modelled the mathematical thinking, reasoning, decision-making and calculation skills to satisfy the conditions stated in the

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[1] A sample of the *Bookshop* and *Restaurant* problem appeared in Cheng (2013).

Bookshop pre-task before allowing the children to investigate the *Restaurant* problem. The children worked in groups of three to record and complete the *Restaurant* problem.

Research Design and Data Analysis

The mode of inquiry we employed in this study was interpretative case study (Merriam 1988). Data collection included audio recordings of meetings, artefacts from the weekly meetings, interviews with teachers after the laboratory class cycle and the researcher's field notes. In the first phase of the data analysis, the researchers listened closely to the audiotapings of the meetings and identified issues and topics that were discussed. The issues and topics were coded (time, scaffolding questions, student grouping, etc.) and the researchers started to write memos regarding the benefits and challenges of the task for the teachers and young children in each of the codes. In the next phase, the researchers used the codes to the transcripts of the interviews and lesson plan and continued to write memos regarding the benefits and challenges of the tasks. Data from the three data sources were triangulated. The codes were organised and grouped into themes. The researchers then wrote the findings using the themes generated.

Results and Discussion

Analysis of the teachers' conversations during laboratory class revealed that the *Restaurant* problem using real-life context offered the participating teachers in this study abundant opportunities for professional development. First, we discussed the benefits of using real-world problems for the teachers and young children in this study. Next, we present three main challenges that the teachers faced when implementing the *Restaurant* problem.

Opportunities for Teachers to Engage in Deeper Discussion During Planning of Lessons

The design of mathematics problems using real-life context tasks required knowledge in several aspects, such as knowledge of curriculum, knowledge of task design and knowledge of children's thinking and their beliefs (Cheng 2013). Coming together as a group to design such tasks afforded the teachers a platform to build upon each other's expertise in creating relevant and good classroom tasks. When planning the tasks, the teachers crafted more open-ended questions of a higher-order nature, drawn away from the standard answers towards seeking “many” plausible responses by the children. In order to facilitate the children’s completion of the *Restaurant* problem, the teachers had to anticipate and classify all the plausible responses and the mathematical skills required with each response. They found themselves drawing from their understanding of children’s thinking to craft scaffolding questions and meaningful explanations to facilitate the task. Table 4.1 summarises how scaffolding can be used to unmask the *Restaurant* problem in the mathematics classroom (adapted from Kim and Hannafin 2011, p. 409).

Because of the diversified ethnic, cultural and family backgrounds of the children, different interpretations of the task by the children were expected. Solutions to the problems can also be vastly different as a result of individual differences, personal values and beliefs of the children. The teachers’ varied backgrounds, differing beliefs and personal values have the potential to play an important role in creating appropriate context and scaffolding questions to elicit the variety of responses possible from the children. Such platforms and tasks afforded the teachers opportunities to engage in rich discussions, widen their perspectives, share and grow as a community.

The opportunity to think more deeply about the use of scaffolding questions in the *Restaurant* problem empowered the teachers to engage the children at deeper and higher levels of cognitive thinking. Ginger said:

> I really had to think more about the scaffolding questions so that the children don’t just say yes or no… sitting down together [to plan the questions as a group] really helps because the scaffolding questions really help [some of] the children to articulate their thought processes [weekly meeting 6].

Mary said, “usually when I do group work, the children were able to perform the task and the discussion was not as lengthy as this lesson [Mary, weekly meeting 6]”. Mary also added,

> I am now made more aware of how to question the children in order to bring out their explanation, their reasoning. So previously, the questions I asked used to be more closed. Now it’s more open. It’s the awareness, the conscious, because I am more conscious of that [interview].

Greater Opportunities for Teachers to Hear Children’s Thinking and Understanding

During the research lesson, the social conversations that emerged during the children’s group work brought a diverse range of interpretations to the problem scenario. The teachers stationed themselves with assigned groups of children and they were able to hear what the children were thinking, what they understood from the problem scenario and blockages they face in solving the problem. For example, through the questions that the children raised during group work, the teachers were more aware of the varied interpretations of key terms in the questions. One of the

Table 4.1 Scaffolding children's unmasking of the *Restaurant* problem

Problem-solving phases	Scaffolding foci	Scaffolding examples
1. Pre-task	Model the problem-solving process for an easier parallel task	Help children to acquire a sense of the problem-solving process
	Model the competencies required for the actual task	Help children develop the competencies required for the actual task
2. Actual task: hands-on experience of the problem-solving process, apply and extend competencies		
Introduction: before the problem	Identify the structure of the problem	Help children identify the "given", "to find" and assumptions in the problem
Understanding the problem	Externalise children's prior knowledge and experiences on the problems	Help children find cues and hints relevant to the problem contexts, background knowledge
		Provide resources for children to explore the problem
Launch: during problem-solving	Obtain a plan for the solution	Help children to search for and connect to similar problems that have been solved (make connections to pre-task)
Planning and doing	Pursue solution	Help children to locate the key problem concepts, data and known and unknown variables and the relationships/connections among them
	Active checking of each step of the working	Help children to identify any other information related to the context
	Handle blockages	Help children to compare solutions with assumptions of the problem
		Help children to replan when solutions do not satisfy all the assumptions or when blockages are encountered
Whole-class discussion: after problem-solving	Surface the mathematics and the mathematical processes in the tasks, e.g. compare and contrast	Help children to consolidate and reflect on the mathematical skills, mathematical processes, mathematical reasoning and problem-solving processes
Checking	Check the result/active diagnosis	Help children to verbalise solutions and explanations
		Help children to detect errors and faulty reasoning
		Help children to contemplate on potential revisions to their solutions

groups could not agree with the items that should be considered as "dessert" and this provided an opportunity to clarify what should be considered as a dessert in the given menu. In accordance with Chan (2005), the "real-world" depiction of these problem tasks provides opportunities for personal value and beliefs to be raised through the discussion. Whenever each item is removed, added or replaced with another item in the menu, ownership lies with the children to check whether all the conditions in the problem are met. Many children had different interpretations of the term “maximum to spend”. The teachers also examined the children’s solution strategies (reported in Cheng 2013) to the *Restaurant* problem during the research lesson and critique. Some of the children’s responses were not anticipated by the teachers. For example, one group of children divided \$30 equally among themselves and each of the children decided what they wanted to buy with their \$10. There were some instances when the teachers were surprised with what the children were able to do. Mary said (weekly meeting 6): “Some of the children surprise me … one student can understand the meaning of maximum to spend and also able to explain what this term means”. Mabel was also surprised that “some of the children are able to explain very well”.

Through the unexpected children’s solutions and responses, the teachers accommodated and assimilated their schema on their understanding of the type of solutions and explanations children would generate for such tasks. Through the expected children’s solutions and responses, the teachers reinforced their understanding of children’s thinking.

Opportunities for Young Children to Develop Mathematical Process Skills

During the research lesson, the teachers observed process skills (e.g. decision-making, comparing, reasoning, thinking, etc.), mathematical skills being reinforced, consolidated and developed through the *Restaurant* problem. The children were also engaged in more diverse and flexible thinking as the real-world problem provided them opportunities to “choose, mix and match items from the menu” and consider the appropriateness of their solution. In accordance to Kwon et al. (2006), the open-endedness of the tasks encouraged the children to adopt divergent thinking and reasoning and promoted active participation in the learning processes. The use of the *Restaurant* problem made the experience of learning mathematics more meaningful and enhanced children’s appreciation of the nature of mathematics. This result supports the findings by Albert and Antos (2000).

Ginger felt that the *Restaurant* problem afforded richer discussion of the thinking and decision processes required by the children to solve the problem. However, it is up to the individual teacher to fully utilise the affordances of the task. Ginger said:

> Some of the children’s goal was to solve the task. They are very happy when they solve the problem. They do not want to think further about the problem… Those groups, I would give feedback during the group work and challenge the children to think more deeply about the problem [paraphrase] (weekly meeting 6).

A Challenge for Teachers to Group Children

The teachers in this study grouped the children such that each group had a good mixed of high-, middle- and low-ability children. While Chan (2005) reported that more vocal students within the group appeared to be more engaged in the task, the teachers in this study faced the challenge to try to "balance the task to the high ability and low ability" (Mary, weekly meeting 6). The teachers felt that the higher-ability children could be stretched even further in the *Restaurant* problem. The low-ability children were observed to be struggling with language, computational skills, understanding the problem, identifying the known conditions and the unknowns even though a pre-task was used to familiarise the children with the actual *Restaurant* problem. One suggestion by the teachers was to group the children according to their ability groups so that the task could be differentiated for the varied groups. For the low-ability group, Mabel suggested using the same menu but reducing the number of items in the group. She also suggested planning a menu for lesser number of people. Ivy suggested reducing the categories of food to the main dish and drink. However, the challenge will be to go through the task in the whole-group discussion. Further thoughts and research are needed in this area.

A Challenge for Teachers to Complete the Task Within Curriculum Time

The second challenge was curriculum time. Such semi-open-ended real-world problems require much time to plan and complete. This is in accordance to Chan's (2005) findings. The team shared the same sentiment that more than an hour is required for rich discussion of the task for this group of children. They recommended that about three periods or 1.5 h would be more ideal for the teachers and children to fully expand and utilise the learning opportunities afforded by the task.

Dilemma as to How Much Computational Skills to Teach Before the Task

All the teachers believed that the basic and core computation skills in the curriculum should be taught first before exposing the children to such tasks. However, there were differing views about whether the "extended" computation skills required of the task should be taught first. Vin observed that the task required the children to go beyond what was normally done during the mathematics lesson, but she was unsure whether the extended skills should be taught to the children before the implementation of the tasks. Vin said:

> Some of the children were unable to add a string of numbers … normally in class, they find a total of two numbers, not a continuous [string of number] … they forget what they have added [halfway through] and they had to start to add all over again, Maybe that is a skill that needs to be taught before the task… teach them how to add 2 numbers and then how to add on and on from there (weekly meeting 6).

Conclusions and Implications

The aim of this study is to maximise the usefulness of a well-designed real-life problem by investigating the affordances of such tasks and the kind of knowledge required to facilitate the implementation the task. The study showed that there are many benefits as well as challenges for the teachers and children using real-world problems. For the teachers, such tasks have the potential to deepen the teachers' mathematical knowledge for teaching. For the children, such task afforded them opportunities to develop their mathematical processes through (1) recognition of the mathematics in real-life context and (2) application of the relevant mathematics in real-world contexts. Computational skills can also be reinforced and extended through such tasks. The real-life problem in this study provides the opportunities to enhance the twenty-first century competencies in our young learners, in particular, critical thinking and inventive thinking. One aspect of the mathematical knowledge for teaching that surfaced in this study was a deeper knowledge of context and children. Having knowledge of the context and children will assist the teachers to design appropriate task and scaffolding questions to unpack the mathematics embedded in the task.

Three main challenges were faced by the teachers in the implementation of the real-world tasks. One noticeably key challenge was to design and implement these tasks such that they are doable within the curriculum time. Real-world context is naturally appealing to many children and an excellent platform to motivate children to solve mathematics problems. However, because of the richness of the context, there is a tendency for the children and teachers to spend more time understanding and expanding the context and problem. This leaves a fraction of the curriculum time to discuss and unpack the mathematics in the problem. This may become one possible "noise" in using real-life problems in our mathematics classroom – unintentionally delaying or deviating away from the intended mathematics to be learnt through the problem. Hence, we need to be very clear when and "how fast" we want the children to get into the mathematics. Another possible "noise" is the thickness of the context. One suggestion is to vary the "thickness" of the context for different purposes of the mathematics lessons and to "dress" the context accordingly to be varied needs and abilities of the children.

The implication of this study should be treated with caution, given the fact that this study was drawn from a single laboratory class cycle. Nevertheless, what we learnt from this study is that a carefully designed real-world problem, aligned with the instructional objectives of the curriculum, provides teachers with the opportunity to learn through planning and implementation of the problem. It also provides young children "gentle small steps" to connect mathematics to their social lives. Real-world problems can be overwhelming to young children when they deal with issues they have not heard of. However, when care and caution are exercised to select context and problem situations appropriate for young children, they can appreciate and apply problem-solving processes to connect mathematics to the world they are beginning to discover. More research is required in the facilitation of such tasks especially in differentiating the tasks to cater to the varied needs and abilities of the children.

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Part III
Problem-Based Learning Environments

Chapter 5
Problem-Based Learning: Conception, Practice, and Future

Woei Hung

Abstract Originally conceived to respond to the failure of traditional lecture-based methods in preparing medical students readily for clinical practice, problem-based learning (PBL) has made an inerasable mark in the history of education. Instead of an instructor-centered, content-oriented, decontextualized teaching and learning mode, PBL uses a student-led, problem-driven, problem-solving, and contextualized learning approach to prepare students for real-world challenges. Forty years after its first implementation, PBL has been and continues to be deemed as an innovative instructional method that helps students develop practical problem-solving, self-directed learning, and collaboration skills. Today, PBL has been implemented throughout almost all disciplines and subjects in professional education, higher education, and K-12 education. This chapter provides an overview of the conceptual framework of PBL, its current research issues and instructional practices, and future directions. First, I will review the theoretical conception of PBL. Second, I will examine PBL models, instructional design, and practice issues, such as utilizing instructional strategies or cognitive tools for facilitating students' learning in various steps and functions during the PBL process and problem/case design issues. Lastly, I will provide recommendations for future research.

Keywords Problem-based learning • PBL models • Problem design • Instructional design

Introduction

Traditionally, the focus of instruction has been on students' acquisition of domain content knowledge. Though the importance of a solid domain knowledge base should never be degraded, knowledge acquisition alone is inadequate to ensure students' ability to apply it in solving real-world problems. Furthermore, today's

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rapidly changing environments and the amount and speed of new knowledge and information being discovered have changed the survival rules of humans. In order to stay competitive, an individual needs to be an independent problem-solver, a lifelong learner, and an effective team player. Therefore, the skills of problem-solving, higher-order thinking, self-directed learning, and collaboration are deemed as essential skills of the twenty-first century.

However, up to this point, literature has shown that traditional instruction is ineffective in teaching these skills (Derry 1989; Larkin and Reif 1976; Neville 2009; Sweller et al. 2011). Geary (2002, 2005) categorized these skills as biologically primary abilities, as opposed to secondary abilities such as reading and writing that are normally learned through formal instruction. Geary (2002) contended that biologically primary abilities such as first language, social skills, and general problem-solving skills are the type of abilities that are acquired unconsciously over a long period throughout an individual's lifetime. It is a slow process of accumulating, interconnecting, and integrating pieces of related knowledge into a sophisticated schema (Bartlett 1932). These learning occurrences are embedded in an individual's daily life (informal learning settings), and therefore, the learning is not seen as "learning" by the individual. Rather, it is likely to be perceived as part of the daily life. As a result, the effort exerted by the individual becomes unnoticed (or unconscious).

Based on Geary's (2002, 2005) theory and the reasoning about the learning process of biologically primary abilities discussed above, it might be safe to state that when the primary learning goal is to develop these higher-order or implicit skills, the instructional method used needs to be able to afford the characteristics of the formation and learning process of biologically primary abilities. Among the existing instructional methods that have been practiced today, problem-based learning (PBL) is one instructional method that possesses these affordances. There has been a debate about the definition of PBL and which model can be considered real PBL. In this chapter, PBL will be defined as a broad term for overarching instructional methods that use problems as the main instructional approach for driving and enhancing students' learning. This definition is based on the fact that PBL has evolved into a number of variations from its original "pure PBL" model that vary in degrees of self-directedness and structuredness of the problems (Barrows 1986; Hmelo-Silver 2004; Hung 2011; Harden and Davis 1998). Nevertheless, though different in these variables, the essence of these PBL models remains the same. PBL integrates learning the skills of problem-solving, self-directed learning, and collaboration into part of the instructional format and process (i.e., using the instructional format to enculturate the students about the process of problem-solving as well as self-directed inquiry and learning). This way, the learning of these skills mimics how they are learned in our daily lives as biologically primary abilities. Furthermore, the cognitive load (Sweller 1994) in the learning process could be directed toward germane types for forming their schemata of these skills. Though it is not perfect (all instructional methods fall short in some ways), PBL provides an environment that is to foster these very types of knowledge and skills. In this chapter, I will briefly discuss the conception, development, and characteristics of PBL, followed by a description of a few established PBL implementation models, and, lastly, a discussion of its future directions.

Origin and Development

PBL was first conceived in medical education in the 1950s in response to the unsatisfactory clinical performance of medical graduates (Barrows 1996; Barrows and Tamblyn 1980). After a comprehensive investigation and evaluation of the instructional practice and the students' learning dispositions, it was concluded that the emphasis on memorization of fragmented biomedical knowledge in traditional health science education was to be blamed for failing to equip students with clinical problem-solving and lifelong, self-directed learning skills (Albanese and Mitchell 1993; Barrows 1996). There was an apparent discrepancy between what the students learned throughout their program and what they truly needed in order to perform competently in clinical settings. Based on the results of the evaluation, the medical educators identified knowledge application, independent problem-solving, self-directed learning, and collaboration skills as the competencies that the students needed to possess, and PBL was conceptualized as an instructional method to afford these instructional goals.

McMaster University in Canada is deemed as the pioneer in the development of PBL. During 1970s, the medical educators at McMaster established their medical curriculum based on this new conception of learning, which became a well-known PBL model that was adopted by many medical schools later. Throughout the history of PBL development, a number of alternative PBL models had also been developed to meet various instructional needs. For example, Michigan State University in the United States, Maastricht University in Netherlands, and Newcastle University in Australia also developed their own problem-based learning curricula (Barrows 1996). Since its first implementation several decades ago, PBL has become a prominent pedagogical method in medical schools and health science-related programs throughout the world. It was reported that today the majority of medical schools in Canada and 80 % of the medical schools in the United States use PBL as the primary instructional method to design their entire or partial curriculum (Karimi 2011).

Higher Education and K-12

The success of PBL in medical education gradually received attention from the educators and researchers outside of medical-related fields, including various disciplines in higher education as well as K-12 settings. Though the adoption of PBL in nonmedical fields occurred approximately 20 years later than medical education, PBL in higher education and K-12 has picked up its momentum since and is accelerating. PBL has been implemented in a variety of professional schools and university level of courses: business administration (Merchand 1995), chemical engineering (Woods 1996), law schools (Pletinckx and Segers 2001), leadership education (Bridges and Hallinger 1996; Cunningham and Cordeiro 2003), chemistry (Barak and Dori 2005), and various college courses (Allen et al. 1996; Savin-Baden and Wilkie 2004).

Though the adoption of PBL in K-12 settings came later than other educational levels, the benefits of PBL in cultivating young students' independent problem-solving mindset are apparent and supported by the educators. Barrows and Kelson (1993) were the pioneers in introducing and developing PBL curricula and teacher-training programs for implementing PBL to high school students. Today, PBL is no longer an unfamiliar instructional method to K-12 educators. Various results of implementations of PBL in K-12 settings have been widely reported, for example, mathematics (Cognition and Technology Group at Vanderbilt—CTGV 1993), science (Kolodner et al. 2003; Linn et al. 1999), literature (Jacobsen and Spiro 1994), history (Wieseman and Cadwell 2005), and microeconomics (Maxwell et al. 2005).

Conception, Components, and Characteristics of PBL

PBL is conceptualized upon a number of human learning theories, including the information processing model, cognitive theories, schema theory, situated cognition, metacognition, and constructivist theories (see, for example, Barrows and Tamblyn 1980; de Grave et al. 1996; Schmidt 1983). Specific theoretical conceptions include connecting new information with prior knowledge and schema (Bartlett 1968) to strengthen the memory traces and make the information useable, elaborating and constructing the information learned (Cermak and Craik 1979; Stillings 1995), contextualizing the knowledge learned (Lave and Wenger 1991), and establishing situational knowledge, collaborative learning (Dillenbourg et al. 1996), social negotiation and construction (Jonassen 1991, 1992), and metacognitive learning (Kitchner 1983). These principles are translated into PBL's operational components. They are (1) problem-driven learning, (2) contextualized, authentic problem-solving, (3) problem/case knowledge structured curriculum, (4) self-directed learning, (5) collaborative learning, and (6) reflective learning (Barrows 1996; Hung 2006; Norman and Schmidt 1992).

In PBL, the students' learning is initiated and consequently driven by a need to solve an authentic, ill-structured, real-world problem. This fundamental design of the instructional method serves to enhance students' motivation to learn (Barrows 1986). Requiring students to solve a real-life problem that occurs in their future professional or personal context could help them realize the relevance of the content knowledge and, as a result, motivate the students to learn (Barrows 1996). Also, human's natural curiosity and desire to take on challenges to conquer difficult problems are another assumption on which problem-driven instruction is built for enhancing student motivation during learning process. Furthermore, PBL curriculum is structured on problems/cases. This organization of curriculum helps students construct and store their domain knowledge in a case-based structure in their memory for effective retrievals of the knowledge in the future (Kolodner et al. 2003). Furthermore, the problems used in PBL are authentic and ill-structured (Jonassen 1997), which contain vague goal states, several unknown problem elements, multiple solutions, and ambiguity about the concepts or principles needed to solve them. In PBL, the use of ill-structured problems is to help students develop their ability to adaptively apply their knowledge to deal with complicated problem situations that are normally seen in real-world settings (Wilkerson and Gijselaers 1996).

Self-directed learning is another critical component in PBL. In order to cultivate students' lifelong learning skills and mindset, PBL requires students to be responsible for directing their own learning. However, this is not to put the entire learning responsibility in students' own hands. Students' learning process is facilitated by instructors (or called tutors). Yet, the role of instructor is not disseminating the knowledge to the students. Rather, the instructor needs to facilitate students to engage in a scientific reasoning and problem-solving process, as well as examine their own learning process during the PBL session. The instructor could either model expert-like problem-solving and reasoning processes for the students or use questions to guide them through the problem-solving process. This way, the students are practicing and developing their own self-directed learning skills and metacognitive skills (Dolmans and Schmidt 1994). Thus, the self-directed learning component in PBL helps students develop the reasoning skills for conducting a scientific problem-solving process (Hmelo-Silver 2004). Furthermore, self-directed learning in PBL does not mean students learn and solve problems in isolation. Besides being facilitated by the instructor throughout the problem-solving and learning process, PBL students collaborate to solve the problem and learn in small groups. This collaboration component is to help students develop social, interpersonal, collaborative, and inter-supportive skills that are much needed in today's workplaces. The learning of this type of soft skills, as mentioned in the beginning of the chapter, is a cultivation process. Instead of teaching the skills of problem-solving, self-directed learning, collaborative learning, and reflective learning with a knowledge transmission approach (i.e., traditional instructional methods), PBL translates these target biologically primary skills into forms of course format, learning process, and learning culture. In this learning environment, students are acculturated to practice these skills and ultimately internalize them into their fundamental dispositions toward learning.

Based on these components discussed above, the characteristics of PBL can be summarized as follows.

Characteristics of PBL

- Problem-driven instruction. The students' learning is initiated by the need to solve a problem. The PBL process simulates the process of solving problems where learning processes are embedded.

- Problem/case-structured curriculum. In PBL, the content knowledge and skills to be learned are organized around problems, rather than as a hierarchical list of topics. This curriculum design helps students organize their knowledge in a case-based structure. This knowledge organization not only enhances the effectiveness of retrieval of the knowledge but also contextualizes the knowledge.
- Authentic, ill-structured problems. PBL uses real-life, ill-structured problems. Students learn to cope with the complexity, messiness, uncertainty, and unknowns of real-life problems and, more importantly, develop their ability to evaluate the viability of competing solutions.
- Self-directed learning. Students individually and collaboratively assume responsibility for initiating and directing their own learning. Instructors are facilitators whose roles are supporting and modeling reasoning processes and facilitating group processes and interpersonal dynamics.
- Small-group settings. In PBL, students work in small groups. Through group discussion and working collaboratively, PBL students enrich their knowledge from multiple perspectives injected by group members on issues to be solved. Also, the small-group working environment provides students opportunities to hone their interpersonal and teamwork skills.
- Reflective learning. Self-directedly or with an instructor's facilitation, students engage in metacognitive processes to improve their own learning. Students monitor their understanding and learn to revise their strategies for effective learning and problem-solving. The incorporation of this component as part of the PBL process helps cultivate students' mindset in engaging in metacognitive activities in their learning process (Hung 2006; Hung et al. 2008; Jonassen and Hung 2008).

Practice, Categorization, and Models

Several decades after the first PBL curriculum being implemented, a number of variations have spawned from the original PBL model (Kaufman 2000; Rothman 2000; Savery 2006). The original PBL model, which is also called "pure PBL," completely eliminates lectures or any other direct instructional forms. Students need to take full responsibility in directing their own learning, yet, with a facilitator's guidance. This PBL model assumes the readiness of the learners' cognitive, psychological, emotional, and social maturity since it was originally conceived for educating medical students who are considered at a high level of maturity in these aspects. Therefore, the pure PBL model in fact requires students of the highest level of independent problem-solving and self-directed learning, as well as assuming responsibility for their own learning during the PBL process. As PBL migrates outside of medical-related fields and is adopted by various disciplines and for different levels of learner populations, such as K-12 students, the assumption of mature cognitive and psychological abilities and skills is no longer valid. Therefore, various degrees of modification have been made to the original model as PBL has been adopted and spread across different disciplines, learner levels, countries, and even cultures (Hung and Loyens 2012). As a result, a wide range of PBL variations exist to meet the diverse instructional needs as well as comply with constraints or restrictions.

Categorization of PBL

Since wide variations of PBL have been implemented and reported, there has been some confusion as well as debate about what exactly PBL is. Some researchers have taken on the task and tried to define and categorize the variety of PBL with various sets of variables. For example, Barrows (1986) proposed a taxonomy that classified PBL into six categories using two variables, which are level of self-directed learning and level of problem structuredness. Hmelo-Silver (2004) discussed three major PBL instructional approaches (PBL, anchored instruction, and project-based sciences) differentiated by their format and the tools used. Also, Harden and Davis (1998) devised a set of 11 steps (or levels) of PBL model categorization.

In examining these different types or approaches of PBL as well as others that have been reported in the literature, Hung (2011) agreed with Barrows' (1986) two dimensions (that are self-directedness and problem structuredness) as the two most fundamental variables that shape the format of the implementation and the requirements of the students in terms of their cognitive processing and involvement. He suggested a two-dimensional spectrum with the variables of self-directedness and problem structuredness as two scales, and a given PBL implementation can be analyzed in terms of its appropriateness for different instructional needs and learner characteristics. Hung (2011) also identified six representative PBL categories with this two-dimensional spectrum of PBL (Fig. 5.1). These six representative PBL categories include pure PBL, hybrid PBL, anchored instruction, project-based learning, case-based learning, and instruction with problem-solving activities (e.g., problem as a test, example, or integrator; Duffy and Cunningham 1996). These six categories represent the different PBL implementations that require different levels of cognitive processing abilities of the students in order to successfully fulfill the demands of self-directed learning and the complexity and ill-structuredness of the problem.

Pure PBL is the original form of PBL. The most distinct characteristic of pure PBL that sets it apart from other forms of PBL is that there are absolutely no lectures or similar forms of knowledge dissemination included in the curriculum. Also, the instruction that starts with a need to solve authentic, ill-structured problems is another hallmark of a pure PBL model. Students who study under pure PBL will need to assume the highest degree of responsibility for directing their own problem-solving and learning process. The philosophy behind the curriculum design of eliminating lectures is to cultivate the student's skills and dispositions of self-directedly identifying what needs to be learned when encountering a problem, rather than being instructed of this information. Also, the problems used in pure PBL are highly

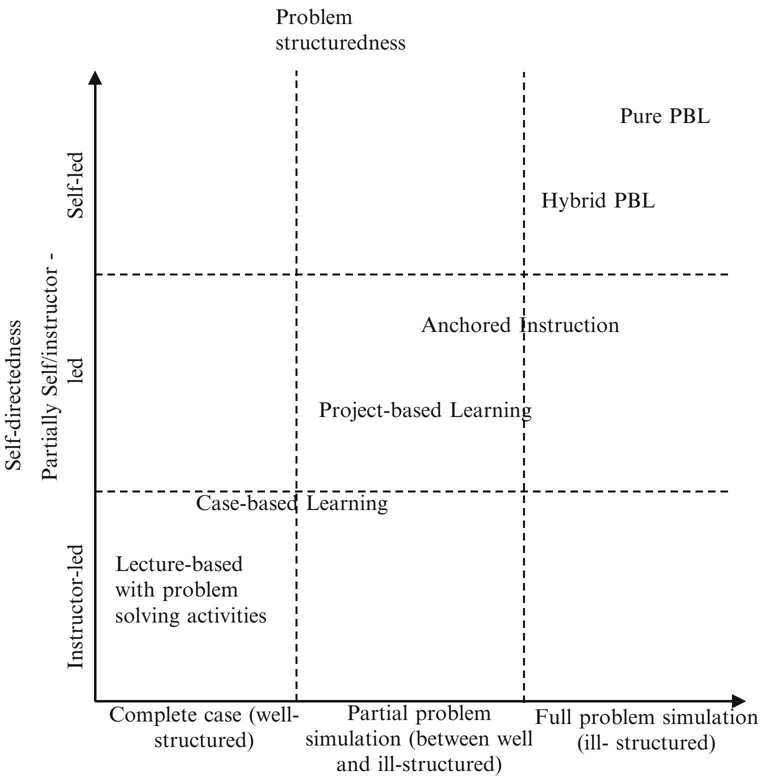

Fig. 5.1 Six representative PBL models in Barrows' PBL taxonomy (Source: Hung 2011)

complex, ill-structured, and as authentic as possible. When solving ill-structured problems, the students will have to face challenges of high degrees of unknown and uncertainty. This is to help the students develop not only the scientific problem-solving process but also their ability to evaluate the options and select a most viable solution based on the circumstance, as well as the ability to adaptively cope with changes and the unexpected.

Hybrid PBL

This form of PBL employs a combination of pure PBL and limited amount of lectures as supplemental instruction. High degrees of self-directed learning, problem-solving initiation, and authentic, ill-structured problem-solving are still the dominating instructional method and student learning format. However, students will receive a limited number of regular lectures or mini-lectures to supplement their knowledge acquisition. The lectures could be planned as part of the curriculum, or added if the instructor determines there is a need for better guiding students' learning, for example, clarifying misconceptions. One example of hybrid PBLs is productive failure model (Kapur 2008, 2010) where structured lectures are given after students have independently worked through the problems and may have experienced some frustration during the problem-solving process. This model provides students with opportunities to undergo real-world problem-solving situations as well as to formally integrate the concepts and principles with their problem-solving experiences into a sound conceptual framework under structured guidance.

Anchored Instruction

Originally developed by the Cognition and Technology Group at Vanderbilt University, anchored instruction uses video-based scenarios to anchor students' learning about math in real-life situations (Cognition and Technology Group at Vanderbilt—CTGV 1993). The scenario-based problem-solving situates students' learning of mathematical concepts in a relevant context and meaningful way. In completing each scenario, students actively engage in a scientific problem-solving process (such as gathering relevant research information, discussing and testing hypotheses, etc.) in order to devise and evaluate solutions using the mathematical concepts. Anchored instruction cultivates the students' mindset employing a scientific problem-solving process. The highly contextualized learning and knowledge construction help students develop conditional knowledge (Paris et al. 1983), which is an important cognitive component for effective application of knowledge. This instructional approach has been categorized as one of the PBL models by Hmelo-Silver (2004), because of its problem-driven learning approach. She explained that, in anchored instruction, students solve problems by using their prior knowledge and the content knowledge is provided to the students by the teacher when needed. Therefore, the teacher/instructor's guidance is more explicit and direct than pure PBL and hybrid PBL in anchored instruction.

Project-Based Learning

This form of PBL is employed in a wide range of disciplines and learner levels. Students are assigned to complete a project that involves devising a solution to a real-life problem. The main difference between project-based learning and the two types of PBL discussed above is that the problem-solving process in project-based learning is more of knowledge application, rather than knowledge acquisition. In pure PBL and hybrid PBL, students need to self-identify what needs to be learned (which is the intended content knowledge and skills) then research the information and apply it in solving the problem. On the other hand, project-based learning functions more of an authentic opportunity for the students to apply what has been learned. Students receive various degrees of necessary content knowledge and skills from the instructor, and then they are given a project to complete using that knowledge (Hmelo-Silver 2004). Therefore, in project-based learning, learning starts with studying the content knowledge, followed by opportunity for application, as opposed to pure or hybrid PBL where knowledge acquisition and application occur simultaneously. Another difference between project-based learning and pure/hybrid PBL is that project-based learning leans more toward instructor-directed learning, while pure/hybrid PBL requires students to be highly independent learners. The structuredness of the problems used in the first four types of PBL is still on the ill-structured end.

Case-Based Learning

This instructional approach belongs to the realm of PBL due to its use of problem/case structure of curriculum, as well as the contextualization of knowledge. By requiring students to study real-life cases that involve the content knowledge, the students realize how the abstract concepts are used and manifest themselves in real-world situations. On the scale of problem structuredness, case-based learning is moving toward the ill-structured end because the cases are usually solved problems. Solved cases are not necessarily well-structured problems. However, they imply that there is a known “right” answer and therefore decrease the students’ willingness to explore the topic, as well as seek for and evaluate alternative competing solutions. Also, the instructor’s influence and direction about students’ learning and discussion of the case may be more present in case-based learning, which could decrease the students’ opportunity to develop their self-directed learning skills.

Lecture-Based Learning with Problem-Solving Activities

When broad definition of PBL is used, some instructions that are lecture based but with a great amount of problem-solving activities for practicing the concepts learned from the lectures are being categorized as one type of PBL (Harden and Davis 1998). This category of PBL is at the lowest degree on both self-directedness and structuredness of the problem in the two-dimensional scale. The problem-solving activities in this category of PBL basically link theoretical concepts to solving practical problems (well-structured or semi-authentic or semi-ill-structured) and practice opportunities. The learning process is predominantly teacher/instructor directed.

Using the two-dimensional scale (Fig. 5.1), PBL educators and instructional designers can identify an appropriate PBL category for achieving their specific instructional objectives, matching the learners’ cognitive readiness and, ultimately, enhancing the students’ PBL learning outcomes as well as overall experience. For example, when developing self-directed learning skills and the ability to deal with uncertainty is the main learning goal and objective, the PBL model that requires learners to use a full degree of self-directed learning and solve highly ill-structured problems (e.g., pure PBL) would be a more suitable approach for achieving the goal. However, when knowledge application is the main learning goal of the instruction and students’ cognitive and/or psychological maturity is at medium level, then the PBL models that use partial instructor and student-led learning, such as project-based learning or anchored instruction, may be more effective in helping students achieve such learning goals. Also, there are instructional situations where contextualizing learning is the main learning goal, the application of learning content is highly nuanced in nature (i.e., lots of gray zones for the applications of the concepts, principles, or rules), or some structure of learning is preferred due to, e.g., timeframe, learner characteristics, etc. In these situations, case-based learning may be a more effective model for guiding students to connect the concepts with the contexts where they are applicable or appreciate the nuance of the concepts or principles that sometimes cannot be explained or studied out of context. Lastly, for learning subject areas that require both conceptual understanding and practices (e.g., mastery of basic math skills), the PBL models that typically use one long complex problem may not be ideal, for example, pure PBL or project-based learning. These PBL models could afford a great environment for learning the concept, however, offer fewer opportunities for students to exercise the concepts under study or practice the procedural skills due to the length of time for solving each problem. In this case, lecture-based learning with problem-solving activities may be a better choice of a PBL model for the instructional purpose.

Future Directions

PBL's popularity has been at a steady growth rate since it was first implemented. A number of issues with the effectiveness of PBL or various aspects of its implementation have been researched which has resulted in a vast body of valuable literature, such as comparing PBL with traditional instructional methods, tutor's roles and facilitation techniques, or group processing. However, as PBL spreads into an even broader range of disciplines, countries, and cultures, new research questions emerge as these additional diversities bring new dimensions into the realm of PBL research. Furthermore, these new dimensions also shed different light on the existing research topics and reveal more new research territories. In the following, I will discuss a few promising research areas that need PBL researchers' attention.

Cultural Migration and Adaptation

As PBL is being adopted by more and more educational institutions in different countries and cultures, certain degrees of modification to PBL implementation may be inevitable. Sometimes, a drastic innovation is incorporated into the implementation to meet the unique education system, for example, Singapore's "one day, one problem" model. In this model, students work on one problem that focuses on one given subject each day. As with any other PBL models, students work in groups under a tutor's facilitation. The students meet three times per PBL cycle with self-study/research taking place in between meetings. At the end of the day, the groups synthesize their research results and share them with the entire class. The shortened PBL cycle of this model is to provide more structures for students' learning since this student population is considered less mature and capable of solving problem independently (Rotgans et al. 2011).

As Hung and Loyens (2012) pointed out, the education system of the country as well as the cultural practices explicitly or implicitly shapes the way PBL is implemented in different cultural contexts. Therefore, implementing PBL in a setting that is different from the original PBL context (where the pure PBL model was conceived) in terms of learner characteristics, educational system, or cultural practices without carefully evaluating the difference and making appropriate adaptations could decrease the effectiveness of PBL. Also, tutors' facilitation style or the students' expectation of receiving direction from tutors may be implicitly influenced by culture. When implementing PBL in a cultural context where authoritative teaching style is the traditional cultural practice, a plan for transition for both tutors and students needs to be part of the curriculum design. Localizing the PBL implementation is necessary to make students' learning effective (Hallinger and Lu 2012) or even to make the adoption possible. For example, the "one day, one problem" model may not work well in some other cultural contexts such as the United States where some students deemed continuous repetitive cycles throughout a semester as an undesirable learning format (Hung et al. 2013).

Researchers may be interested in investigating issues such as what aspects of PBL need to be adjusted to meet the requirements of the education system of the country or the cultural practice, what kinds of issues there might be when implementing PBL in a new cultural context, and what issues there might be in terms of students' ways of learning and study style. These are a few examples that PBL educators may need to take into account when implementing PBL in a new cultural environment.

Curriculum and Problem Design

When PBL is employed for a given learner group and a given context, the first and foremost important implementation consideration is curriculum and problem design (Trafton and Midgett 2001; Duch 2001; Dolmans et al. 1993; Jacobs et al. 2003; Nasr and Ramadan 2008; Wells et al. 2009). Hung (2006, 2009, 2011) has discussed the effects of problem design in influencing students' learning in PBL environments. Problems are the center of PBL. In PBL, all learning activities and processes start with and evolve around the problems that students are required to solve. Thus, the PBL problems are not only the instruction of PBL curriculum but also the structure of the curriculum. Hung (2006, 2009) has proposed a 3C3R model and 9-step PBL problem design process to help PBL educators and instructional designers craft the critical components (i.e., content, context, connection, researching, reasoning, and reflecting) in PBL problems that could affect students' learning cognitively and, in turn, their learning outcomes. Furthermore, the relationship between psychological and affective effects of PBL problems and the students' sense of ownership of the problem (Hung and Holen 2011) and students' motivation to solve the problem have been observed and studied (Ak et al. under review). The design of psychological and affective aspects of PBL problems is especially critical when implementing PBL in a new cultural context for the students to be able to relate to the problem. Also, localizing the problems could eliminate a number of affective and cultural barriers during the students' learning as Hallinger and Lu (2012) discovered.

Group Processing (Group Learning) – Collective Cognition

Group processing is a research topic that has been researched since the early stages of PBL development (Albanese and Mitchell 1993; Hung et al. 2008). As opposed to individual learning as a normal form of learning in traditional instructional methods, PBL employs a small-group learning format to provide students with a collaborative learning environment. In this environment, students solve problems and study the content knowledge in a collaborative and sometimes collective way. However, when the format of learning shifts from individual based to group based, a number of issues emerge, for example, personal conflict (Azer 2001), uneven contributions from the members (Wells et al. 2009), or domineering or passive participatory styles. These issues have been observed, reported, analyzed, and categorized as primary factors for causing dysfunctional group processing in PBL. Yet, while these issues have not been satisfactorily resolved by the interventions proposed and studied by PBL researchers, another issue related to group processing may warrant attention. That is, Hung (2013b) argued that when group members work seamlessly as a learning system (or cognitive system), the group members (students) will benefit not only from their individual learning and their members' knowledge but also from the group's collective learning ability. In other words, the learning power from a group that can learn collectively is greater than from a group of members who can learn individually. Thus, how to help students to work collectively and develop their group/team cognition that can transcend their learning to another level is an uncharted territory for PBL research. Moreover, the tutor is an important role in the group processing and learning in PBL. However, different from a typical team-based problem-solving process, tutors do not assume the role of leader but a role of advisor/consultant. Also, to effectively facilitate the group, the tutor needs to be part of the group cognition. Therefore, team-based problem-solving and learning infuse a whole new perspective for the tutors to re-conceptualize what the necessary characteristics, abilities, skills, tasks, and responsibilities of an effective tutor are in this team-based learning system.

Learning Technology and Cognitive Tools

Traditionally, the facilitation of students' learning in PBL mainly relies on the instructor (or facilitators). Though the functions of facilitators are important and indispensable, the facilitation from the instructor alone may not be sufficient for all learning objectives. Some external tools may be needed for providing students with additional cognitive support during their learning process where the functions of facilitators may fall short. Still in its infancy, some PBL implementations have started to experiment with utilizing concept mapping to facilitate students' problem conceptualization during the PBL process (e.g., Eitel and Steiner 1999; Hsu 2004; Tseng et al. 2011; Zwaal and Otting 2012). Hung (2013a) also suggested other external cognitive tools that could help students conceptualize problems and organize their knowledge not only with a problem/case-based structure but also with the underlying mechanism that explains how every variable works individually as well as collectively so that the students have a deeper understanding about the topic. These tools include influence diagrams and system modeling. The main functions of these cognitive tools are to help students externally represent (1) the most critical variables/components in the problems, (2) the relationships between and among the related variables, and (3) the underlying mechanism that explains how the system works. When students are engaged in these problem representation construction processes, these tools provide a natural and nonintrusive form of facilitation in their cognitive processing process, which in turn enhances their learning outcomes. While the effects of utilizing external cognitive tools to facilitate students' problem-solving processes and conceptualization of the problem and the domain knowledge are promising, the role of facilitator may need to be re-conceptualized in terms of (1) what types of skills do facilitators need in order to optimize the effects of these cognitive tools in enhancing students' learning outcomes and (2) what is the relationship between the students, facilitators, and the cognitive tools in students' learning process.

Conclusion

PBL is an instructional method deemed innovative even after four decades of implementation. It is built upon a solid foundation of contemporary learning theories and educational psychology to amend students' problems, such as application and transfer of knowledge, independent problem-solving abilities, and lifelong learning skills. Vast bodies of research have shown the merits of PBL in helping students acquire these biologically primary abilities. However, PBL is not a panacea for all instructional needs nor is it without implementation issues. New issues emerge at different stages of PBL's development, which make this instructional method lively and interesting. Through continuing research and searching for interventions to alleviate the issues that have emerged, continuing improvement of students' learning is promised.

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Chapter 6
Using Problems to Learn in a Polytechnic Context

Karen Goh, Violet Chan, Mae Lee, and Glen O'Grady

Abstract This chapter examines the relationship between problems and learning in a problem-based learning (PBL) environment using the context of a case study of a polytechnic in Singapore. The authors detail how curriculum is problematised (into different types of problems) around a set of desired educational outcomes and explicate how problems are used for the purpose of triggering interest and engagement, as well as promoting deep understanding, guiding classroom facilitation and informing student assessment in the learning process. Empirical evidence of the effectiveness of problems in learning in three disciplines is shared, with suggestions of how the use of problems in learning can be supported by academic policies and professional development for academic staff. An overarching theme of the chapter focuses on how PBL is a method for learning that facilitates deep learning and develops life skills such as collaboration, sense-making and problem-solving capabilities for the work place.

Keywords PBL curriculum • Problem design • Situational interest • Authentic learning • Workplace learning

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Introduction

The practice of problem-based learning (PBL) to promote constructivist, collaborative and self-directed learning has been a growing feature of institutions of higher learning for over 40 years (Schmidt 1993; Schwartz et al. 2001) As a pedagogical strategy, its close affiliation with workplace and interdisciplinary learning (Boud 1985) contributed to its increasing popularity outside the traditional realm of clinical education in applied disciplines such as health sciences, information technology, business studies and engineering. The more recent trend of adopting PBL in technical and vocational settings to organise and deliver content supports a global, postindustrial and knowledge-driven society where graduates in emerging industries and new professions are expected to be problem-solvers and collaborators in a highly complex workforce (Low et al. 1991; Yip et al. 1997). Set against this economic backdrop, the transition from the paradigm of a skilled workforce to human capital potential necessitated educational reform in Singapore in order to keep up with the changing profile of the twenty-first century professional.

Polytechnics became ideal sites to enact pedagogical change. The unique place of polytechnics in Singapore's educational tertiary landscape was reinforced by Dr Ng Eng Hen, then Education Minister, when he cited the 'hallmark of Singapore's polytechnic education' as 'its responsiveness to the changing needs of industry' and explained that it will continue to be relevant for the next two decades because of the 'pace of disruptive technology' ('Polytechnic education' 2010). Singapore's newest polytechnic – Republic Polytechnic – was well positioned to adopt a problem-driven pedagogical framework to support its practice-based educational system to prepare learners for new technologies as well as new forms of knowledge and professionalism.

This chapter describes the rationale behind the implementation of a problem-based curriculum and learning system at Republic Polytechnic in response to the desired goals of postsecondary education and details its support mechanisms that contribute toward creating and sustaining an organisational culture of problem-solving. Problem samples from the fields of applied science, engineering and information technology are shared to illustrate how the characteristics of effective problem design are applied to help learners relate to industry contexts and make sense of content in more authentic and engaging ways.

Desired Outcomes of Polytechnic Education in Singapore

The polytechnic agenda in Singapore serves a key economic function in preparing diploma-level graduates to work in expanding professional, technical and service-oriented sectors as well as for further and continuing education (Chan 2008, p.138) to ensure their sustained employability. With the expansion of the polytechnic sector beyond preparing a skilled workforce to responding to more 'white-collar' aspirations (Low et al. 1991, p.108) and new forms of 'professional specialisms' arising from scientific and technological advancements (Hoyle and Wallace 2005, p.97), polytechnic education is increasingly seen as a viable pathway that opens doors to attractive employment opportunities as middle-level professionals and technologists through offerings of a wide range of practice-oriented courses in traditional and emerging industries. This was recently echoed by Singapore's Education Minister, Heng Swee Keat (Toh 2012), who cited higher gross monthly salaries and greater employability – with 9 in 10 polytechnic graduates securing jobs within 6 months of graduating (Joint-Polytechnic GES Committee 2011) – as evidence that polytechnic graduates have bright career prospects.

The emphasis on preparing polytechnic graduates for a knowledge-driven economy and lifelong learning society means that students must be equipped with relevant specialised knowledge, skills and professional aptitude. This translates into a need for an educational experience that aligns with evolving industry practices and responds to 'the increasing speed with which knowledge is applied to practice' (Field 2006, p.23) as students interact with new forms of knowledge and innovation.

Case Study of Republic Polytechnic

In response to the desired outcomes of polytechnic education, Republic Polytechnic embarked on an educational mission to develop practice-oriented and knowledgeable middle-level professionals who can respond to a highly technological society (Alwis and O'Grady 2002). Its core feature of using problems as triggers for learning stemmed from recognising the value of deep learning, applying content understanding to novel situations (Ramsden 2003), activating individual and collective prior knowledge (Barrows and Tamblyn 1980), engaging in peer learning through small group discussions (Barrows 1992) and including more authentic assessment and reflective practices (Harvey and Norman 2007; Woods 1994). This robust learning experience will lead to transformative learning where students 'develop understandings of themselves and their contexts, and the ways and situations in which they learn effectively' (Savin-Baden 2000, p.9). Hence, PBL as an educational strategy provided the polytechnic with a framework to design a coherent curriculum, teaching and assessment structure that could support a new generation of learners to be inquiring, self-directed, collaborative and ready for the complex realities of the world.

As Singapore's newest polytechnic, Republic Polytechnic was constituted in 2002 with the mandate to radicalise technical education beyond a utilitarian function (Le Vasan et al. 2006, p.26), using a unique implementation of PBL characterised by organising a module consisting of a set of problems crafted around specific and interdisciplinary concepts and objectives, with each problem worked on by small student teams and guided by a staff facilitator (Alwis and O'Grady 2002). This framework forms the core organising principle for designing curriculum, conducting assessment and delivering lessons at the institution across all diploma programmes and years of study. Its well-defined procedure of structured meetings interspersed with independent study periods (see Appendix A) was designed specifically to cater to its student profile by offering clear educational signposts through an iterative curricula structure and help effect positive change on students' self-esteem and learning dispositions (Le Vasan et al. 2006, p.28) through small group discussions that are facilitated by a faculty member.

The institution has a current student population of over 14,000 students enrolled in 37 full-time diploma courses; this is supported by a full-time teaching faculty of over 600 and a pool of academic associates. All new academic staff members are required to complete an in-house academic development programme, with full-time faculty members working toward the Certificate in Facilitation and Certificate in Problem Crafting – two institutional milestone programmes launched in 2003 and 2006, respectively, with the aim of systematically describing, developing and evaluating PBL practices in teaching and curriculum design using an evidence-based approach.

The institutional commitment to a learning experience that is authentic, engaging and relevant is supported by an investment in a staff professional development framework that actively promotes industry attachments, pedagogical content and skills development, reflective practice and coaching in order to develop faculty expertise in both designing authentic problem packages and teaching them effectively so that learners become critically engaged knowledge creators and collaborators.

Supporting a PBL Culture

The shift toward learner-centred models of teaching and learning like PBL means different roles in engaging with knowledge. While students take on new roles as knowledge collaborators rather than knowledge receivers, teachers assume new roles as facilitators of learning as opposed to knowledge transmitters. Effective facilitators guide learners in actively constructing knowledge in collaborative, self-directed and critically reflective ways (von Glasersfeld 1996) and help new learners adapt to their environment by designing learning contexts that validate meaning through transactional dialogue (Savin-Baden 2000) and social negotiation (Savery and Duffy 1998); they also promote safety in collaborative learning by cultivating healthy group dynamics (Bligh 2002; Lee and Tan 2004). Rotgans and Schmidt's (2011a) study of PBL in a polytechnic context also highlights the value of cognitive congruence in teachers as a significant predictor of situational interest in students in active-learning classrooms.

In the case of Republic Polytechnic, which has infused PBL into its learning culture, there are further challenges in professional development that go deeper than merely familiarising staff with academic procedures and teaching skills. From the experiences of faculties and institutions that have introduced PBL to their curriculum, the issues of advocacy and 'buy-in' are especially pertinent in convincing staff of the merits of this learning approach (Prideaux et al. 2001); furthermore, there must be a strong organisational culture and leadership that supports a PBL curricula (Schor 2001), together with sound administrative and departmental planning, support and coordination (Blue 2001). Researchers in the area of PBL staff development (Kolmos 2002; Savin-Baden 2003) are critical of atomistic training models that are inadequate in supporting the learning needs of these teachers and highlight the need for constant dialogue about educational issues, staff concerns and reflection in inducting staff to a PBL culture (Allen et al. 2001; Miflin and Price 2001; Taylor 2001).

These research findings reinforce the importance of a systemic educational approach to achieving 'pedagogical, professional and institutional congruence' between principles and practice (Goh 2011, p.79). Creating an immersive culture necessitates a commitment to redesigning physical, social and cognitive learning spaces that encourage collaborative problem-solving and situating teacher education in authentic modes of learning so that the values associated with learning through problems can be enacted safely and effectively.

To engage students and staff in a culture of PBL, Republic Polytechnic designed a unique learning space, framework and initiatives which include customised skills development, PBL certificate programmes, reflective practice and continued engagement in industry. Key initiatives and relevant empirical findings of their effectiveness are shared in the following sections.

Learning Infrastructure

In successfully enacting a learning culture of collaborative problem-solving, the physical space is a critical element of the learning design framework. The 20-hectare green campus is purpose-built for a wireless and paperless environment where the open exchange of information is seamless. Each facilitation room caters to a class size of 25 students and a facilitator, with table clusters of five to promote small group discussion. The design overturns the paradigm of an authoritative space and places the ownership of learning on students.

Beyond the classroom spaces, learning is also contextualised in a myriad of discipline-driven laboratories and training facilities where simulations, workshops, on-the-job training and specialised skills development take place. Such learning sites encourage authentic and innovative ways to engage with curriculum as they replicate workplace learning and create a culture of interdisciplinary and interprofessional collaboration (Billett 2002; Lave and Wenger 1991).

Learning Framework for Students

The academic framework was conceptualised and designed to provide a holistic learning experience that would nurture students to be inquiring, inquisitive, socially responsible and professionally prepared for industry and life. Creating such an experience required a commitment to engineering a curriculum, teaching and learning framework that encouraged, sustained and regularly assessed these desired learning outcomes so that a habitual culture of problem-solving could be engendered. This enculturation process is achieved through a learning structure where students engage in problem analysis and self-directed learning, report their responses or solutions for critique and are assessed within a day (see Appendix A).

Findings from empirical studies examining the effectiveness of this learning process (Yew and Schmidt 2012) reveal that the iteration of concepts through discussions, research conducted during the self-directed learning phase and the verbalisation of ideas and issues during the problem analysis stage influence students' learning achievements. In particular, the verbal sense-making phase of engaging with a problem (at both a class and group level) has a direct effect on students' learning results. Hence, opportunities must be created for individuals to verbalise their prior knowledge, conceptual understanding and positions; facilitators necessarily also play a critical role in creating these opportunities and providing appropriate scaffolds to support students' learning and sustain situational interest (Rotgans and Schmidt 2011b). This structured learning process has a pervasive effect on increasing students' confidence to articulate their views and accumulate content knowledge over time. In addition, other learning opportunities such as workshops, seminars, internships and project work provide variation to the structured learning norm so that the application of knowledge and industry exposure is constantly occurring.

Faculty Development Initiatives

An in-house PBL academic framework supports academic staff in designing and delivering a problem-driven curriculum through a range of activities, such as workshops on designing problems and facilitating learning, consultancies, coaching and two certificate programmes in facilitation and problem crafting. Insights from researchers in the area of PBL staff development (Kolmos 2002; Little 1991; Savin-Baden 2003) reveal a need for critical reflection, role modelling and metacognition to be built into learning activities so that knowledge, skills and experiences are overtly raised, transferred and applied.

The certificate programmes, in particular, provide important empirical data about the attributes and practices of effective facilitators and problem crafters, which in turn influence training and consultancy approaches and shape the standards of PBL staff competencies. Data collected from certification portfolios, interviews and feedback letters have been instrumental in making explicit the characteristics, expectations and exemplars of good PBL practices through critical reflection and evidence from student learning artefacts. In addition, certified staff members take on roles as peer coaches and mentors to support their own faculty in developing the necessary competencies to enable their students to learn well; outstanding facilitators and specialist problem crafters are highlighted as role models and engaged as peer reviewers to support the certificate programmes. In this way, a community of PBL practitioners is created and sustained.

Organisational Commitment

Last but not least, organisational commitment and institutional leadership are essential to supporting and sustaining a PBL culture. Managing issues of advocacy, endorsement from stakeholders and public perceptions about the quality of learning and learners is important in sending positive signals to existing and potential students, staff, industry partners and parents that learning through problems is a viable and effective method of learning that prepares graduates for lifelong learning and lifetime employability. While the alignment of curriculum, assessment and teaching strategies presents one arm of a transformative learning experience, organisational management presents another arm of systemic change where a long-term 're-educative' strategy (de Graaff and Kolmos 2007, p.36) creates conditions for growth and recognises the importance of human values and attitudes in shaping the identity of the institution.

The polytechnic's strategy in human resource development and institutional branding is investing in people and promoting the values of a problem-driven culture. This is achieved through a strong commitment to professional development – from a structured academic roadmap, recognition of certified staff, membership schemes in professional bodies, and continuous educational research to opportunities for industry attachments, these serve to keep staff updated and engaged so that they can design relevant problem contexts and projects that support authentic learning. The values of problem-solving and innovation are also publicly encapsulated in the institution's mission statement and communicated through its outreach programmes. In 2012, Republic Polytechnic launched the PBL Institute to strategically position itself as a PBL training and research facility and strengthen its outreach arm in the region. In that same year, a collection of research studies was published in a book, *One-day, one-problem: an approach to problem-based learning* (O'Grady et al. 2012), to evaluate the efficacy of the institution's PBL practices in the areas of learning, assessment, problem design and professional development.

Learning through problems as a pedagogical strategy must therefore be supported at an organisational level for it to be effective and pervasive. From the physical design to learning frameworks and capability development, an integrated approach promotes congruence and greater buy-in, thereby increasing confidence among students, staff and industry stakeholders.

The Role of Problems in Learning

With the polytechnic mandate that graduates must possess relevant knowledge, skills and professional aptitude for a knowledge- and innovation-driven environment, the broad programme structure of each diploma is shaped by mapping industry requirements and professional practice with key graduate competencies. By envisaging current and future professional roles and environmental trends, programme leaders are responsible for positioning learning goals and graduate profiles that create a unique value proposition for future employment and further education for their graduates. Broad diploma-level objectives are cascaded down to smaller module units organised around general, disciplinary and specialised knowledge tiers. Curriculum linkages are then built, and teaching and learning strategies are formulated to develop the necessary competencies.

The problem-driven curricula in these modules are designed to provide learners access points to activate and connect prior knowledge with new ideas so that they develop cognitive and social habits of making decisions about ‘knowledge and knowing’ (Savin-Baden and Major 2004, p.36). Problems in PBL contextualise real-world issues and are typically a set of descriptions of phenomena or situations in need of explanations and resolution (Schmidt 1983). Problems can introduce different types of knowledge, such as procedural or explanatory knowledge (Schmidt and Moust 2000b), and may be presented in diverse forms such as case descriptions, study assignments and literary quotes (Moust et al. 2007). Decisions over the appropriate form and context of problems are often driven by knowledge of the industry and its intellectual and professional attributes, which in turn are translated into learning objectives and activities within a structured curriculum.

The problem-driven curriculum in the polytechnic is designed around a set of specific objectives derived from broader learning goals to help learners engage with relevant knowledge and skills and exercise intellectual flexibility in problem-solving in different contexts. Learners typically focus on a problem for one module in a daily structure of learning activities, beginning with identifying learning issues from a problem trigger, working both collaboratively and independently to formulate an informed analysis and resolution of the given phenomena or situation and then proposing and defending their response at a peer review level (see Appendix A). This problem inquiry process that the learners enact creates what Lipman (2003) describes as an aberration or discrepancy in what we encounter, which then captures our attention and demands our reflection and investigation. As learners explore the ideas within the context of the problem, integrate them with prior knowledge and navigate discussions with teammates, they become engaged and interested in seeking a resolution, thus encouraging other behaviours such as collaborative work and self-directed learning (Hmelo-Silver 2004).

Sockalingam and Schmidt (2010) argue that in certain contexts, the quality of problems plays a more significant role in influencing students’ learning than their prior knowledge and the facilitator’s function. They identify 11 characteristics of effective problems which are classified into ‘features’ and ‘functions’: ‘features’ of the problems refer to characteristics that are *design elements* of the problems, such as problem format, clarity, familiarity, difficulty and relevance, while ‘function’ characteristics refer to the *potential outcomes of engaging with the problem* and describe the extent to which the problem stimulates critical reasoning, promotes self-directed learning, stimulates elaboration, promotes teamwork, stimulates interest and leads to the intended learning issues. Problem designers use this framework to craft problems that appeal to learners in terms of its features and accessibility while ensuring that the problem is adequately scoped and structured to promote functional characteristics such as higher-order critical thinking and social negotiation and engagement.

With the problem playing such a pivotal role in driving learning, it is essential that problems are carefully designed to be both interesting and useful to learners (Khoo 2003). Good problems should be complex enough to promote flexible thinking as well as motivate the intrinsic need to learn (Hmelo-Silver 2004); yet they should remain accessible so that learners are not navigating in the dark and are empowered to make choices about relevant information and construct cogent arguments for the positions they take on issues and tasks. In Rotgans and Schmidt's study on situational interest in the PBL classroom (2011b), they define situational interest as the interest aroused in the moment by environmental stimuli such as the problem or facilitator discussing an intriguing phenomenon. Their findings suggest that the PBL classroom provides an ideal site for learners to engage in active learning, which leads to deeper processing of information and eventually better academic performance. A high premium is placed on the problem trigger which influences interest and shapes information-seeking behaviour. When designed to be interesting and appealing to learners, the problem can motivate them to be more self-directed in their learning and engage them in interpreting, analysing and resolving the problem with their peers.

These attributes of a good problem are incorporated into the Certificate in Problem Crafting programme, where candidates who are engaged in designing problems submit a portfolio of problem samples accompanied with a critique and evidence of student assessment outcomes for evaluation. The portfolio is peer-reviewed by an in-house panel of educators and disciplinary experts; this is accompanied by an interview with the candidate, which allows for a robust discussion of the problem design process, strengths and limitations of the lesson scaffolds, as well as opportunities for critical reflection and feedback from the panel to improve practice. The evidence-driven focus of the certification process is critical in engaging problem designers at the polytechnic in examining the efficacy of problems in shaping specific conceptual outcomes and skills through corroborating curriculum intentions with student performance in formative and summative assessments.

Designing Authentic and Engaging Problems

While there are different problem types and formats in PBL curricula (Dolmans and Snellen-Balendong 2000; Schmidt and Moust 2000b), Dolmans et al. (1997) highlight the simulation of real-life scenarios as one of the seven principles of problem design, arguing that they require learners to employ a myriad of critical thinking and information-processing skills in searching for, interpreting, analysing and evaluating resources and ideas. Problems which use real-world contexts also present opportunities for generating more than one plausible solution or pathway of inquiry and promote applied and interdisciplinary learning, since concepts, resources and tools are drawn from various fields.

To illustrate some of these characteristics of effective problems that leverage authentic and application-based scenarios and activities to engage learners, this section presents and analyses three problem samples from the fields of applied science, engineering and information technology – these samples have been identified as exemplary problems by the Certificate in Problem Crafting panel for their effectiveness in motivating students to learn and apply new concepts, engaging and sustaining their interest and developing their critical and collaborative skills. They are pitched at a conceptually and contextually accessible level that allows sufficient familiarity of ideas for students to relate relevant prior knowledge, yet are appropriately challenging to introduce new concepts to deepen understanding and reasoning.

Materials Science Module – A Problem on Polymer and Composite Science

In the study of materials science, learners need to delve into the exploration of how the structure of material affects its properties and performance. One of the learning requirements is developing learners' ability to address how various types of materials behave in different applications. The seriousness of this field of study cannot be overemphasised when one analyses the impact of its real-life application.

The problem trigger uses a case description format as its problem type by relating a real incident that took place in 2005 when the aircraft rudder of an Airbus A310 – a structure 28 ft high – fell into the sea. At 35,000 ft and carrying 270 passengers and crew members, such an incident spells of a near catastrophe. Faced with this dramatic yet plausible scenario, learners are expected to investigate the causes behind the aircraft rudder failing in midair. Through a process of inquiry and examining relevant resources, they learn that the properties of materials can change when exposed to environmental factors such as temperature changes, moisture and ultraviolet light exposure; they are also reminded of the potentially dire consequences of material failure and the importance of failure prevention. This motivates them to propose measures to prevent similar incidents in the future.

The problem is crafted in such a way that learners have to recall and identify links between concepts like 'thermal expansion' and 'addition polymerization' learnt in previous modules. In addition, new concepts that build on these concepts are introduced, such as 'photooxidation reaction', which builds upon an earlier concept of 'addition polymerization'. To scaffold the students' investigation of the mystery of the falling airbus rudder, they are given a news resource that provided background information such as the materials used in the rudder, the kind of environmental conditions the aircraft may be exposed to and the type of inspection performed. In addition, there are also experts' commentaries on what they thought might be contributing factors to the failure. These form the essential content cues and parameters for learners to begin their investigative work and research and explore the information and evidence given to find a sound resolution to the problem and support their proposed strategies.

Learning in the context of a real-life incident motivates learners to move beyond rote learning of the technical effects of temperature, moisture and photooxidation on composites; it also develops their ability to critically examine the varying effects of environmental factors on materials in different settings. Facilitators teaching this lesson observed that the problem stimulated interest because of its real context and the space provided for learners to make critical decisions about safety; they observed that learners went beyond what was covered in the scaffolding questions provided and were resourceful in finding relevant information that helped them suggest performing nondestructive testing techniques like ultrasonic testing to address the problem.

Manufacturing Planning and Control Module – A Problem on Production Cost Optimisation

Students learning about manufacturing and control benefit from a hands-on approach in solving a problem set in a real context of a toy manufacturing company. The problem requires them to adopt the role of a professional in their industry to manage the production line of the toys, from ordering raw materials from the supplier, assembling them from various subassemblies to the final assembly and forming the final product. A manufacturing process flow is provided as a structural guide, together with specific information on each step of the process and its corresponding cost. Students are expected to order the raw materials required for five products and assemble them with the objective of minimising the ordering, materials and holding costs. This problem requires them to describe key manufacturing concepts, explain decisions undertaken by a manufacturing plant and formulate strategies to minimise total production cost.

Manufacturing is a largely unfamiliar area for polytechnic students who have little work experience, and merely reading resources and learning the theoretical framework for manufacturing operations have their limitations. With this problem, students are encouraged to provide deeper consideration of the goals, activities and decisions in a manufacturing plant by visualising a real manufacturing operation. To increase the realism of the setting, an activity was designed so that everyone in the class can participate in one of the roles within a typical manufacturing operation. Each team member is given a specific role, from raw material order planning, subassembly, final assembly, to quality control, and he or she will experience what it is like to be part of a manufacturing plant and understand how each process is linked, thus enabling students to plan and make better decisions to achieve a smoother and more profitable operation – this requires them to propose and evaluate suitable strategies. In doing so, they gain fresh insights into the challenges in the operations of a manufacturing plant and are more prepared to anticipate what should be done to make the plant successful.

Students shared that they appreciated how the contextualisation and visualisation of the problem allowed them to access the unfamiliar manufacturing world – this feedback prompted a review of the lesson to incorporate an actual site visit to a manufacturing plant in subsequent runs of the lesson. With an understanding of the broad ideas of manufacturing and the planning and control activities involved in a manufacturing plant, students were more confident in tackling subsequent problems in the module.

Programming Module – A Problem on Introductory Programming

The infocomm technology industry is a rapidly growing field that is marked by fast-moving changes. Fuelled by globalisation and rapid technological advancements, the industry constantly seeks forward-looking employees who are able to fulfil the core competencies of programming, as well as demonstrate analytical, problem-solving, collaboration and communication abilities. Premised on the belief that learning can take place most effectively when learners are active in creating tangible objects in the real world, each problem in the introductory programming module is crafted to maximise students' engagement, with the explicit intent of creating tangible outputs such as text-based games, drawings or utility programmes.

One problem requires students to script a python programme to create a drawing using simple shapes such as squares, circles and triangles. They are required to create a similar drawing as shown in Fig. 6.1. By asking students to draw a picture

Fig. 6.1 Drawing created using simple shapes

composed of repetitive shapes with distinct differences in colour and dimension, students are prompted to break down what they see and observe similar patterns and differences. This problem places equal importance on the understanding of concepts such as repetition and generalisation, as well as deriving a workable solution. It is designed to allow them the opportunity to propose ways of leveraging the similarities in shapes to simplify the task (Fig. 6.1).

Beyond mastering the technical skills of writing codes and familiarising themselves with the syntax of writing generic functions using the python programming language, there is a higher cognitive goal where students are expected to break down a problem into smaller parts and formulate a plan before writing the code for their design. This problem also allows students the opportunity to collaborate in teams, thereby achieving the secondary learning objectives of planning, communication and teamwork. Students recognise the value of collaboration when they realise the problem cannot be solved through a ‘divide and conquer’ method; instead, students need to plan a sound approach and agree on the dimensions of all the objects before writing the code so that they do not end up with disproportionate dimensions.

Students who experienced this lesson shared that they enjoyed the creative and cognitive space offered by the problem; they felt empowered by the choices and decisions they could make; they also had a tangible task to work toward and could visualise the scripting output better. In the process, they also had fun learning the more technical aspects of programming.

The Challenges of Designing Effective Problems

As illustrated by the examples above, the problem design process places an emphasis on how conceptual gaps between experts and novices are bridged and the interpretive process involved in sense-making (Brockbank and McGill 1998). Problem designers face the challenge of organising their vast disciplinary knowledge and experience into scenarios, analogies and situations that allow cognitive room for students to activate prior knowledge, scope learning issues, extrapolate and abstract meaning and engage in a purposeful problem-solving process. This process can be enacted in a number of ways, such as through an experiment, research, simulation, practice or discussion, and it is usually through a thoughtful combination of activities that guide the inquiry process from initial cognitive dissonance (Festinger 1957) to the lesson’s intended outcomes. Feedback letters to candidates from the Certificate in Problem Crafting programme reveal that effective problem designers are able to anticipate learning obstacles (in the form of knowledge gaps, possible misconceptions or technical unfamiliarity) students might face and thus design the necessary resources, activities and prompts to support these learning transitions, create room for conceptual transfer and application and incorporate cognitive development such as analytical reasoning and critical reflection in the lesson sequencing.

Learning Through Problems – What Students Say

The student experience of learning through problems provides important insights into the efficacy of this pedagogical approach and how effective problems should be designed. An online survey is administered to all students once a semester to collect data on their learning experiences. This survey includes a section on module feedback that provides an indicator of students' overall perception of a module that typically comprises a set of fifteen problems as its curricular structure. The survey instrument measures students' perceptions of the value of learning and quality of curriculum (problem quality and learning resources). It comprises two parts: the first part involves 14 Likert-type items along a 5-point scale, and the second part features two open-ended questions (see Appendix B).

Module data for Academic Year 2012 Semester 1 are reported and analysed in this chapter. A total of 209 modules were evaluated at a response rate of 94 %, with an institutional mean of 3.84 from a maximum score of 5. Of these modules, 96.7 % achieved or exceeded the institutional target of 3.5. To investigate the problem design qualities that students seem to favour in helping them learn, four of the highest-rated modules across four diploma programmes are selected and analysed further. These modules – from diploma programmes in the fields of hospitality and wellness, aircraft and aerospace engineering, pharmaceuticals and outdoor leadership – offer a disciplinary spectrum of the range of applied courses offered at the polytechnic, with some of these modules taking place in laboratories and simulated spaces to mirror work environments. A quantitative summary of the student feedback results focusing on the perceived value of learning and the perceived quality of curriculum for these four modules are summarised in the table below (Table 6.1).

Analysis of the students' response ($n = 135$) to the first open-ended question ('What did you enjoy most about the module?') reveals recurring themes which were coded into these categories – 'practical/real', 'relevant to future/useful', 'interesting/enhances learning' and 'engaging learning process/environment' (Table 6.2).

These themes resonate with the characteristics of effective problems in that students are engaged in learning when they can draw links between abstract concepts and professional practice and classroom and life. Furthermore, students indicated that they remembered theories better this way, such as carrying out mathematical calculations for drug administration, enacting leadership principles in context and receiving immediate feedback on skills application. One student commented on the value of opportunities for practice during the lesson: 'What I enjoyed most about this module is that there are a lot of hands-on activities that allow us to understand what is expected of us when we become a licensed [practitioner] in the future'. Another student highlighted how technical calculations were made more interesting as 'questions are different all the time and really allow us to use the various formulas or methods that we have learnt to get the answer'. The

Table 6.1 Quantitative results of student feedback for modules with highest rating

Module type	*N*	Perceived value of learning	Perceived quality of curriculum	Module rating mean
Hospitality and wellness	32	4.6[a]	4.09	4.35
Aircraft and aerospace engineering	47	4.48	3.96	4.22
Pharmaceuticals	89	4.38	3.97	4.17
Outdoor leadership	49	4.42	3.89	4.15
Institution	*15,658*	*4.01*	*3.67*	*3.84*

[a] The survey was designed along a 5-point scale, anchored at 1, strongly disagree and 5, strongly agree.

Table 6.2 Qualitative results of student feedback for modules with highest rating

Themes	%
Practical/real	70.3
Relevant to future/useful	35.5
Interesting/enhances learning	45.1
Engaging learning process/environment	23.7

$n = 135$

space to reason and deepen conceptual understanding in a peer setting was also shared by a student: 'Looking from different perspectives, enabling me to understand why and what, also to tackle problem with the strategies and models taught. In this module, it helps to build the many 'grey' areas [and] reasoning out the understanding of responses'.

Students also recognised that the assessment of their learning was more authentic when they were given opportunities to verbalise their ideas and work collaboratively and individually to demonstrate their understanding. They cited the use of examples provided through worksheets, the diversity of resources such as videos, working templates and laboratory tools and their facilitators' professional experiences as useful scaffolds to develop a deeper understanding and application of new concepts to other modules and real life. The qualitative data also showed that the perceived usefulness of the course increased when facilitators were cognitively congruent or able to express ideas in ways that students can comprehend and socially congruent or able to relate to students' challenges (Schmidt and Moust 2000a), thereby helping students make these connections through providing examples, explanations and opportunities for clarification, sense-making and participation.

'Interest' is a key indicator of student engagement, with students commenting on the problem scenarios, learning activities and tasks provided in the problem packages as critical determinants of their interest in the module. Research on situational interest (Hidi and Renninger 2006; Schraw and Lehman 2001) shows that the learning environment enacted through mental and social activities has a significant effect on how students learn. In a PBL classroom, the learning stimulus is often presented as a problem trigger that presents a puzzling situation or a challenge that arouses curiosity, creates cognitive dissonance (Festinger 1957) and provides an intellectual space for students to navigate as they make choices, conduct research and formulate responses. Findings from Rotgans and Schmidt's (2011b) studies on situational interest in a polytechnic classroom reveal that situational interest increases significantly after the problem is presented and that a socially and cognitively congruent facilitator is a significant factor in predicting students' level of situational interest in the classroom. These findings resonate with the high facilitator ratings for the four modules. In other words, students see a direct correlation between their own interest in a course and how it is delivered through both its curriculum structure and facilitation approach.

The survey data provide important feedback for continued improvements to the PBL curriculum – specifically the design of problem triggers, scaffolds and resources – and inform professional development programmes so that students continue to have engaging, authentic and useful learning experiences. Problem crafting workshops and consultancies and the institutional practice of awarding the Certificate in Problem Crafting with its accompanying review and quality assurance processes are avenues to enable professional reflection and hone skills as a problem designer. Together with feedback from industry partners, problems are regularly refined so that they remain both accessible yet challenging to students and provide them with up-to-date knowledge, standards and norms.

Conclusion

The experience of Republic Polytechnic in using problems to learn is by no means accidental or experimental. The intentionality behind creating a physical, social, virtual and intellectual space to support and sustain a culture of authentic problem-solving is driven by a broader purpose of nurturing polytechnic graduates who can succeed in a highly complex and competitive world. Employer feedback of graduates has been positive, with many commending them for their willingness to take risks, innovate and work well with others – the twenty-first century work attributes that help graduates to be adaptable and forward-looking team players. These attributes are largely shaped by a problem-driven curricula and pedagogical method that provide continued opportunities for authentic learning, individualised feedback and critical and creative engagement with content.

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Appendix A: PBL Framework for Students

This table outlines the baseline PBL framework for students at Republic Polytechnic. There are slight variations to the structure depending on the nature of the module or discipline – for instance, lessons may be conducted in laboratories or studios, and skills development may be infused at various stages of the day – however, the key learning principles of student-centred learning and holistic assessment are adhered to.

Learning Phase	Learning outcomes and actions
Phase 1 *(guided by PBL facilitator)*	*Exploration of problem*: Students are presented with the problem trigger for the module. They activate their prior knowledge and raise learning issues to organise and scope the problem
Study period *(independent work)*	*Research and discussion*: Students carry out further research and examine resources and other forms of scaffolding to address learning issues and generate possible hypotheses
Phase 2 *(guided by PBL facilitator)*	*Strategy-formulation and meta-cognitive processing*: Students share their initial findings, ideas and learning obstacles and devise strategies to help them work more effectively on the problem
Study period *(independent work)*	*Consolidation of ideas/argument*: Students agree on a problem approach in their groups and consolidate their findings, arguments and rationale into a suitable presentation format
Phase 3 *(guided by PBL facilitator)*	*Presentation of solutions/defence and critique of argument*: Students present their group responses and have the opportunity to respond to questions and comments from their facilitator and peers. The facilitator presents a closing review
Assessment *(formative and summative)*	*Reflection journal, self and peer evaluation*: Students complete their individual and peer assessment and review their understanding of the day's content through a quiz. The facilitator makes a judgment about each student's quality of learning, provides individual and group feedback and assigns an individual grade based on three dimensions of learning observed throughout the day: attainment of knowledge and skills, engagement with knowledge and skills and engagement in collaborative learning

Appendix B: Student Feedback Survey – Module Section

*Part 1***.** The module rating section of the student feedback survey is designed along a 5-point scale, anchored at 1, strongly disagree, and 5, strongly agree. It provides an indicator of students' overall perception of the module in terms of its value to their learning as well as the quality of the problem and learning tasks and learning resources. It is obtained from the average score of the following survey items:

Constructs	Items in survey
Perceived value of learning	1. The module's objectives were clear to me
	2. The topics of this module seemed useful for my future professional practice
	3. The topics we addressed in this module were interesting
	4. In general, I enjoyed the module
	5. I have learnt many useful things in this module
Perceived quality of curriculum: problem quality	6. The problem triggers/learning tasks given to us were clear to me
	7. The problems/learning tasks sufficiently triggered thinking and/or discussion
	8. We were generally able to figure out what we could do next from the problem triggers/learning tasks presented to us
	9. The problems/learning tasks stimulated me to find out more on my own
	10. I had difficulties relating the problems/learning tasks to what I already know
Perceived quality of curriculum: quality of learning resources	11. The learning resources helped me to tackle the problems/learning tasks
	12. The learning resources (e.g. reading materials, software, equipment, apparatus) that I required for the problem/learning tasks were available adequately
	13. The learning resources were too difficult to understand, apply or operate
	14. The student presentations/demonstrations and 6th P for the day/learning block helped me better understand the relevant concepts/skills

Part 2. Open-ended questions

- What did you enjoy most about the module?
- In what ways can the module be improved?

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Chapter 7
Pedagogical Interfaces in a Problem-Based Learning Environment: Cognitive Functioning at PBL Stages

Bee Leng Chua, Woon Chia Liu, and Oon-Seng Tan

Abstract Problem-based learning (PBL) is an inquiry-based approach that is widely adopted by educators as it provides the platform for cognitive intervention for our learners. Embedded within PBL are cognitive activities that allow learners to develop their cognitive functioning. According to structural cognitive modifiability (SCM), humans have the propensity to change the structure of their cognitive functioning. Therefore, as educators, we have the potential to hone the cognitive functions of our learners by taking into consideration their mental processes and the learning environment. Within the context of PBL, it is important to be cognizant of the specific cognitive processes employed by the learners as they interact with the PBL environment with the aim of developing their cognitive functions. Grounded on SCM and Tan's (2000) cognitive function disc (CFD), this chapter proposes a framework of the cognitive and metacognitive requirements that are present at each PBL stage. The identification and mapping of prominent cognitive functions throughout the pedagogical stages of PBL can serve to advance classroom practices as it allows the usage of PBL schema as a scaffold for more mindful cognitive coaching within the PBL classroom.

Keywords Problem-based learning • Structural cognitive modifiability • Cognitive functions

Introduction

In preparation for the twenty-first-century workplace, education systems are faced with the challenge of preparing students for unpredictable changes in the economy. Singapore students must develop into technologically savvy, independent lifelong learners who are flexible in the face of changing job demands. Their ability to engage in lifelong learning would be based upon a strong foundation of knowledge

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and learning skills. The rapidly changing environment requires an inquiring, disciplined individual, who possesses the aptitude for critical and creative thinking, in addition to confidence in problem-solving.

The focus of education must shift from knowing to thinking, with a greater emphasis on actively involving students in the processes of meaning-making and knowledge construction. Students must be equipped with the cognitive attitudes and skills needed to approach new problems and acquire new knowledge (Jones and Jones 1992). As educators, we must understand that learning is an active process of exploration, adaptation, connection and integration, where new cognitive structures for new knowledge can be developed (Tan et al. 2005). We have the potential to hone the cognitive functions of our students by taking into consideration their mental processes and the learning environment.

In order to help students take greater ownership of their learning, and to become more cognizant of their cognitive and knowledge construction processes, teachers will need to model and reflect such practices. Thus, initial teacher education needs to expose preservice teachers to an inquiry-based approach like problem-based learning (PBL). PBL allows preservice teachers to enhance their thinking processes through exploring perspectives, questioning assumptions, looking for relationships and synthesising information. Immersing the preservice teachers in such learning environments would engage their cognitive functions and enhance their learning capabilities.

This is a conceptual paper that looks into the development of learners' cognitive functioning within a PBL environment. As a case of point, we will illustrate and describe an application of the proposed conceptual principles in the implementation of educational psychology course for preservice teachers at the National Institute of Education (NIE), Singapore. This chapter will first discuss the theory of structural cognitive modifiability (SCM) which posits the plasticity of intelligence and modifiability of human cognitive functions. Second, with the belief that learners' cognitive abilities can be enhanced by their learning environment, the schema of PBL and its characteristics at each PBL stage are next deliberated. Third, a conceptual framework based on Tan (2000)'s cognitive function disc (CFD) and the conceptual promises of PBL are developed to identify preservice teachers' cognitive functioning at each PBL stage. Lastly, implications for instructional design in terms of scaffolding learners' PBL and recommendations for future research are made.

Problem-Based Learning (PBL) and Teacher Education

Problem-based learning is an innovative pedagogical approach, whereby real-life problems (rather than direct instruction) are the focal points for learning (Boud and Feletti 1996). In PBL, learners are engaged in the active learning of content knowledge through problem-solving, which is usually under the guidance of instructors and facilitators. PBL is a pedagogical innovation that originated from the medical profession and involves learners working on authentic problems through an iterative cycle of collecting, connecting and communicating information.

In the 1950s, the Case Western Reserve Medical School and McMaster University Medical School presented problem scenarios in the form of patient cases to trigger their medical students' learning. Proponents of PBL in medical education contended that PBL's benefits included an early exposure to patients and clinical settings, a heightened self-generated motivation arising from the application of acquired knowledge and the acquisition of various learning skills, which assisted the medical students in becoming lifelong learners (Barrows and Tamblyn 1980; Kaufmann 1985). Other positive effects include greater knowledge retention, the acquisition of self-directed learning skills and greater motivation towards self-directed and collaborative learning (Albanese and Mitchell 1993; Wheeler et al. 2005).

The relevance of the approach and the realisation of the intended learner outcomes saw PBL move beyond medical schools and health professions in the 1990s and into other professional preparation programmes in the fields of political science, social work, education, architecture and business (Boud and Feletti 1997; Cordeiro and Campbell 1996). Within the local Singaporean context, the use of PBL as a pedagogical approach is also evident in the education scene. Polytechnics such as Temasek Polytechnic (Tan 2000) and Republic Polytechnic (O'Grady and Alwis 2002) that have strong links to industry have an established history of using PBL in their curriculum.

Considering the many similarities between medical and teacher education, and the success of PBL in medical education, PBL has been recognised as a viable pedagogy in initial teacher education (Iglesias 2002; Mcphee 2002). Adopting PBL within medical and teacher education allows educators to introduce a semblance of professional reality to the learners during their professional education studies. PBL pedagogies emphasise modelling of good practices, encourage reflective practice and place a greater focus on actual ground considerations and practical constraints (Graves 1990). As a constructivist, student-centred approach to learning, PBL is seen as a promising approach to nurture critical thinkers, effective problem-solvers, self-directed learners and reflective practitioners (Albanese and Mitchell 1993). Indeed, the PBL process of inquiry has been demonstrated to develop preservice teachers' thinking skills, problem-solving skills, analytical skills, information processing skills and self-directed learning skills (Etherington 2011; Koray et al. 2008; McPhee 2002). However, despite the interest in PBL in initial teacher education for over a decade (Iglesias 2002; Mcphee 2002), there are, to date, limited research studies conducted (Chua 2013) to examine the impact of PBL in initial teacher education.

Within the context of professional teacher education, PBL is deemed to be able to trigger the cognitive, reasoning, motivational and collaborative processes that are crucial in today's teaching and learning environment (Barrows and Myers 1993; Chrispeels and Martin 1998). The understanding and identification of the types of cognitive functioning associated with the various stages of the PBL environment is thus crucial for teacher educators to better understand how to enhance preservice teachers' mental and thinking processes for them to be self-directed learners, active collaborators and metacognitive reflective practitioners (Shulman and Shulman 2004).

Structural Cognitive Modifiability (SCM)

Researchers seeking to enhance the learner's ability and desire to learn need to consider this fundamental question: 'Can thinking be taught?' Jean Piaget, one of the pioneers of child psychology, posited that cognition development occurs when the learners actively interact with the environment. He advocated that a learner's cognition could be enhanced when he is exposed to appropriate stimuli for the stage of development he is at (Piaget 1952, 1959, 1970). Vygotsky also viewed learners as active constructors of knowledge. He suggested that learners first co-construct knowledge through socially meaningful interactions with people around them and then internalise it at an individual level (Vygotsky 1978). In other words, the learner's intelligence is conceptualised as a process entity rather than a state entity, which is affected by the environment which the learner is immersed in. Thus, exposure to problem-solving experiences is one of the approaches that can facilitate learners' cognitive development (Tan et al. 2005).

Riding on the work of Piaget and Vygotsky, Reuven Feuerstein was one of the pioneer cognitive psychologists in proposing an emphasis on targeting deficiencies in 'cognitive functions', to affect durable, long-term change. Feuerstein (1990) developed the theory of structural cognitive modifiability (SCM), which posits that humans have the propensity to change the structure of their cognitive functioning. He highlighted the importance of understanding specific cognitive functions and creating learning environments for mediating the development of these thinking functions. The changes brought about by these learning environments would go beyond content and skill changes and instead directly affect cognitive structures in a substantial and durable manner. Tan (2000) demonstrated that there were significant changes in polytechnic students' cognitive abilities after a cognitive modifiability intervention (CMI) programme. He developed the cognitive function disc (CFD) as a framework for identifying cognitive dysfunctions and the prerequisites of thinking so that educators can adopt SCM-based pedagogies to bring about cognitive modification. It is through these interactive approaches and cognitive activities that the learners gain awareness, cognition and metacognition to improve their cognitive functioning (Tan and Seng 2005). The development of these cognitive functions would facilitate learner's mental processes and facilitate the transfer of thinking, problem-solving and self-directed skills across learning contexts.

Cognitive and metacognitive processes pertaining to collecting, connecting and communicating information (Tan 2000) are especially important in PBL. Vermunt (1996) distinguishes between cognitive processing activities and metacognitive regulatory activities. Cognitive processing activities refer to the mental processes used to process learning content, for example, looking for relationships and generating and elaborating on ideas. Metacognitive regulation activities, on the other hand, are involved in the regulation of cognitive processing activities and hence indirectly contribute towards learning. Such activities involve monitoring whether the learning process proceeds as planned, diagnosing the cause of difficulties and adjusting the learning process as necessary.

In PBL where learners need to (i) tap on their prior knowledge and have metacognitive awareness of what they know and do not know; (ii) employ cognitive and metacognitive learning strategies to analyse the problem, identify learning issues and set learning goals; (iii) pace their learning and use appropriate learning strategies to make judgements on ideas and facts proposed and acquire new knowledge to solve the problem presented; and (iv) monitor and evaluate their learning and determine whether their learning goals have been met. Situating learning in real-world problems in PBL allows learners to elucidate their cognitive and metacognitive processes to themselves, their peers and tutors. This visibility allows monitoring and evaluation of learning which develops learner's cognitive and metacognitive functions and allows for effective transfer of knowledge and learning strategies in new situations. It is evident that embedded within PBL are cognitive and metacognitive activities that allow learners to develop their cognitive functioning.

PBL is a viable pedagogical approach to develop learners' cognitive functions. This paper utilises Tan's CFD in conjunction with the PBL schema, to form a conceptual framework describing the cognitive functions elicited at each stage of the PBL.

The PBL Model

PBL is an iterative learning process that involves both individual and collaborative problem-solving processes. The general PBL schema adopted by institutions worldwide usually begins with an initial problem analysis, followed by the generation of learning issues and the integration of knowledge (Barrows and Tamblyn 1980; Savin-Baden and Major 2004; Tan 2001). The final stage of PBL usually involves the presentation and evaluation of the solution. The key characteristics of PBL include (1) the use of authentic trigger, (2) self-directed learning, (3) collaborative learning, (4) scaffolding of learning and (5) reflective practice.

PBL is used in NIE to bring the 'authentic school environment' into the university. Through the reflective analysis of real and complex school/classroom problems, preservice teachers will be able to (1) bridge the theory and practice gap by being aware of the various facets of teaching in practice and how theoretical underpinnings can inform and refine such practices and (2) engage in thinking processes such as probing for deeper understanding and connecting with different perspectives which enhance their self-directed learning and problem-solving competencies (Vernon and Blake 1993). By modelling this pedagogical approach in the curriculum, preservice teachers in NIE can also experience the feasibility and potential of PBL in engaging their future students in the twenty-first-century classrooms.

One of the courses to adopt the PBL approach is the core educational psychology course, 'Educational Psychology 1: Theories and Applications for Learning and Teaching'. This course provides the foundation for preservice teachers to understanding the psychology behind learning and developing learners. Specifically in this course, preservice teachers synthesise the concepts of student development and learning theories and apply this knowledge in teaching and designing learning experiences. PBL is used because past cohorts of preservice teachers found the theories too theoretical and abstract and failed to see its application in the classroom. The use of the PBL approach allows the preservice teachers to apply their theoretical knowledge to real classroom issues and hence deepen their mastery of the educational theories. In groups of three to five, the preservice teachers will have five weekly two-hour sessions, which correspond to the five different stages of the PBL cycle. Preservice teachers have the autonomy to decide whether additional face-to-face or online sessions are needed to solve the problem scenario presented.

The schema for PBL process (Tan 2003) and its stages as reflected in Fig. 7.1 are generalisable across PBL approaches adopted across tertiary institutions and schools. Guided by the conceptual understanding of PBL, the characteristics of each PBL stage are first discussed generically and elaborated specifically in the context of NIE educational psychology course. Each stage of the PBL cycle can be understood as a pedagogical interface that facilitates the thinking processes that stem from the interaction between the learner's past knowledge, the problem scenario and other sources of information for new knowledge creation. The five stages of PBL are:

Stage 1: Meeting the Problem

Learners are introduced to the problem scenarios. In PBL, learners are presented with problem scenarios that are authentic and have real-life relevance. The problem scenarios posted are unstructured and need to be considered from multiple perspectives. With the advancement in technology, videos can now be incorporated into the problem scenarios, thus providing a richer perceptual experience for the learners. According to Tan and Looi (2007, p. 148), 'multimedia enables rich contextualised problem cases to be represented realistically and digitally, which means that learners can review the problems as many times as necessary, and scrutinise the problem in its rich context'. In the context of educational psychology in NIE, the problem scenarios are classroom challenges that were faced by teachers in typical Singaporean schools. Utilising authentic scenarios strengthens the learners' theory-practice link and allows them to transfer their learning to their professional practice in the future. Preservice teachers in their respective PBL groups are given their authentic problem scenario in both video and written script format. These real classroom challenges play a pivotal role in triggering preservice teachers' inquiry process.

Stage 2: Problem Analysis and Learning Issues

During this phrase, the learners in their PBL groups will brainstorm and analyse the problem scenario, whilst generating hypotheses and possible explanations. The group will embark on the identification of learning issues and learning objectives

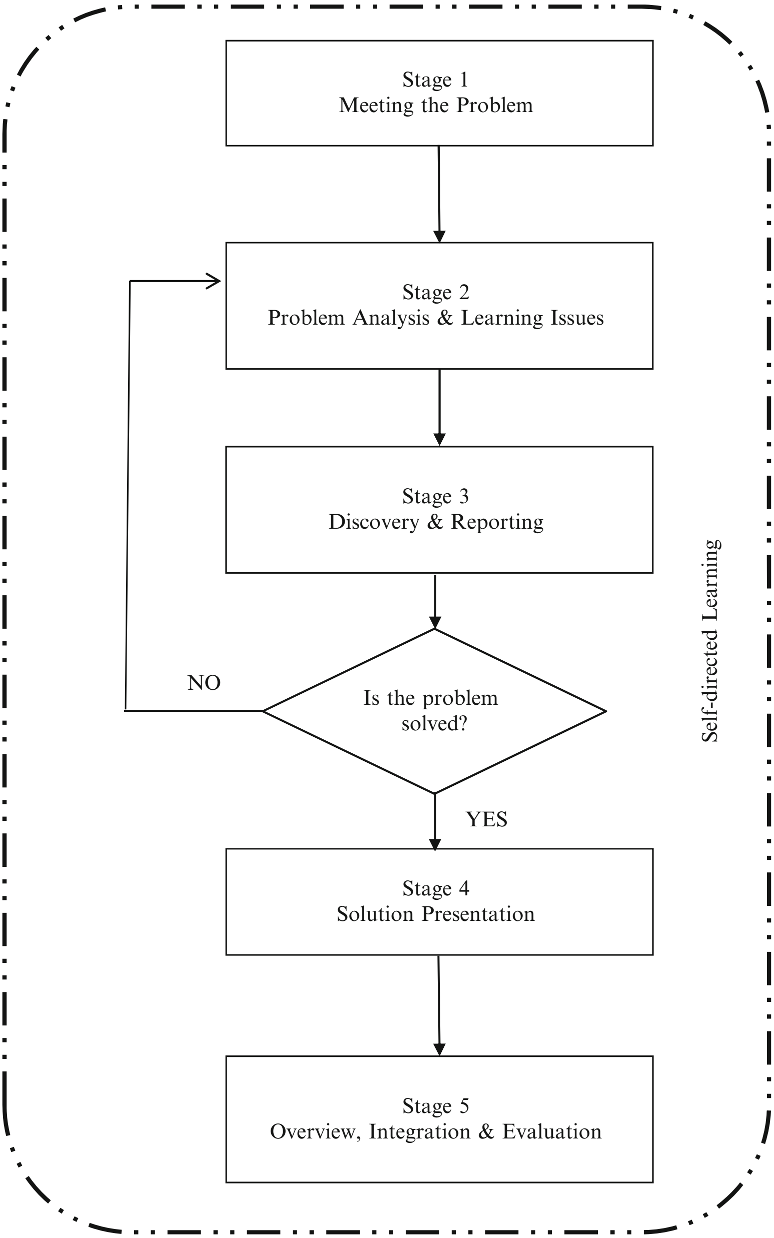

Fig. 7.1 The PBL cycle (Adapted from Tan 2003)

and the formulation of a problem statement. For example, the focus for the preservice teachers at this stage is to ask relevant and thought-provoking questions that would facilitate their problem-solving process.

Stage 3: Discovery and Reporting

With the identification of the learning issues, learners individually prepare notes and pointers to share and peer teach other members of the group. Integration and consolidation of information occur both at an individual level and at a group-sharing level. During this stage, learners constantly advance the group's collective understanding through seeking clarification, questioning and challenging one another. In NIE, this process of sharing, building and creating new knowledge collaboratively begins at the *discovery and reporting* stage which occurs at the third week of their PBL experience. During the 3-week period from the discovery and reporting stage to the solution presentation stage, the preservice teachers will initiate meetings outside the scheduled tutorial periods. These meetings can be either face to face or online, with the objective of sharing their learning, before reaching a consensus on the solution(s) for their problem scenario. At the end of this stage, learners ask themselves the central question, 'Is the problem solved?' If the learners perceive their current solution(s) to be inadequate, they will return to the previous stage 'problem analysis and learning issues'. This is an iterative process that will continue until the learners are satisfied with their solution.

Stage 4: Solution Presentation

The purpose of this stage is for the learners to make their thinking visible by articulating their group's problem statement, research hypotheses and proposed solutions. Mind maps, journal of problem inquiry, theories and other relevant information, which lead to their proposed solutions, are to be included inside the presentation. The length of the presentation is approximately 20 min, followed by 5 min of question and answer (Q&A). The main purpose of the presentation is to explain and justify their group's proposed solutions to their peers and tutor. During Q&A, their classmates will analyse and compare the proposed solutions with that of their peers and those recommended by experts. For the educational psychology course, there are no right or wrong solutions as long as the preservice teachers are able to substantiate their solutions with reasons supported by relevant learning theories. Due to the fact that the problem scenarios are based on complex classroom issues and challenges, having multiple solutions for a single scenario is plausible.

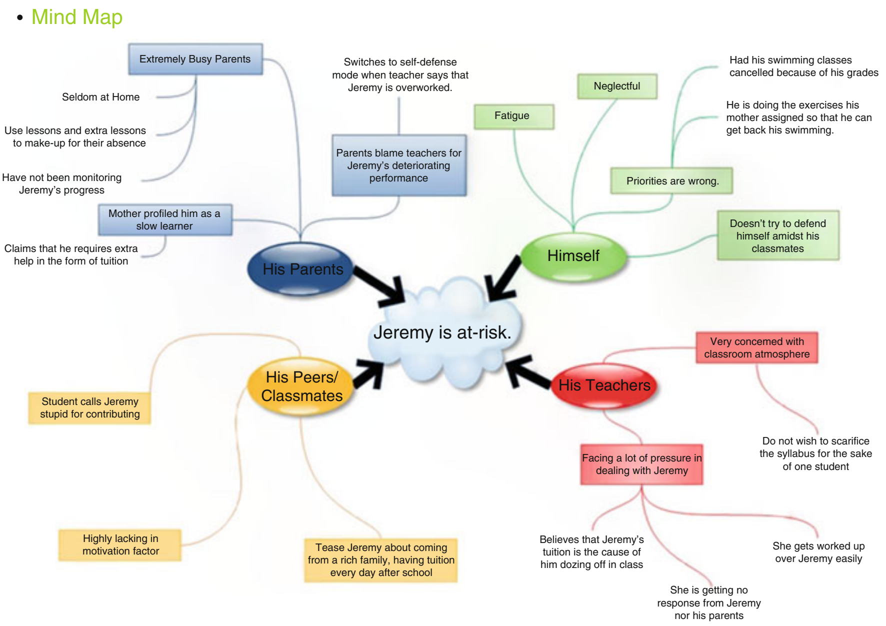

Fig. 7.2 An example of the mind map created by preservice teachers (With kind permission from Springer Science+Business Media: Chua et al. 2015, Figure 10.8)

Stage 5: Overview, Integration and Evaluation

Learners are required to reflect and synthesise on their individual learning at this final stage of the PBL journey. The act of deliberate reflection encourages higher-order cognition such as analysis, clarity of thoughts (Garrison 1993) as well as metacognition and self-regulated learning. For the preservice teachers, at this stage, they assimilate new knowledge to their prior knowledge in educational psychology, whilst reflecting on how the PBL processes may have influenced their motivational, affective and cognitive outcomes. They also reflect on its viability as an innovative pedagogy for their future students.

Throughout the PBL stages, the use of e-tools (i.e. mind maps, problem analysis templates and question prompts) and e-platforms (i.e. asynchronous discussion threads and synchronous online collaborations) on[1] PBworks is made available to the preservice teachers. Figures 7.2, 7.3 and 7.4 demonstrate the use of mind maps, question cues and discussion threads to support, facilitate and document preservice teachers' thought processes through the various stages of their PBL experience.

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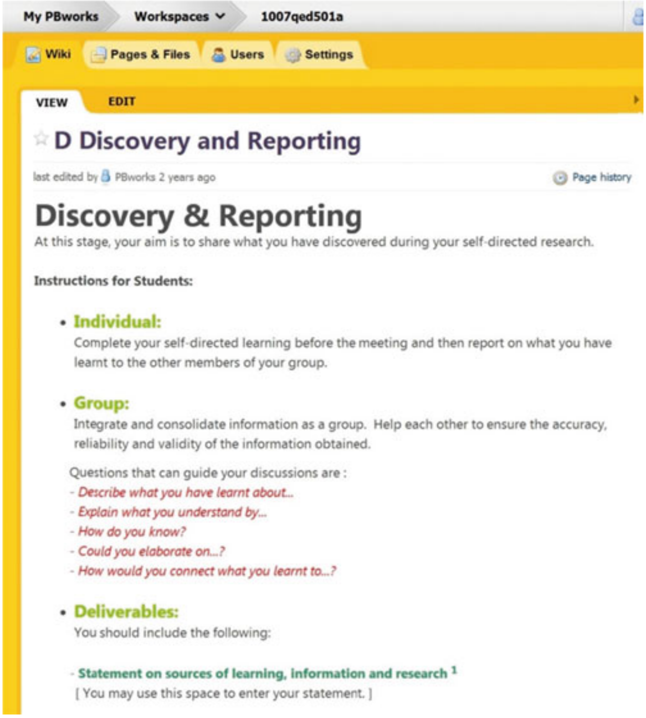
[1] PBworks is a Web 2.0 cognitive tool that enhances peer interaction and facilitates sharing and distribution of knowledge and expertise amongst a community of learners (Lipponen 2002).



D Discovery and Reporting

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Discovery & Reporting

At this stage, your aim is to share what you have discovered during your self-directed research.

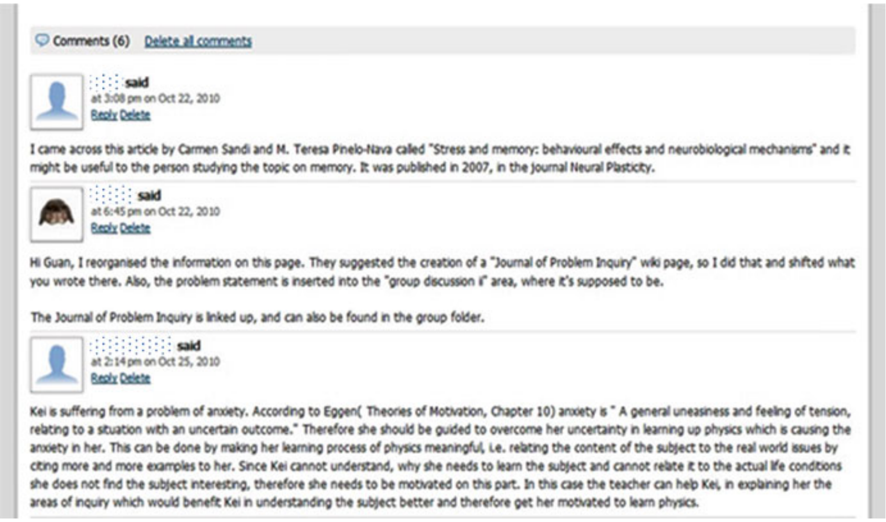
Instructions for Students:

- **Individual:**
  Complete your self-directed learning before the meeting and then report on what you have learnt to the other members of your group.
- **Group:**
  Integrate and consolidate information as a group. Help each other to ensure the accuracy, reliability and validity of the information obtained.

  Questions that can guide your discussions are :
  - *Describe what you have learnt about...*
  - *Explain what you understand by...*
  - *How do you know?*
  - *Could you elaborate on...?*
  - *How would you connect what you learnt to...?*
- **Deliverables:**
  You should include the following:

  - **Statement on sources of learning, information and research** [1]
  [You may use this space to enter your statement.]

Fig. 7.3 An example of the question prompts provided within PBworks



[redacted] said
at 3:08 pm on Oct 22, 2010
Reply Delete

I came across this article by Carmen Sandi and M. Teresa Pinelo-Nava called "Stress and memory: behavioural effects and neurobiological mechanisms" and it might be useful to the person studying the topic on memory. It was published in 2007, in the journal Neural Plasticity.

[redacted] said
at 6:45 pm on Oct 22, 2010
Reply Delete

Hi Guan, I reorganised the information on this page. They suggested the creation of a "Journal of Problem Inquiry" wiki page, so I did that and shifted what you wrote there. Also, the problem statement is inserted into the "group discussion i" area, where it's supposed to be.

The Journal of Problem Inquiry is linked up, and can also be found in the group folder.

[redacted] said
at 2:14 pm on Oct 25, 2010
Reply Delete

Kei is suffering from a problem of anxiety. According to Eggen(Theories of Motivation, Chapter 10) anxiety is " A general uneasiness and feeling of tension, relating to a situation with an uncertain outcome." Therefore she should be guided to overcome her uncertainty in learning up physics which is causing the anxiety in her. This can be done by making her learning process of physics meaningful, i.e. relating the content of the subject to the real world issues by citing more and more examples to her. Since Kei cannot understand, why she needs to learn the subject and cannot relate it to the actual life conditions she does not find the subject interesting, therefore she needs to be motivated on this part. In this case the teacher can help Kei, in explaining her the areas of inquiry which would benefit Kei in understanding the subject better and therefore get her motivated to learn physics.

Fig. 7.4 An example of the discussion thread initiated by preservice teachers (With kind permission from Springer Science+Business Media: Chua et al. 2015, Figure 10.9)

Cognitive and Metacognitive Functions in PBL

PBL is a process-oriented form of active learning that emphasises the understanding of concepts and the ability to think critically, reflect meaningfully and work collaboratively with others (Ahlfeldt et al. 2005). It focusses on the strengthening of learners' critical thinking skills, reflective skills and self-directed learning skills to develop active and autonomous lifelong learners (Bechtel et al. 1999; Major and Palmer 2001; Sungur and Tekkaya 2006; Tiwari et al. 2006). Nonetheless, 'much more research is needed to better understand how, when and why PBL fosters the development of self-directed learning' (Blumberg 2000, pp. 224–225). To our knowledge, there has been no prior study which examines learners' thinking process as they solve problems at each PBL stage. It is with an understanding of the pedagogical and cognitive interfaces in a PBL environment that educators could facilitate the development of students' cognitive functions.

Tan's (2000) CFD was used to identify the cognitive functions that were inherent in the PBL cycle. At NIE, being cognizant of the PBL schema, seven experienced PBL educational psychology tutors with at least 3 years of facilitation experience were asked to select individually from Tan's CFD (2000), the top 20 cognitive functions pervasive in the PBL environment. The responses from the seven tutors were collated, and the top 20 cognitive functions according to frequency counts of the responses were identified. This led to the development of the conceptual framework as reflected in Fig. 7.5 for the identification of preservice teachers' cognitive functioning as they progress through the PBL cycle. All of these functions are theorised to be present in varying degrees, within each stage of the PBL cycle.

Armed with the conceptual framework (Fig. 7.5) for the identification of cognitive functioning and based on existing PBL literature, we use NIE's PBL educational psychology course as a case of point to identify the cognitive and metacognitive requirements that are most prevalent within each PBL stage for the preservice teachers. These cognitive and metacognitive requirements have been listed in Table 7.1 which is followed by a discussion on its use at each PBL stage.

At the *meeting the problem* stage, an unstructured and complex task requires the learners to *select relevant cues* and *identify the problem* from their perspectives. Learners have to take into account the viewpoints of the characters within the problem scenario, in addition to the *different perspectives* of their own groupmates, whilst deriving their own personal interpretation. This will give rise to identification of many plausible problems depending on the learners' perspectives. When faced with authentic ill-structured problem, it is pivotal that learners are cognizant to focus on the *big picture* and not dwell on microscopic minor issues. This entails learners to demonstrate *flexibility in their thinking* and to *generate as many ideas* as possible at this stage as the focus is not on what learners 'want' to learn but rather what they 'need' to learn in addressing the problem from multiple angles.

During the *problem analysis and learning issues* stage, when *analysing* the problem, learners need to *look for attributes and features* that might contribute towards a *problem definition*. After a problem definition has been reached by the group, they

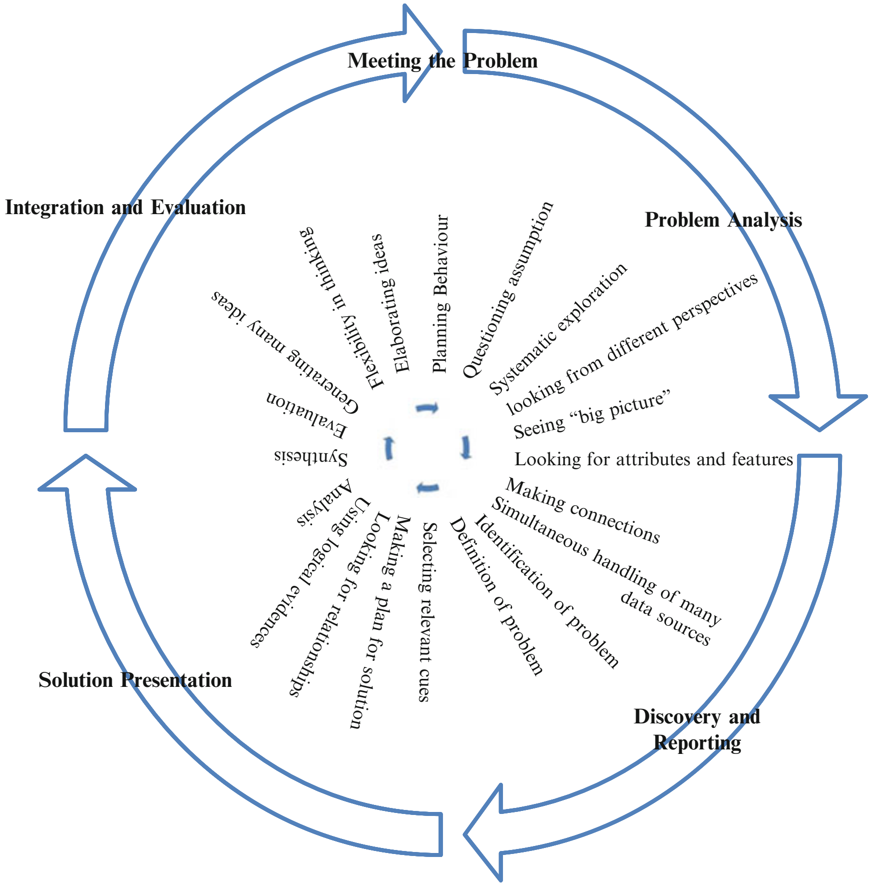


Fig. 7.5 Conceptual framework for the identification of cognitive functioning within/across PBL stages

may proceed to raise and *question the assumptions* underlying their understanding of the problem scenario. They have to establish scenario-specific *relationships*, by linking the events, dialogue and information cues in the scenario together to form a general understanding. Learners employ the cognitive function of *systematic exploration* to narrow their focus and explicitly define the problem. This will promote understanding to tease out the appropriate learning issues (Kahney 1994). The metacognitive function of *planning* is utilised when learners plan out their research agenda based on the learning issues and objectives that have been identified.

At the *discovery and reporting* stage, preservice teachers have to acquire new knowledge and to articulate and justify this learning to their groupmates. They need to *simultaneously handle data from different sources* and use *logical evidence* to substantiate their viewpoints. Peer teaching is the defining characteristic of this stage, where group members will ask each other questions and *elaborate* on their

Table 7.1 The cognitive and metacognitive requirements at each PBL stage

PBL stage	Cognitive requirements	Metacognitive requirements
Meeting the Problem	Selecting relevant cues, looking from different perspectives, identification of problem, generating many ideas	Seeing the big picture, flexibility in thinking
Problem Analysis and Learning Issues	Analysis, looking for attributes and feature, questioning assumptions, looking for relationships, systematic exploration and definition of problem	Planning behaviour
Discovery and Reporting	Simultaneous handling of many data sources, using logical evidences, making connections, elaborating ideas, making a plan for solution and synthesis	Evaluation
Solution Presentation	Generating many ideas	Planning behaviour
Overview, Integration and Evaluation	Synthesis	Evaluation

own respective parts. Therefore, the individual learner must be able to *synthesise* their peers' content and their own personal understanding. By doing so, it facilitates their ability to *see the interconnections* between concepts, principles, prior knowledge, new knowledge and knowledge across disciplines (O'Neill and Hung 2010). Learners can form connections outside of those mentioned within the problem scenario. These 'external' connections may link the problem scenario with their past experiences, educational psychology theories and content knowledge from other modules too.

With a shared understanding and *synthesis* of the concepts that have been raised by their group members, they can proceed to plan their solution. Once a general consensus has been reached on the final solution(s), the learners will *evaluate* the effectiveness of their proposed solution(s). If the solution(s) is deemed to be inadequate, the learners will revert back to the earlier stage of 'problem analysis and learning issues'.

During the *solution presentation* stage, learners would have the opportunities to aggregate their learning and *plan* for the presentation of their solution. The group must select the appropriate learning artefacts (e.g. mind maps, journal entries) to include within the presentation, whilst maintaining an engaging and captivating approach, within the duration of a 20 min presentation. The cognitive processes of *idea generation* will again be heavily relied on at this point of the PBL process as learners generate new insights after listening to the presentations of other teams. The metacognitive function of '*planning behaviours*' is exercised when the group visualises the overall flow and execution of the presentation and when each member prepares their respective parts.

Finally, at the *overview, integration and evaluation* stage, preservice teachers would reflect on their research and learning process (Liu et al. 2009). The metacognitive function of *evaluation* is carried out on individual as well as group learning.

It involves evaluating their overall performance, identifying the challenges that were faced as well as recommendations for optimising their cognitive functioning in future learning experiences. *Synthesis* occurs at this stage as learners reflect on the subject content, in addition to the intrapersonal cognitive and metacognitive processes undertaken to reach this stage. The conscious effort taken to inquire into their research and process skills allows the preservice teachers to internalise and apply them in future applications and disciplines. This results in greater flexibility in their thinking for future problem-solving processes.

Conclusion

The importance of equipping our learners with cognitive and metacognitive competencies to be critical thinkers, reflective practitioners and creative problem-solvers is crucial in our twenty-first-century knowledge-based economy. According to Tan (2003), education has to equip our learners with the ability to (1) foster independent lifelong learning, (2) assume greater personal ownership of learning, (3) learn how to learn from multiple sources and resources, (4) learn collaboratively and (5) learn to adapt and solve problems. In this increasingly complex world, the intentional development of learners' thinking, meaning-making and knowledge creation abilities will help them cope with unpredictable changes in our twenty-first-century societies.

With a better understanding of learners' employment of cognitive function within and through the PBL stages, there can be more mindful facilitation and development of learners' thinking process during their problem-solving experience. PBL facilitators would be able to design more effective question prompts that target the specific cognitive functions. To date, there have been few studies that examine the 'mediational role' of scaffolding on cognitive processes. Ge and Land (2004) conducted one such study, which involved examining the use of different question prompts in the scaffolding of different PBL processes. They posited that PBL designers should utilise more 'elaboration-focussed' question prompts when scaffolding the problem representation process, whilst relying on more 'reflective' question prompts when scaffolding the solution process. Ideally, the model can serve as a reference for PBL curriculum designers to design specific scaffolds to support specific cognitive functions. Also, PBL designers can consider a 'cognitive-centric' approach in designing PBL environments. In lieu of designing PBL curriculums around the content knowledge to be covered, future PBL environments can be designed around modifying specific cognitive functions.

It is important to note that this paper only attempts to provide a framework of the cognitive and metacognitive requirements of each PBL stage. Future empirical studies can provide a definitive answer as to whether the identified functions were indeed present amongst the learners. Examining the student -reported cognitive functions at each PBL stage would be useful in identifying any discrepancies in the tutors' understanding of PBL and their learners' understanding.

This paper offers a new perspective to current existing PBL research by utilising Tan's (2000) CFD in identifying the cognitive and metacognitive requirements of each PBL stage. Past research has demonstrated how the use of cognitive tools varies throughout the progression of the problem-solving process (Bera and Liu 2004) and that they are linked to specific cognitive processes (Liu et al. 2004). Thus, a better understanding of the cognitive functions at each PBL stage would help PBL facilitators design better cognitive tools to better facilitate the development of learners' cognitive functioning which is pivotal in the problem-solving process in PBL. Future research may look into further enhancements to the CFD to enable it to be used as a checklist for the learner to gain insights into one's own cognitive abilities and engage in a mindful monitoring of their personal cognitive development.

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Chapter 8
Finding Common Ground During Collaborative Problem Solving: Pupils' Engagement in Scenario-Based Inquiry

Frederick Toralballa Talaue, Mijung Kim, and Tan Aik-Ling

Abstract Finding common ground, or grounding, among individuals engaged in an activity is essential to productive collaboration. Many studies have analysed grounding processes as a site of collaborative learning and have focused mainly on its cognitive aspects. However, to enhance our understanding of students' learning processes, the intellectual activity must be viewed along with the social and cultural contexts in which it is naturally embedded. In this chapter, we present a descriptive case study exploring, from a sociocultural perspective, grounding engaged by a group of Primary 3 pupils (aged 9) in a problem-solving task. The task was designed into a scenario-based inquiry (SBI) lesson. The SBI approach showcases in video narrative format an everyday context-related problem that students need to investigate. The accompanying collaborative inquiry activity is intended to aid them in deepening their understanding of science concepts and developing skills for integrating and applying science knowledge. Data were collected on the day of implementation of an SBI lesson on the topic *Properties of Materials* using video and audiotape recordings of group work. The analysis of one group's discourse focused on both the linguistic and sociocultural aspects for the joint accomplishment of the problem-solving task. Our findings indicate that their grounding processes involve resolving differences by drawing upon shared everyday experiences and marshalling them as bases for propositions and meanings, employing rhetorical strategies for informal argumentation discourse, mobilizing past rehearsed modes of decision making to reach consensus and building identities as knowledgeable and communicatively competent persons among peers. We discuss our insights about these findings with respect to pedagogical supports that could address issues on student collaboration in classroom problem-solving contexts.

Keywords Grounding • Collaborative problem solving • Everyday argumentation

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Introduction

The scenario-based inquiry (SBI) is a pedagogical strategy that aligns with the aims for teaching science as inquiry (Tan et al. 2013). It intends to engage students in a collaborative activity for solving a science-oriented, real-world problem. In this way, it is hoped that they not only learn the content of science but also become acculturated to the epistemic practices of the science community, which include marshalling evidence, communicating reasoned arguments and reaching consensus. Any collaborative problem-solving activity necessarily involves *grounding*, which refers to the interactive process of constructing and maintaining a common ground of mutual understanding between individual participants (Clark and Wilkes-Gibbs 1986). Most approaches in educational research on grounding have focused exclusively on how interpersonal interactions unfold and have excluded the examination of how students' *ways of being* as encultured members of particular communities shape interactional dynamics (Baker et al. 1999). A more holistic approach to studying grounding must therefore pay attention not only to cognitive aspects but also to sociocultural dimensions (Akkerman et al. 2007).

In this chapter, we explore how grounding was achieved by a group of Primary 3 pupils (aged 9) engaged in a problem-solving activity nested within an SBI lesson. Given that grounding is essentially a process of language interaction, we focused on the discourses jointly produced by the participants. Language is a cultural tool for, and at times the object of, collective thinking (Baker et al. 1999). We employ language to make sense of ideas, communicate notions, solve problems, resolve differences, cooperate, advantage oneself, etc. (Gee 2005). In closely examining the discourses students produced, our case study aimed to describe grounding processes 9-year-old pupils performed to accomplish their perceived goal/s of the tasks. Knowledge of grounding processes is important as primary teachers seek to find practical ways to support children's learning of science through problem-solving and inquiry pedagogies (Hmelo-Silver et al. 2007).

We argue that the discourses Primary 3 students produced are anchored in their everyday experiences and knowledge both in terms of content and the strategies for making arguments and group decisions. While the pupils recognized collaborative knowledge construction as the goal of the SBI problem-solving task, they simultaneously engaged in the politics of building credible viewpoints through active co-construction of relevant social identities. We explain the above claims by first describing the intimate connection between SBI and PBL approaches and clarifying the sociocultural notions of grounding and collaborative learning we used. Next, we describe the methods employed, including the instructional context and analytic framework of our descriptive case study. We then elaborate on our findings under two major themes: *playing the resolution game* and *building identities contingent on problem-solving task*. And to conclude this chapter, we discuss some insights drawn from our findings that relate to pedagogical supports for learning primary school science in small group settings.

Scenario-Based Inquiry and Problem Solving

The SBI approach is a pedagogical strategy that provides hybrid spaces for science and everyday knowledge. It presents opportunities for children to talk about science in an engaging way by integrating familiar contexts into learning activities (Tan et al. 2013). In a typical SBI lesson, students first watch a short video clip that presents the problem of interest through a real-life or fictional story. Appealing to students' imagination and interest in storytelling, such a format is meant to increase engagement in the succeeding group work on a structured problem-solving task.

In the design of tasks for SBI lessons, we incorporated elements of problem-based learning (PBL) (Barrows 1996) in order to support the understanding of science concepts and epistemic practices. The inquiry scenario in the video includes both relevant and noise information that complexify the problem and promote decision-making processes. SBI lessons also have an open-inquiry design, which promotes self-regulated learning, thinking from multiple perspectives and collaborative reasoning as students try to reach consensus. Learners who effectively engage in a collaborative problem solving recognize the goals of tasks and positively contribute to group effort by collecting and negotiating information and advancing collective knowledge to relevant issues that must be eventually addressed (Buchs et al. 2004). Collaborative group work in primary schools has been shown to develop both students' conceptual understanding and work and play relations (Tolmie et al. 2010). Moreover, students who learn concepts through transactive dialogue are more likely to appropriately apply knowledge and skills in new similar situations (Duch et al. 2001). However, despite the potential benefits, we have noted that teachers become concerned about the tension between everyday and scientific language in pupils' talk, how this tension could curtail attainment of learning objectives and the difficulties students have in carrying out productive collaboration (Tan et al. 2013).

Grounding and Collaborative Learning

Our analysis of grounding in this study is aligned with sociocultural perspectives on cognition and learning. Cognition is conceptualized as located within the activity of a group and as such related to how individuals participate in or contribute to joint activity and discourse (Matusov 1996). However, group cognition is viewed not as the composite of individual minds but as constituted by the group itself as a unitary entity. It manifests as patterns in the contribution processes that are oriented towards defining the goal of the activity. We also take the view that learning occurs through *participatory appropriation* (Rogoff 2008). This means that an individual's understanding of, and responsibility for, joint activities are dynamically altered over time through their actual participation in such activities. Thus, participation in the science learning activities of the classroom community facilitates learning through collective and negotiated processes of meaning-making or knowledge construction (Lemke 2001) with knowledgeable others (Lave and Wegner 1991; Vygotsky 1978).

To view learning as acculturation into the practices of the community of science learners is also to recognize that students necessarily experience shifting conceptions of the self in relation to their changing roles and relationships within that community (Greeno 1998). Indeed, learning is not only about cognitive achievements but also about changes in an individual's identity as a valuable participant in social practices.

An integral component of any collaboration is maintaining common ground or *grounding*. Roschelle and Teasly (1995) define collaborative activity as 'a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem' (p. 70). This widely accepted definition implies that grounding and collaboration are interdependent. However, it has been argued that they do not necessarily coincide (i.e. grounding may occur without collaboration but with competition instead) considering that participants may be oriented not to the same objects and communicative functions at any particular stage of group interactions (Baker et al. 1999). The objects of grounding or collaboration include meanings, propositions, rights, obligations, self-images, etc. Communicative functions refer to whether the participant is willing and able to continue the interaction (contact level), perceive the message (perception level), understand the message (understanding level) and adequately respond to the message (agreement level). These levels form a hierarchy such that the agreement can only be achieved when contact, perception and understanding have been satisfied.

Collaborative learning may be considered as learning from grounding with two foci: learning in collaborating and learning in attaining mutual understanding (Baker et al. 1999). *Learning in collaborating* refers to the level of grounding wherein participants attempt to understand each other's intended actions within the joint activity. This foregrounds the use of language to mark utterances as sharing information, expressing opinions, rejecting propositions, etc. *Learning in attaining mutual understanding* points to the semantic, or meaning-making, aspect of grounding. This dimension is salient in the use of language to achieve common understanding of certain terms and expressions of a domain of knowledge such as science. It has been suggested that learning from grounding is fuelled by optimal levels of difference between individual perspectives and is associated with gradual transitioning from a predominantly pragmatic focus to that of a more semantic one. These concepts provide the bases for analysing the processes of grounding that pupils engaged in during the problem-solving activity.

Methods

Instructional Setting

The SBI lesson we observed in a well-regarded primary school was implemented as a learning activity for the unit *Properties of Materials*. It was the first time for the pupils to encounter this topic as a science lesson and to experience an SBI approach. The learning activity was not meant as enrichment but as a regular lesson held in their usual classroom. They were expected by the teacher to learn about the diversity of nonliving things by exploring the properties of various materials and relating these to their use. The syllabus specifies that pupils would be required to show objectivity by using data and information to validate observations and explanations about the properties and uses of materials (Curriculum Planning and Development Division [CPDD] 2007).

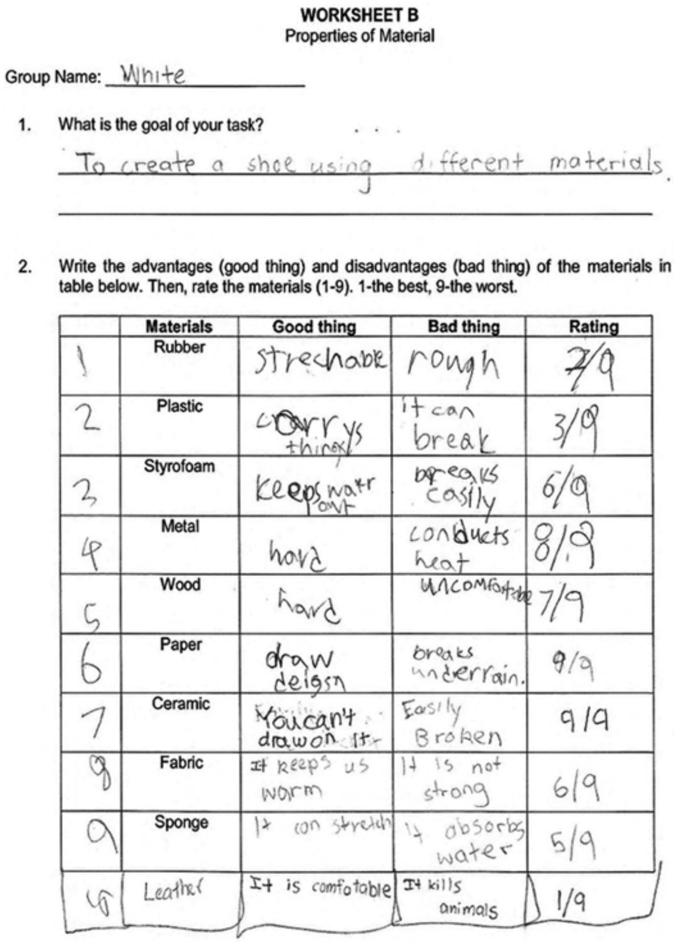
An eight-minute video of the inquiry scenario entitled *Perfect Shoe for Princess* was shown at the beginning of the lesson. This video was developed by a group of pre-service university students under the tutelage of one of the researchers. Its narrative was adapted from the folktale *Cinderella*, a popular story that could easily capture the pupils' shared imagination and engage them in the problem-solving activity. The new version featured the prince's dilemma of replacing the broken glass slipper he originally intended to give to the princess. The shoemaker gave the prince ten different materials to choose from. Being undecided, he turned to his audience (i.e. pupils) for help in choosing the ones that would be most suitable for the new shoe.

As an instructional scaffold for this problem-solving task, the teacher designed a complementary two-part worksheet that small groups of students had to fill out together. Part A guides them in the exploration of the properties of pieces of rubber bands, a plastic bag, a small Styrofoam board, a metal ruler, a piece of wood, name cards made of paper, a ceramic mug, a piece of *batik* cloth, a dishwashing sponge and a leather belt. They were prompted to name the kind of material the objects were made of, list some of their properties and answer short questions on the material's other observable qualities and/or other examples of common, everyday objects that are similarly constituted.

In Part B, which was the focus of our analysis, the students had to tackle the problem of choosing which of the materials would best suit the *perfect* shoe for the princess. The worksheet for this part first required them to list some advantages (*good thing*) and disadvantages (*bad thing*) for using each material (Fig. 8.1). They then had to rank each using a scale from 1 to 10. Note that the worksheet indicates '1–9' since there were originally only nine materials to work on. The leather belt was added only on the day of the activity.

Data Sample

The teacher chose a focused setup by having groups of pupils work with the materials and the worksheet at their assigned tables. We chose one group to study and their interactions were captured in digital video and audio recordings. One member of the research team acted as this group's moderator (Mod). As can be seen in Fig. 8.2, seven students huddled around Leo (L), who nominated himself as group leader and recorder. The other group members include Ashvin (A), Billy (B), Denise (D), Jia (J), Kim (K) and Waya (W). The teacher did not assign special roles to these pupils. The working groups were limited to a small number so that the teacher could monitor the whole class more closely.



WORKSHEET B
Properties of Material

Group Name: White

1. What is the goal of your task?

To create a shoe using different materials.

2. Write the advantages (good thing) and disadvantages (bad thing) of the materials in the table below. Then, rate the materials (1-9). 1-the best, 9-the worst.

	Materials	Good thing	Bad thing	Rating
1	Rubber	strechable	rough	2/9
2	Plastic	carrys things	it can break	3/9
3	Styrofoam	keeps watr out	breaks easily	6/9
4	Metal	hard	conducts heat	8/9
5	Wood	hard	uncomfortable	7/9
6	Paper	draw deigsn	breaks underrain.	9/9
7	Ceramic	You can't drawon it	Easily Broken	9/9
8	Fabric	It keeps us worm	It is not strong	6/9
9	Sponge	It can stretch	It absorbs water	5/9
10	Leather	It is comfotable	It kills animals	1/9

Fig. 8.1 The group output for Part B of the SBI activity

Data Analysis

We applied discourse analysis that pays attention to linguistic and sociocultural aspects to explicate the processes of grounding. A focus on lexical content (e.g. word choices) and rhetorical strategies as well as the cohesive structure of talk was necessary to understand the group's joint construction of knowledge. The dialogues were treated as social modes of thinking (Mercer 2004), consistent with the view of discourses as complex and socially recognized ways of representing experience that communicate particular perspectives about the world, including values, beliefs, orientation and certain identities (Gee 2005).

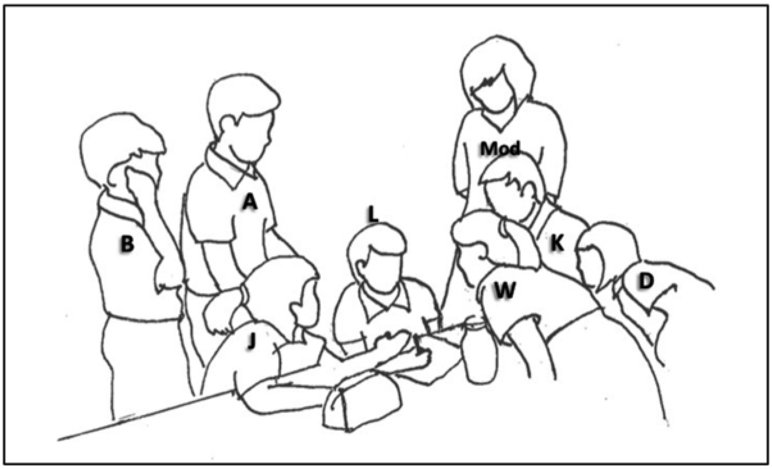


Fig. 8.2 Spatial context of the group doing the activity

The segment of video and audio recordings analysed corresponded to the problem-solving activity (Part B of the worksheet). This lasted for about seven minutes and was fully transcribed, with its pragmatic features noted (Jefferson 2004; see Note after each excerpt). Each researcher independently analysed the data to identify themes and patterns and track relations among them. Individual findings were then discussed and consolidated in team meetings to reflect the team consensus. We also engaged the teacher participant in a debriefing session to validate our findings.

Playing the Resolution Game

We observed that the pupils playfully interacted in exploratory talk as they tackled the problem-solving task, characterized by critiquing and building upon each other's contributions (Mercer 2004). Almost all pupils took turns in contributing to the sense-making and decision-making processes. The knowledge-building discourse produced reflected varying differences in dispositions among the participants, and collaboration through semantic grounding was more prevalent than pragmatic grounding.

In the following sections, we elaborate on the following features of the semantic grounding achieved by the group: (1) pupils drew on everyday experiences and mobilized them as bases for propositions and meanings; (2) pupils employed rhetorical strategies in an everyday argumentation type of discourse to accomplish the task of resolving differences to achieve the goal of knowledge construction; and (3) with prompting from an adult, pupils tapped on prior experiences of inclusive modes of decision making.

Drawing on Everyday Experiences

One of the pedagogical goals of the task for using the SBI activity was to draw out students' ideas about some materials that might be used for making a shoe. For the teacher, it was important to find out pupils' conceptions of properties of materials in order to follow up with more targeted instruction in succeeding lessons. We found that the pupils aligned with the teacher's goal through active contributions to the discussions. All maintained overt involvement except for Billy. But students who seem *passive* are not necessarily uninvolved in the activity. When they pay attention to the discussion, we could still assume at least some cognitive engagement.

As can be seen in Table 8.1, the pupil's ideas were expressed as short and simple property descriptions while some were more elaborate ones. Regardless of the length, we noticed that underlying these contributions are stories of everyday encounters with the materials. For example, Jia's idea that plastic *can carry things* (line 63, 65) is a reference to grocery plastic bags, an object that the pupils, even if they have not had the chance to examine them in Part A of the activity, would all be

Table 8.1 Examples of students' everyday ideas about materials

Topic	Speaker	Line #	Contribution
Rubber	Leo	3, 6	it is stretchable
		16	it's rough
	Waya	1	it's very hard and that's a good quality
		10	the bad thing is that it breaks easily
		13	it is not comfortable
		20	your orange shoe is made of rubber
	Jia	14	it's not that comfortable
		21	rubber makes the orange shoe
	Ashvin	15	it's not very comfortable
Plastic	Ashvin	61, 75	it's breakable
	Waya	62	it's not breakable
	Jia	63, 65	it can carry things
		74	it is not unbreakable
	Denise	67, 69, 71, 77	if you put too much, it will break
	Leo	70	it will break, if you put too much
		72, 76, 78	it can break, it you put too much
		89	It is the best. It makes the shoe sole and bends easily
		94	the side of my Adidas shoe is made of plastic
Metal	Leo	156	it conducts heat
		160	it is hard
		165	one can walk with a metal shoe but it will give a burning sensation because it conducts heat
	Kim	159	one cannot walk with a metal shoe
		164	one cannot walk with it because it is heavy
		168	it would melt

familiar with since buying goods from shops is a common family activity. In the next turn of talk, Denise built on Jia's idea, saying that plastic *will break if you put too much* (lines 67, 69), another reference to unfortunate instances when grocery bags tear or snap under the strain of a heavy load. Later on in the discussions, Leo declared that plastic is *the best* (line 87) because it is used to make his shoe soles *bend easily* (line 89). Yet another example is Leo's narrated encounter with Styrofoam *float[ing]* on water *like a boat* (line 108), which to him demonstrates that Styrofoam *keeps out water* (line 106).

The stories fit Mark Turner's (1996) description of *small spatial stories* as common renderings of everyday experiences that indicate not so much what we know but how we know. As we will show in the following sections, these small spatial stories were used to make and defend propositions, create counterarguments, elaborate on ideas and add humour and a sense of playfulness to the activity. We found the appeals to personal experience as suggesting subscription to the norm to uphold claims based on real-life encounters, those *seen with one's own eyes*, as more trustworthy than others (Sarangapani 2003).

Dialogue and Manoeuvring in One's Favour

Another built-in feature of the activity is the collaborative task of reaching consensus on relevant justifications for the suitability of each material for making a shoe. We found that while the pupils were oriented to this conciliatory goal, they were not hindered from steering the resolution of differences to their favour, to persuade others to agree with their propositions (Goodwin and Goodwin 1987). The pupils demonstrated nascent argumentation abilities through an awareness of their dialectical obligations and knowledge of a variety of rhetorical strategies for collective reasoning (Nielsen 2013), some of which are listed in Table 8.2.

As the three excerpts below will show, semantic grounding persisted throughout the discussions and was constituted through transactive dialogue on opposing ideas that reflected differences in students' everyday experiences with the materials. In Excerpt 8.1, the pupils negotiated the degree of discomfort one might experience with rubber as a shoe material. Excerpt 8.2 shows how they tackled the proposition that plastic is *breakable*. For Excerpt 8.3, they debated whether metal's heaviness or its ability to conduct heat is more important as basis for saying metal is unsuitable as a shoe material.

Excerpt 8.1 exemplifies semantic grounding on the properties of rubber. It occurred early on in the group's discussion and was the first instance Jia and Ashvin expressed disagreement with Waya's idea that rubber is *not comfortable* (line 13). Jia and Ashvin excitedly opposed Waya when she implied absolute discomfort (lines 15–16).

We find in lines 20–22 that the three pursued the argument with an awareness of their obligations to account for their respective viewpoints. Waya addressed the objection raised by invoking shared knowledge of a concrete object, *orange shoe*,

Table 8.2 Some rhetorical strategies produced in the activity

Function	Line #	Student	Examples
To substantiate a claim	87	Leo	plastic is the best **‘cause** (.) **‘cause** you see ah
	108	Leo	**you know why↓** the last time I dumped the whole stuff piece on the water and it just floated like a boat
To narrate a supporting story	233	Kim	wash it (.) **tsyeh tsyeh tsyeh↑**((sound of tearing paper)) (.) then everything break off already
To emphasize a claim	91	Leo	( ) The cover the thing **mah** ((colloquial expression))
	94	Leo	‘cause **you know** my Adidas shoe is the side of a plastic
	120	Leo	no↑ it’s **really really** bad↑
	156	Leo	**definitely** not it conducts heat
To express attitude and offer a claim	92	Ashvin	**I think** this is rubber already
To express disagreement	97	Ashvin	**but** you see guys ( ) the rubber is good

Excerpt 8.1 How uncomfortable is rubber that’s ‘not comfortable’?

Line	Speaker	
12	Leo:	bad thing that uhmm
13	Waya:	it’s not comfortable=
14	Jia:	=[it’s not that comfortable
15	Ashvin:	[it’s not very comfortable=
16	Leo:	=it’s rough ((writes answer)) ok
17	Ashvin:	I rate it about (..) five
…		
20	Waya:	think of what your orange shoe is made of
21	Jia:	rubber↑
22	Ashvin:	exactly↑ ((W looks at her shoes))
23	Mod:	oh so you rate this five↓

Note: [, the onset of overlapping talk; =, latched utterances; word, speaker emphasis; ↑ or ↓, shifts in intonation of utterance; (..), pause that is less than 0.5 s and more than 0.1 s; and (( )), annotation of speaker’s action or transcriber’s comment on contextual features

(line 20). We interpret her move as marshalling evidence for a claim. By stating that she finds Jia’s rubber shoes as uncomfortable, Waya attempted to solicit empathy for her appraisal. But both Jia and Ashvin forcefully frustrated her attempt. Their interjections (lines 21–22) showed an assertive attitude to buttress a counterargument.

This particular stretch of talk evidently indicates semantic grounding, the object of which is Waya’s proposition. It reached the agreement level, i.e. the pupils adequately responded to each other’s message. Jia and Ashvin rejected the

Excerpt 8.2 Is plastic 'breakable'?

Line	Speaker	
60	Leo:	plasti::::::c=
61	Ashvin:	=is breakable
62	Waya:	not [breakable
63	Jia:	[no↑ no it's not a good thing ((wrong column to put answer)) oh↑ it it can carry things (..) it can carry things
64	Leo:	plastic what↓
65	Jia:	plastic can carry things
66	Leo:	ca::::ry ((continues to write))
67	Denise:	sometimes (.) if you put too much (.) things it will (…)
68	Leo:	lol hhhhh
69	Denise:	bu:t the thing is that sometimes if you put too [much
70	Leo:	[it will break
71	Denise:	it will break
72	Leo:	it can break (.) it can break
73	Denise:	it can break
74	Jia:	this is not unbreakable
75	Ashvin:	it can still break
76	Leo:	ca::::n
77	Denise:	yeah because it's too much
78	Leo:	brea:::k ((writing))

Note: wor:::d, lengthening of the preceding sound; =, latched utterances; [, the onset of overlapping talk; word, speaker emphasis; ↑ or ↓, shifts in intonation of utterance; (..), pause that is less than 0.5 s and more than 0.1 s; (.), pause that is less than 0.1 s; and (( )), annotation of speaker's action or transcriber's comment on contextual features

proposition. Waya did not argue any further so we have no immediate indication that she rejected or conceded to the counterargument. Later on, when the group had to decide on the rating, it seemed that Waya implicitly agreed with the suggested low rating of two.

Excerpt 8.2 provides another example of semantic grounding reaching the agreement level, but this time the object is the meaning of certain words. Students disagreed on whether plastic can be appropriately described as *breakable* (lines 61–62).

Waya opposed Ashvin's idea that plastic is *breakable* (lines 61–62). No reasons were offered at that point but it is plausible that Waya thought that *breakable* is a more appropriate adjective for fragile, easily broken materials such as glass, ceramic and other types of plastic objects. In her next bid to talk (line 67), Denise took advantage of Jia's nomination that *plastic can carry things* (in line 65) and aligned her position with that of Ashvin's (line 61). She provided an exception (*sometimes*) to Waya's idea by stating the condition under which plastic *will* break, that is, *if you put too much things* (line 69).

The students' discussion shifted to whether *will* or *can* is more appropriate to use. Instead of verbalizing reasons, Leo unleashed a volley with Denise (lines 70–73), who eventually had to concede. Ashvin also lent support to Leo's idea (line

Excerpt 8.3 How about walking with metal shoes?

Line	Speaker	
154	Leo:	[metal next=
155	Kim:	=metal next
156	Leo:	definitely not it conducts heat
157	Kim:	and metal cannot (.) once you [( )
158	Leo:	[good thing
159	Kim:	you can't walk it [(.) ehhhh ((fearful and painful sound))
160	Leo:	[hard (…) [hard ((writes answer))
161	Mod:	[what do you think of your Robocop?
162	Leo:	[bad thing↓
163	Ashvin:	uhmmmm
164	Kim:	not bad (…) hey ((calls to Leo)) you cannot walk with it (.) metal is so heavy but uhhhhhhh ((gestures lifting something heavy))
165	Leo:	no (.) you can walk with it (.) but then the thing is it conducts heat (.) so when you wear it (.) it's like tssssss ((sizzling sound)) feet like gonna burn↑ [haaaaa ((painful sound))
166	Kim:	[oh my god↑
167	Jia:	o::ka:::::y
168	Kim:	yeah (.) but it would melt↑ isn't it↓
169	Waya:	( ) melt
170	Denise:	°ye::::s (.) give it-up↑°

Note: [, the onset of overlapping talk; =, latched utterances; (.), pause that is less than 0.1 s; word, speaker emphasis; wor:::d, lengthening of the preceding sound; ↑ or ↓, shifts in intonation of utterance; (..), pause that is less than 0.5 s and more than 0.1 s; (…), pause that is greater than 0.5 s; (( )), annotation of speaker's action or transcriber's comment on contextual features; and ° °, noticeable quieter than surrounding talk

74). The negotiated meaning remained implicit throughout this exchange. The sense in which Denise used *will* does not only connote *future occurrence* but also *certainty*. In other words, Denise reiterated the conditionality of her earlier idea, that is, *if loaded too much, plastic is certain to break*. In contrast, Leo uses *can* in the sense of *ability* or *capacity*. Thus his proposition could be heard as *plastic has the ability to break under strain*. This segment illustrates a cooperative interaction where some meaning remained unexpressed because they are presupposed to be common knowledge (McDonald and Kelly 2012). Perhaps the cooperation could have had more productive outcomes if the pupils provided an elaboration of what they meant to say.

Even at later stages, the pupils continued to engage in semantic grounding processes, as exemplified by Excerpt 8.3. Like Excerpt 8.1, this segment had a proposition as its object – metal is a bad material for a shoe. However, the group unanimously accepted this proposition and the exchanges simply aimed to elicit and clarify slight differences in their reasons. Excerpt 8.3 also features the pupils' playful storytelling and self-regulation to finish the task.

Leo kicked off the discussion by nominating the idea that metal is *definitely not* a suitable shoe material because *it conducts heat* (line 156). Kim engaged the idea, suggesting through onomatopoeia that one can walk with metal shoes but must bear the painful heat (line 159). In a later turn, he continued to employ the same strategy of using aural and physical effects to paint a convincing story about why one cannot walk with metal shoes. This time he gestured and imitated the sound of someone struggling to lift something heavy (line 164).

As if jumping on the bandwagon, Leo quickly uttered his protest using the same onomatopoeic device Kim used, suggesting a burning sensation that one would feel if the metal shoe conducted a lot of heat and became intolerably hot (line 165). Like Waya in Excerpt 8.2, Leo marked the reason for his protest as a contrasting point of view (*but then*) that his listeners had to consider (idiomatic phrase, *the thing is*). While Kim seemed totally drawn into Leo's story, expressing shock and surprise (line 166) and following through the imagined storyline that metal *would melt* eventually (line 167), the girls signalled it was time for the boys to end their playful storytelling. Jia's drawn-out utterance of *okay* (line 167) and Denise's *yes* (line 170) seemed to convey impatience with their groupmates' extended exclusive exchange.

Similar to the findings of Goodwin and Goodwin (1987), we found storytelling as another discourse embedded within the group's argumentation. Some were animated conversations, either on or off topic that brought humour into the activity. We thus sensed playfulness as they produced argumentation discourse, rather than what some teachers label as *fighting* (Corsaro 2003). Conversational storytelling as we would sometimes have around family dinner tables involves having everyday narratives challenged and revised through careful observation and logical reasoning. This familial activity resembles scientists' practice of revising theories to account for counterevidences (Ochs et al. 1992).

Deciding on the Final Rating

Reaching consensus on the final rating for each material was a challenging decision-making process for the group because of differing opinions (Johnson et al. 2007). In this section, we describe what succeeded the excerpts presented above in terms of the decisions made for rating the material as shown in Fig. 8.1. The grounding interactions between the moderator and the pupils targeted the mode of decision making, which changed character in the course of the activity. We suggest that the moderator's intervention prompted the group to tap on past experiences with inclusive decision making.

In the first instance (Excerpt 8.1), the process resembled that of a noisy marketplace bargaining, with each bidding for a preferred *price* for rubber. The students' utterances were short and latched onto each other. The moderator had to step in to repair the students' confusion about the rating scheme, saying *one is the best and nine is the worst*. Jia verbalized her enlightenment. So did Ashvin, but it took him some time to internalize it as he still went on to suggest *seven* until Jia challenged him. After further clarification from the moderator and the other members, Ashvin eventually agreed to Jia's insistent demand to rate rubber *two*. Moving on to plastic

(Excerpt 8.2), the students again engaged in bidding. Leo took it upon himself to settle the matter. He offered a rather persuasive argument for a high rating, claiming that plastic bends easily and is the material for some shoe soles (e.g. Adidas™ rubber shoes). Ashvin was convinced. Perhaps the others were likewise convinced. But in the end, Leo overrode other suggestions and wrote down *three* on the worksheet.

Sensing another coup d'etat by Leo for Styrofoam, the moderator intervened to ask what rating each student thought and suggested that they take the average. They agreed on *six* after further nominations and a rough estimation. At this point, one wondered if they would carry over this orderly and democratic mode of decision making. They did so for metal (Excerpt 8.3), settling on *eight*. Interestingly, without prompting from the moderator, Leo initiated a shift to a voting system when they moved to wood. It is plausible that they had already done this in past collaborative activities so that the moderator's implicit suggestion to take each member's choice into account only served as a prompt. The new decision-making mode again figured when they had to agree on what to write as a bad thing for paper, which they thought could catch fire and tear off easily when soaked in the rain.

Building Identities Contingent on the Problem-Solving Tasks

We now turn to the aspect of grounding concerned with the social identities that were interactionally created, either consciously or unconsciously, as students produced exploratory discourse. These co-constructed identities were particularly made salient through their persuasion moves (Johnson et al. 2007) that served to give weight to each contribution and manage task completion. For example, in Excerpt 8.1, Waya's utterance (*think of what an orange shoe is made* of, line 20) could be read not only as being accountable for her earlier contribution but also as signifying a willingness to engage in transactive dialogue. Both Jia and Ashvin affirmed Waya's construction of herself through their engagement with her ideas. Conversely, Waya's actions endorsed Jia and Ashvin as knowledgeable and reasonable participants.

The pupils thoughtfully carried on the sociocognitive roles as *contributors of content knowledge* and *promoters of reflection* to foster group reasoning (Hogan 1999). They stood from an awareness of the obligation to defend their position in the arguments, accounting for the reasonability of their ideas. This awareness was demonstrated through offering claims voluntarily and with elaboration and justification in certain instances. Remarkably, the students deployed explicit questions only on four instances: two during the properties discussions and two during rating decision making.

Indeed, being well informed and having communicative competence as participants were privileged identities in the pupils' interactions (Kyratzis 2004). Leo was most active in displaying his knowledge and skills in rhetoric. But his explicit identification as knowledgeable and having initiative was something Waya was ready to dispute even from the beginning of the problem-solving activity (Excerpt 8.4).

Excerpt 8.4 Waya puts Leo in his place

Line	Speaker	
6	Leo:	°it's stretchable° ((writes answer on worksheet)) (…) ready↑
		( ) you know ( ) I'm the only one who was actually thinking of ah (.) something
7	Waya:	because (.) but he's still still not good

Note: ° °, noticeably quieter than surrounding talk; (( )), annotation of speaker's action or transcriber's comment on contextual features; (…), pause that is greater than 0.5 s; ↑ or ↓, shifts in intonation of utterance; ( ), unintelligible speech; and (.), pause that is less than 0.1 s

In his utterance, Leo positioned his groupmates' effort and level of involvement as inferior to his own. But Waya disagreed with this construal and directly questioned his overestimated superiority. As a response to his negative implication, she asserted that they had been sharing the responsibilities in carrying the tasks forward. In her view, the fact remained that other students have contributed substantially to the earlier discussions and even took turns fetching the materials and taking the group recorder role.

It is also notable that Leo displayed shifts in the quality of leadership (Richmond and Striley 1996). At first, he was *alienating* and ignored others' contributions, as when he wrote down *rough* as a bad thing for rubber although this idea did not even figure in the group discussion. Then he took on a *persuasive* persona, taking longer turns to defend his case. At later decision-making junctures, he became more *inclusive* by calling for a show of hands.

Other interactional roles were important in completing the activity within the time allotted by the teacher (Turner 1991). The group was given only about ten minutes so it was critical for them to move steadily across the list of materials to be evaluated. Leo was not appointed as group leader but he constructed himself as such while doing the role of group recorder, with ratification from the group members. He signalled the completion of one task segment, announced movement to the next one and also drew attention to worksheet items that needed answers. At one instance, he filtered an irrelevant proposition and, in another, issued a stern reminder to get back on task. While Leo did all his *duties* with vigour and steadfast attention, he received help from others as well. Jia, who was seated next to him, made sure that answers were recorded in the proper column and that Leo himself is not carried away by his own storytelling. Transitions between task segments became something like playful echoed announcements to make sure that everyone was on the same page.

Drawing Insights from the Case Study

We set out in this case study to explore the grounding processes of a group of Primary 3 (aged 9) pupils to accomplish the problem-solving tasks of an SBI lesson. We saw a high level of participation in the exploratory talk predominantly characterized by semantic grounding focused on meanings, propositions and the mode of decision making. The emergence of this particular kind of productive discourse is significant considering that these pupils presumably drew from a limited repertoire of ways of talking and enacting school science, having been exposed to formal science lessons for 4 months only. It is highly plausible then that their actions to achieve common ground were sourced from broader *ways of being* practised in everyday social life at home or in the playground. This is evidenced in the predominance of talk resembling informal argumentation children typically engage in during play, as well as the references to cultural knowledge in their claims. The young students in this study clearly demonstrated nascent argumentation discourses that we believe are rehearsed in other peer group contexts within and outside school (Duch et al. 2001; Zittoun et al. 2007).

Our findings point to two main tensions that shaped the dynamics of the students' grounding activities. First, the open critical examination of contributions suggests that students were constantly engaged with the question of plausibility of evidence to justify claims. It appeared to be normative for this group to appeal to everyday experiences as authoritative sources of knowing. Students seized opportunities to contest opposing interpretations of evidences, suggesting the implicit recognition of differences in meanings and assumptions that must be negotiated in dialogue (Hatano and Inagaki 1991). If this were not the case, we would not have seen any argument and reasoning in their talk. Differences in understanding must not be viewed as problematic; it is, in fact, a necessary catalyst for learning (Baker et al. 1999) and significantly correlated with achievement gains (Tolmie et al. 2010).

The second main tension relates to students' negotiation for peer group status as knowledgeable and competent participants in the problem-solving task. From our perspective, the students in this study mobilized identity as a resource not only to compete as persons having trustworthy viewpoints but also for managing the completion of the problem-solving task. This social process was manifest not only in the subject of their utterances but more so through the same pragmatic markings and other rhetorical strategies deployed for constructing knowledge. As the effective use of persuasive strategies varied within the group, some students were viewed as more credible and believable than others. But the group's focus on what Buchs et al. (2004) call *relational solutions*, which is associated with worse learning and more negative relationships, remained as a predominantly background process. What was more foregrounded was a concern for *epistemic solutions* that aimed at accomplishing tasks.

This study has provided an illustration of the intimate interplay between the cognitive and social aspects of grounding activities within a collaborative problem-solving context. With our focus on only one group's interactions which is a one-time engagement with SBI, we obviously cannot generalize for the whole class or for their age group. But the patterns we have unraveled provide a sampling of the potential forms of pupils' grounding processes. As such, they are still valuable for anticipating the pedagogical supports that could possibly match young student's competencies in order to foster and maximize learning through problem solving.

First, teachers need to rethink how collaborative activities can become more accommodating of pupils' everyday knowledge and reasoning through narratives. It is through small spatial stories that children begin to make sense of the phenomena around them (Turner 1996). Also, these constitute building blocks for enlarging and augmenting their understanding and identity (Bruner 1996). Second, considering that pupils default to the mode of everyday argumentation, it becomes essential for teachers to guide them to evaluate and critique the value of evidences. The explicit teaching of argumentation skills finds extensive support in science education literature but so does an experiential approach (Kuhn 2010). Giving pupils more opportunities to participate in goal-directed meaning-making activities coupled with meta-level reflection would be beneficial to improving students' production of a authentic argumentation discourse. Third, teachers could provide pupils explicit and practical introduction to group-work skills, particularly on the use of language for collective reasoning (Mercer et al. 2004; Tolmie et al. 2010). It has been argued that teacher-imposed rules of student engagement in collaborative work can be too restrictive. Instead, what has worked well is allowing students to enter into a kind of social contract for ways of talking and acting 'appropriately', letting them have a hand in identifying and agreeing on the ground rules (Mercer 2004).

And lastly, pupils' difficulties in shifting group decision-making processes into a more inclusive science classroom practice highlight the need for differences in opinions to be recast in a positive and constructive light (Sarangapani 2003). Teachers can guide students to appreciate the value of other's contribution to collective knowledge, as well as encourage them to elaborate on their ideas. These could develop expertise experience in problem solving over time and nurture openness to extend oneself to group members who might need help contributing to collective learning goals.

In line with the key objective of this book, we have presented in this chapter a description of an authentic problem-solving activity for learning science and its implementation in a primary classroom. We have described how pupils articulate, assert and support their ideas, which are key communicative skills crucial in the twenty-first century. Noting that these skills were still nascent, we have identified possible pedagogical supports that could nurture these skills. We also have focused on illuminating the grounding processes of young students not so much to make claims about the effectiveness of SBI as an instructional innovation, which would require more extended studies and larger sampling of group interactions, as to understand the cognitive and sociocultural dimensions involved in collaborative sense making and problem solving. This emphasis is aligned with the recent moves in science education to bring inquiry practices closer to pupils' classroom experiences. It entails teaching science not as a canon but as a process for coming to understand tentative science concepts and their evidentiary bases (Quinn et al. 2011). As educators and researchers continue to rethink school science as the social practice of science in the making, it remains imperative for us to recognize and build upon students' native abilities for engaging in productive discourse for knowledge construction in the classroom.

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Part IV
Authentic Practice in School

Chapter 9
Cultivating a Remix Movement in an East Asian Culture

Kenneth Y.T. Lim, David Hung, Ming De Yuen, and Hon Jia Koh

Abstract This paper aims to introduce the notion of remix as play and as tinkering in the larger context of students' formal education and informal learning opportunities. It discusses issues of East Asian societal cultures, school practice and home support, with respect to balancing the notions of schoolwork and play. The paper illustrates case examples when play and tinkering are fostered within an examination-based education system. In addition, the paper also describes how the dispositions for play and remix arise through the complex relationships of home, school, cultural environments, the supports and opportunities accorded and personal inclinations, interests and dispositions (Hung et al. Asia Pacific Educ Rev 12(2):161–171, 2011). We propose remix as a key need for societies to flourish in the twenty-first century; we further posit that East Asian societies in particular stand to gain from developing such cultures and dispositions.

Keywords Play • Tinkering • Thinkering • Remix • East Asian societies • Twenty-first century learning • Wicked problem • Design thinking

Introduction

Examinations are a dominant feature of the education system and social structure in East Asian societies.[1] Historically, the first public written examination system was introduced in China as a merit-based approach for appointments to government office. In theory, people of humble birth could rise to the upper class by their own

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[1] When we speak of 'East Asian', we mean China and the countries that were heavily influenced by its culture: Japan, Korea, Taiwan, Singapore, etc. We are aware that the cultures and subcultures of the places we just applied the label 'East Asian' to dramatically differ from one another and that the term 'East Asian' is itself a constructed and contested concept. The broad term 'East Asian' is not meant to suggest that the people and cultures within it are identical but to highlight the similarity of certain social and political cultures that, when considered collectively, is meaningful. When we speak of 'Western countries', we are also using the term loosely in the same context.

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will and effort, and those who wished to attain government office often spent years on memorisation of a set of classics. This culture continues to influence the assumptions of many East Asians of what constitutes a good qualification (Webber 1989). Today, examinations are still seen as the main pathway for placement into elite institutions, such as prestigious secondary schools and universities (Dawson 2010; Harman 1994). Be it in South Korea, Hong Kong, Japan, Taiwan or Singapore, parents believe that a good education – as recognised through placement in higher education – provides a child with better opportunities for life. In recent years, the term 'tiger mom' has been made popular by Amy Chan and is used to describe a mother who is a strict disciplinarian. Chua reported that in one study of 48 Chinese immigrant mothers, the vast majority 'said that they believe their children can be 'the best' students, that 'academic achievement reflects successful parenting,' and that if children did not excel at school then there was 'a problem' and parents 'were not doing their job" (Chua 2011).

A social practice emanating from the parents' desire to provide what they consider to be 'the best' for their children is the practice of private tutoring arrangement or cram school – "juku' in Japan, 'buxiban' in Taiwan, 'hagwon' in Korea, 'tutorial school' in Hong Kong…' (Kennedy and Lee 2007, p.74), the aim of which is to prepare for high-stakes national examinations (Kim and Park 2010). While the system has been great at getting students to score well on standardised tests, they fail to prepare them for higher education and the knowledge economy. In an article entitled 'The Test Chinese Schools Still Fail' in The Wall Street Journal, Jiang Xueqin, a prominent Chinese educator, wrote:

> China has no problem producing mid-level accountants, computer programmers and technocrats. But what about the entrepreneurs and innovators needed to run a 21st century global economy? China's most promising students still must go abroad to develop their managerial drive and creativity, and there they have to unlearn the test-centric approach to knowledge that was drilled into them…The failings of a rote-memorisation system are well known: lack of social and practical skills, absence of self-discipline and imagination, loss of curiosity and passion for learning. (Jiang 2010)

We all want students to be better prepared for today's and tomorrow's world. But what preparation is needed? Do we need more people who are good at memorising answers to questions and feeding them back? This paper questions such assumptions of what might constitute 'the best' for children and argues that play and tinkering should not be overlooked in the academic pursuit for credentials and qualifications.

Western countries typically do not foreground qualifications to a similar extent. Instead, embedded in their cultures is the belief that play is important – characterised by messing around with artefacts and ideas. Such a phenomenon is consistent with the current rise of the maker movement in the United States. This movement represents a renewed recognition and emphasis on 'constructionism' (Papert and Harel 1991, p.1–11). This is evidenced by the technologically mediated do-it-yourself (DIY) culture in the United States (Anderson 2012). It spans pursuits and interests in making physical artefacts through the availability of makerspaces, tools and technologies such as the 3-D printer and extends to fabricative activities involving arts, crafts, electronics, woodworking and metalworking. The movement is characterised by a focus on using and learning practical skills and applying them through the exercise of design thinking. Networks of practice among members are common and they cultivate skills, intellect and dispositions for thinking through tinkering (‘thinkering’) (Dougherty 2012; Johnson 2012). Thinkering may be thought of as the disposition to critically analyse designs and systems, to take them apart and to put them together in novel – and often unexpected – ways. The implications of this movement are far reaching and they inform a post-industrial understanding of societal organisation and values.

Another Look at Successful Learners

Since the Industrial Revolution, the development of civil societies in the West has been characterised by periods of steady growth and relative stability. Progress was understood from a Kuhnian perspective of paradigms, perturbations and consensus building; this resulted in long periods of steady state, each of which lasting for several decades. In turn, these steady states meant that skills and knowledge could be developed over time. With a stable career path, both knowledge and skill sets remained relevant throughout a person’s lifetime. The systems of education designed along functional philosophies were able to service the needs of countries well.

Moreover, framed from an industrialised worldview, education systems prepared citizens for jobs roughly categorised as white collar and blue collar. Vocational training was also a means to equip learners with skills relevant for mass production and manufacturing in factories. The universities prepared the more academically inclined for jobs typically classed as white collar.

This dichotomy between the academics and vocational is waning, especially in the age of DIY cultures. In fact, one of the reasons why the maker movement has its origins – and has been appropriated into the formal education system – in Germany (as opposed to the United States) is because of the much stronger emphasis on vocational education in the German education system. This is consistent with embodied cognition, and thus we argue in this paper for the blurring of a ‘minds-on’ and ‘hands-on’ binary towards a more dialectical framing.

Blurring the Binary Between ‘Minds on’ and ‘Hands on’

The maker movements in the United States are grounded within social networks (Anderson 2012). As they transposed themselves from Germany to America, these movements reframed their countercultural orientations from their original political manifestations to more technological ones. Thus, these movements fed off open-source communities, both in terms of open-source software and – more recently – open-source hardware.

As they continually refine and iterate their ideas and artefacts, members of the maker community leverage these same networks. The rapid cycle iterations between fabrication, critical evaluation, peer feedback and refinement clearly illustrate the dialectic of ‘minds on’ and ‘hands on’ (Anderson 2012; Wilson 1999).

The industrial revolution privileged the Cartesian model in which the decontextualisation of knowledge (away from embodied apprenticeships) was legitimated and students learned and began to be assessed predominately through a minds-on pedagogy. Such a constitution of the education system worked well through the nineteenth and much of the twentieth centuries. This is no longer the case. It behoves us to seriously reconsider our worldview and to foreground the dialectic of cognition and context.

The Knowledge Economy and Wicked Problems

The East Asian system of bureaucratically imposed educational standards and standardised tests, with heavy emphases on examination results, has serious pedagogical implications. Teaching and learning are increasingly reduced to formula, rote memorisation and mastery of routine operations. Foondun (2002) reported on an instance of ‘private tutoring’:

> emphasis … on specific examination skills … [and] … inordinate cramming and learning by heart lengthy lists of verbs, comparatives, masculine and feminine, singulars and plurals etc. … But there is worse. In one examination, examiners found 40 scripts of 40 pupils identical. The teacher admitted that ‘he had prepared about 100 possible questions and made his pupils learn the answers to them by heart’. (p. 505)

This system, while efficient at producing workers with high qualification for routine workers jobs in a manufacturing- and service-based economy, is inadequate to prepare workers for ‘knowledge work’. The best jobs in the global economy are going to these ‘knowledge workers’ who can address ill-structured problems in unpredictable ways. Problem solving is a process in which we perceive and resolve a gap between a present situation and a desired goal, with the path to the goal blocked by known or unknown obstacles. Nelson and Stolterman (2003, p. 13) differentiated between the tame problems and the wicked problems. They argued that much of formal education or training is based on preparing students to better identify and solve problems in a reactive mode with tame problem-solving procedures. Wicked problems according to Rittel and Webber (1973) have ten characteristics, among them are:

- Each wicked problem is essentially unique.
- Wicked problems cannot be exhaustively formulated and have no definitive formulation.
- Wicked problems have no stopping rule. Since you cannot define the problem in any single way, it is difficult to tell when it is resolved.
- There is no immediate or ultimate test of a solution to a wicked problem.

Nelson and Stolterman argued that treating a wicked problem as a tame problem results in waste of energy and resources and creates solutions that are not only ineffective but also creates more difficulties. Strategies for tame and wicked problems differ in kinds, not in degree.

The challenges of the twenty-first century are these ill-structured, wicked problems, and it is these problems that the workers of the twenty-first century must craft solutions to. The idea of 'knowledge worker' was first described by Peter Drucker in his 1959 book, *The Landmarks of Tomorrow*. He suggests that knowledge worker productivity is the most important challenge for management in the twenty-first century. Knowledge workers acquire knowledge through a combination of education, experience and personal interaction and then use that knowledge to holistically achieve organisational goals in changing environments. Drucker (1999, p. 142) describes six major factors determining knowledge worker productivity. One of the factors is that continuing innovation has to be part of the work and the responsibility of knowledge workers. Another factor is that this requires continuous learning and teaching on the part of the knowledge worker.

It is important for our society and culture to be able to populate themselves with competent 'knowledge workers' who have the education, experience and desire to practise problem solving and design from a broader perspective than the traditional routine cognitive operations.

Leveraging the Full Diversity of the Talent Base in Education

From the latter half of the twentieth century – precipitated by the forces of globalisation and the imperatives of networked social and economic architectures – the assumptions of steady state that had so successfully undergirded statecraft in Singapore and the West rapidly lost their validity. Instead, we characterise societies in the twenty-first century as being in a continual and dynamic state of change, driven, for example, by the exponential generation of data (Anderson 2012; Thomas and Brown 2011). The implications of such instabilities include those pertaining to how children learn, the nature of disciplinary understanding and the social co-negotiation of structures of authority and trust.

Instead of conforming everyone into the same mould of academic excellence rigidly defined, we see imagination and play as critical to broadening societal discourse about success. The talents of our academically slower or lower achieving students can be harnessed. These latter cohorts of children have always been stronger at expressing themselves through nontraditionally academic means, such as through the visual and performing arts and through craft and design thinking (Oreck 2004). With regard to the latter especially, there is an increasing recognition – since Hagel et al.'s (2008) seminal paper in the Harvard Business Review – that these dispositions and sets of expertise are of critical value to ensuring the nimbleness and adaptivity of societies in the twenty-first century. This is in large part because disciplinary domains are less accurately described as 'stocks' of knowledge but as 'flows' in an age of the networked learner. In such a characterisation, learners are adopting much more co-equal stances with more traditional domain arbiters as they participate and negotiate in the de- and reconstruction of knowledge and the ontologies thereof.

Weinberger (2012) has highlighted the malleability of modern manifestations of knowledge and how this malleability has resulted in the arbitrations of knowledge as being more contested than it has ever been in human history. It is our view that – from such a framing, at least – good questions are more important than good answers. We can learn from maker movements in the West as to how talents can be harnessed.

The Example of Peter

It would be useful at this juncture to illustrate such dispositions towards the malleability of knowledge through an example. Peter is a Singaporean student, presently 15 years of age. Between the ages of three to five, Peter was observed to doodle and in his drawings exhibit the traits of rearranging, combining and adding originals to create something entirely new. His drawings would be instantiations of different creations (e.g. animals, robots, etc.) and in multiple variations, in both portrait and landscape orientations. Between the ages of five and ten, Peter was also observed to love playing the subgenres of role play within the different fictive worlds of Lego. He was observed to have very strong visual abilities and able to construct complex models from these Lego blocks and subgenres, such as Star Wars.

Starting around 10 years of age, he was observed to combine these various subgenres, e.g. Star Wars with Bionicle, as well as within the specific subgenres, and create his own models. Since he loved to play with these toys, his parents encouraged him by buying these to have his interests cultivated. Peter would read fewer books compared to his siblings and spent much time in his own room through the next few years playing with toys.

Most recently, over the past 2 years, Peter has been taking art classes as his co-curricular activity. These sessions have required him to draw and engage in sculpting and in other forms of art which require the use of hands. In these self-expressions, Peter was constantly improving upon and changing the models which he produced.

Concurrently, Peter also became interested in playing the guitar. He acquired the technical skills from online tutorials. Like many musical instruments, the guitar is set up to easily afford itself to experimentation and is thus consistent with Peter's disposition towards experimenting.

As an example, the following exchange was recorded a year ago, shortly after Peter was given an electric guitar by his parents:

> Peter: hear this production. I created it by mixing both the classical and electric guitar.
> Interviewer: What do you mean?
> Peter: well, I used Garageband. Do you know what is Garageband?
> Interviewer: yes, I heard of it before. It's some software on the Mac first?

Peter: yes, I learned how to use Garageband in Sec One [Grade Seven] in school.
Interviewer: so what did you do?
Peter: I recorded by song with the electric guitar. I learned how to record from the internet.
Interviewer: ya, but I also heard the classical guitar in the background.
Peter: precisely. I used my ear-piece and while the piece is being played through the recording, I played the classical guitar.
Interviewer: you mean, you superimposed the classical guitar over the electronic guitar.
Peter: yes, yes.
Interviewer: you interposed two recordings over each other using Garageband.
Peter: yes, yes.
Interviewer: I get it.

Our observations over the years suggest that the disposition for remix – rearranging, combining, editorialising and adding originals – is to create something entirely new. This disposition is as fundamental for his creation as the skills for engaging in the production of physical artefacts. From the case study of Peter, his dispositions for remix started at a very early age and he was accorded the opportunities to mess around with different ideas through drawing, constructing with Lego and attempting different approaches in art and music. He was naturally disposed to experimentation and preferred less procedural and routine canonical approaches and methods although he was able to exhibit traits of conforming to norms and rules.

One would have also observed that Peter was accorded a home environment in which his parents encouraged him to pursue his interests and provided him with the infrastructure (e.g. space in his room, Internet access) and the tools (e.g. the guitar) for him to play and mess around. His environment allows and encourages the creation of derivative works by combining or editing existing materials to produce something new.

Peter was also provided with a social environment which encouraged experimentation. The School of the Arts (SOTA) which he is currently enrolled in is a specialised school for students interested in the arts. Experimentation, discovery learning and a milieu for remix are more evident in the SOTA than in other schools which are focused largely on the pursuit of academic excellence in the formal and canonical sense.

In summary, Peter was given the a) opportunities to remix (including the tools and infrastructure), b) the social cultural environment which is afforded both by the SOTA and the home and c) the initial innate disposition and interest in drawing and playing with Lego which inherently have the characteristics of remix.

Maker Movements and Play

The recent phenomena of maker movements in Germany and the United States are very good examples of the increasingly participatory culture of learning, which characterises so much learning in authentic contexts outside of the formal spatial and temporal bounds of schooling. Turning Descartes's cogito ergo sum on to its postmodern head, maker movements recognise that understanding is socially constructed and frame it in terms of *participate ergo es* – we participate, therefore we are; the very act of legitimate peripheral participation in socially authentic contexts engages selves in dialectic coupling with the social corpus in ongoing shapings and negotiations on identity.

Homo sapiens*: The Knowing Man*

The learnings that accrue from defining ourselves as social beings – in relation to social others – are very different from those which arise from an understanding of self as a stand-alone construct; the latter reinforces a notion of the acquisition of knowledge as stock, and the former foregrounds an understanding of the negotiation of knowledge as flow.

To elaborate, learners engaging in participatory performances in which they derive authenticity thrive on – and look forward to – having their respective creative processes critiqued by social others; one only needs to look at trust-based online communities – such as Flickr, YouTube, eBay, Amazon and fan-authored wikis – for evidence of this. This can be thought of as akin to a shift from a quasi-Cartesian 'I am what I own/I am what I control' to 'I am what I share with others to build upon'.

In such settings, learners derive meaning and authenticity from their membership and participation in interest-driven communities – no one needs to tell them to persevere and improve, instead they engage in a complex series of performances encompassing goal setting, resource evaluation and self-assessment and peer assessment according to both personal and socially moderated standards. In such performative environments, the traditionally binary distinctions between success and failure are rendered meaningless, because the learners realise for themselves that they are not only seeking a continuously shifting bar but – critically – that they have some influence over the nature of the bar itself. That is to say, the learners realise for themselves that they have the ability to create their own contexts for personally meaningful experiences of learning.

Homo Ludens – The Playing Man

Learners engage in the creation and curation of contexts, through deliberate participation in play. The concept of 'play' in educational literature is a difficult notion to define. It is widely accepted that there are a range of views of play, including biological, historical, societal, educational and developmental.

Groos (1898) argued a now well-accepted instrumentalist theory of play that came about by natural selection as a means to ensure that animals would practise the skills they need in order to survive and reproduce. Young animals play more than older ones (since they have more to learn) and those animals that depend less on instincts for survival, and more on learning, play the most. Groos eventually extended his insights from animals to humans (Groos 1901).

He pointed out that humans, having much more to learn than other species, are the most playful of all animals. Human children, unlike the young of other species, must learn different skills depending on the culture in which they are developing. Play allows children to prepare for life by providing opportunities for the practice of skills and offering the possibility of exploring ways of learning what they will need to know as adults.

Craine (2010) argues that children play, far from been frivolous, is actually innate and necessary. He notes that children in very challenging circumstances (such as waiting in emergency hospital rooms, living during the Holocaust) play spontaneously. These children often have little to play with and face pain, hunger or uncertainty, yet they use whatever they have to play creatively. He proposes that this desire to play may be an innate part of being human.

In this paper, we are not just concerned with children play or childhood development. We are working with a boarder definition of 'play'. When we use the term 'play' in this paper, we refer not only to situations, in which participants are actively involved in the structured activities of games or leisure, but also a certain desirable disposition or model of activity that eschew fixity. This approach enables learners to understand, analyse, deconstruct and reconstruct systems and ideas freely. Play in our broader understanding here can, and certainly, exist in formal games. But it does not have to.

Sculptor Richard Serra, known for his huge installations of sheet metal bent into spirals, ellipses and arcs, talks about his process of creating: 'In play you don't foresee an end product. It allows you to suspend judgment. Often the solution to one problem sparks a possibility for another set of problems…. In the actual building of something you see connections you could not possibly have foreseen on that scale unless you were physically there' (Bell 2010).

Nobel Prize-winning physicist Richard Feynman stresses the importance of play in his own study: 'I'm going to play with physics, whenever I want to, without worrying about any importance whatsoever' (Feynman 1985, p. 157). Feynman (1985) went on to relate how he worked out on equations that are critical to his study of quantum electrodynamics, the work that went on to win him the Nobel Prize:

> I was in the cafeteria and some guy, fooling around, throws a plate in the air. As the plate went up in the air I saw it wobble, and I noticed the red medallion of Cornell on the plate going around. It was pretty obvious to me that the medallion went around faster than the wobbling … I had nothing to do, so I start to figure out the motion of the rotating plate … It came out of a complicated equation! Then I thought, 'Is there some way I can see in a more fundamental way, by looking at the forces or the dynamics, why it's two to one?' … I ultimately worked out what the motion of the mass particles is, and how all the accelerations balance to make it come out two to one. (p. 157–158)

Feynman showed them to his advisor who said, 'Feynman, that's pretty interesting, but what's the importance of it? Why are you doing it?' Feynman replied 'There's no importance whatsoever. I'm just doing it for the fun of it' (Feynman 1985, p. 158).

Failures

Framing learning through the disposition of play is important, because it has the corollary that ‘failure’ (as traditionally defined) is an option – to the extent that it is understood as a learning opportunity (Schank 2001; Galarneau 2005) – the whole concept of ‘cheating’ (taking a shortcut to success) is also rendered invalid because the learners would not stand to gain personally from having ‘cheated’. Cheating is only a worthwhile strategy if assessment is understood as a stand-alone output (‘stock’), as in ‘I won’/‘I achieved the highest score’. It loses its validity once personal worth is understood as a developmental process (‘flow’), as in ‘I am getting better at this’/‘I am understanding better how this works’. Further, few think of leveraging the technologies to ‘cheat’, because they realise for themselves the hit that would mean to their reputations in these communities – the premium that Shakespeare’s *Othello* placed on reputation still rings true today. In this way, these interest-driven communities have helped redefine understandings of apprenticeship, in ways which extend its roots from social enculturation into a more contemporary understanding of the nature of the learner and the learned.

Henry Petroski, in a series of books, advocated a philosophy of building upon failure as a basis for design success and that all design is an evolution of a previous design. He suggested that the common belief ‘form follows function’ is inadequate as an explanation for how many of the objects we take for granted – forks, paperclips, zippers, etc. – came to be. Instead, these objects are the current result of a long, often meandering developmental process, one driven by the shortcomings of previous designs: ‘form follows failure’ (Petroski 1992a). The form of the new design follows the real and perceived failure of things as they are and what they are supposed to do. Designers observed the failure of existing things to function as well as might be imagined and, focusing on the shortcoming of things, altered those items to remove the imperfections, producing new, improved objects. He further developed his ideas by giving us examples of engineering failures that can teach us how to build better bridges, buildings and machines with well-known examples of well-intentioned but ultimately failed design in action -- the galloping Tacoma Narrows Bridge, the collapse of the Kansas City Hyatt Regency Hotel walkways and so on (Petroski 1992b). The single most important driving force behind innovation and change is the failure of existing design. As shortcomings become evident and articulated, a new and ‘improved’ design comes into being.

The Red Bull FlugTag as an Example

The Red Bull FlugTag is an event in which competitors attempt to fly home-made, size- and weight-limited, human-powered flying machines. The event is held annually in more than thirty cities worldwide, including in East Asia. The flying machines are usually launched off a pier into the sea (or suitably sized body of water). Most competitors enter for the entertainment value, and the flying machines rarely fly at all. Anyone is eligible to compete in the FlugTag event. The craft must be powered by muscle, gravity and imagination. Teams that enter the FlugTag competition are judged in three categories; distance, creativity and showmanship.

The example of FlugTag is useful in shaping the general discourse about learning and what constitutes success in learning. This is because it shows that the binary distinction between 'success' and 'failure' can be made intelligible to Asians in Confucian societies, in terms of thinkering. In other words, the people who participate in FlugTag know they are going to 'fail' in the sense that the event is constrained by the physics of heavier-than-air flight. Yet they still sign up to participate, even though they know they are going to fail. Why so? They do so because they do not frame their participation in terms of the simplistic binary of success and failure.

The second insight about FlugTag is that it is an event during which the participants are able to engage in a dialectic between their cognitive knowledge and their embodied experience, as they thinker.

As they thinker, 'fail' and thinker again, they are developing intuitions about how systems operate, about how to leverage social networks and about disciplinarities pertaining to the challenge at hand; depending on the nature of the challenge, these disciplinarities might range from principles of physics (in the case of FlugTag) to culinary design.

These are preceding two key characteristics of FlugTag, namely, that it is designed such that participants know they are signing up for what is for all intents an 'impossible' challenge – the competition is not in 'winning' per se but in 'failing' in the most elegant or most interesting or most imaginative ways – and that while competing to 'fail' in these ways, they are actually learning much more than if the challenge was designed in a more traditional manner. Such events have the potential to kickstart – and subsequently nurture – maker movements and thinkering cultures in East Asia. Such challenges need not necessarily to be centred around fabrication (as they have been in the West), but can also leverage the characteristic of remix inherent in immigrant societies such as Singapore, such as in improvisational music, comedy, the performing arts, cuisine, multicultural crafts and industries related to the lively (and internationally recognised) clubbing scenes. In turn, the thinkering dispositions and maker cultures which would be nurtured would help broaden the electoral discourse into wider understandings of success and 'failure'.

Remix

We acknowledge the inextricable nature of cognition and context. In fact, Thomas and Brown (2011) posit that tools and environments today afford learners to create new contexts. The Singapore government has been very effective at creating new contexts for learning through careful planning. For example, in order to cultivate talent in the arts, sports and mathematics/science, specialised schools (e.g. SOTA, Sports School and NUS High) were conceptualised and founded. The creation of contexts is not only the privilege of the established institutions but is possible even for those traditionally seen as outliers and at the periphery of society, such as students from Assumption Pathway School, which was set up with the specific mandate to help the most at-risk children in Singapore.

The dispositions to play and imagination should be encouraged. Students have the potential to create contexts through powerful, compelling and complex narratives. Such recontextualisations of talent enable new forms of interactions to occur. These include leveraging professional practice. Over time, students (and teachers) would build closer relationships with practitioners within the same community-networks.

We acknowledge that these specialised schools are expensive relative to typical schools; in the overall ecology of schools, we need to have a diversity in which talents can be harnessed and cross-fertilisations are encouraged.

Play Is Not Frivolous

Policy makers need to understand that the value of these creative diversions lies not directly in the learning within the interest domain (e.g. skateboarding, knitting) but in the literacies and dispositions engendered by the socially networked embodied practice that participation in such interest domains involves. These literacies and dispositions can (and should) be mediated (through brokering) to be directed towards improved performance in more traditionally understood outcomes (e.g. academic grades).

The state-sponsored structuring should therefore manifest itself through the brokering and not in the setting aside of creative spaces per se. The illustration below provides a case example of a spontaneously emergent interest-driven makerspace that would stand to gain from such a light-touch state brokering. The student in Fig. 9.1 is a member of the National Cadet Corps (Air) uniformed youth organisation in a state-funded school in Singapore. He and his friends from this co-curricular activity have extended their interest in aeromodelling into thinkering critically about electronics and mechanics more generally. The diagram shows the student holding a go-kart he and his friends created by taking apart and cannibalising parts and materials from existing off-the-shelf remote-controlled vehicles (in this case, a motorised glider). Created using funds pooled from their own savings and using scrap materials and tools from the school's metal- and woodworking workshop, the go-kart represents an authentic example of remix and thinkering that reflect the kinds of students that East Asian societies will have to increasingly depend upon in order to stay relevant, adaptive and responsive in the twenty-first century. Going forward, it would do well for state-funded initiatives to consider how passion-driven street-craft communities might be encouraged through the provision of infrastructure and access to shared resources/tools/expertise.

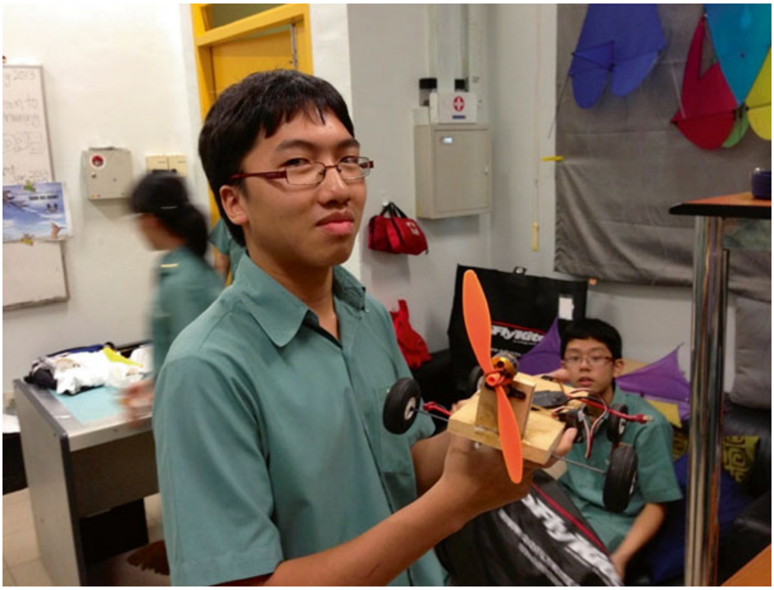

Fig. 9.1 Thinkering in the context of aeromodelling and beyond

Remix as a Disposition and a Movement: The Case Study of Singapore

In this framing of a more broad-based and textured blueprint for East Asian societies, opportunities need to be provided for the nurturing of spontaneous grassroots movements and communities of interest. In Singapore, such emergent movements and communities have already started, facilitated as they have been by social media. Going forward, we see such movements and communities as playing an increasingly larger and more critical role in shaping the socioeconomic and sociopolitical discourse in Singapore – it therefore behoves us to thoughtfully design for such discourse to be channelled towards economically productive ends, rather than just being so much white noise.

Recent grassroots movements in America (and, to a lesser extent, in Europe) offer valuable models from which to design for a uniquely Singaporean interpretation of socially networked and entrepreneurial communities to emerge and flourish. As stated earlier in this paper, these maker movements originated in Europe (specifically Germany, originally as underground political subcultures) and have permeated throughout many cities in America. American maker movements – and their impact upon shaping sociopolitical discourse – have been the subject of study by academics from Harvard to Stanford. They have developed through very different trajectories from their European roots and have taken on a strong fabricative flavour. As such, they are often (though not universally) associated with geeks, gamers and generally those with a technological bent. Such evolutions from the original augur well for further mutations in the unique cultural contexts of East Asia.

Regardless of their histories, flavours and trajectories, the maker movements all have in common what we have referred to earlier in this paper as the 'thinkering' disposition. In this respect, thinkering has much in common with many improvisational performance arts, and examples of thinkering can be drawn from music such as jazz, stage drama and comedy (e.g. the Singaporean productions/artistes such as the Mr. Brown Show, Hossan Leong and Kumar) and culinary and cocktail-mixing art forms (e.g. mixology and its influence on the club scene along Clarke Quay in Singapore).

These latter examples are significant because these are the very same areas in which Singapore is fast building up regional and international reputations (Chang 2002). More critically, these same examples are significant because they represent viable, point-at-able exemplars of areas in which local faces are represented and are recognised by the electorate at large. Local personalities who have built for themselves sustainable career trajectories in these – and similar areas – will play potentially vital roles in shaping the socially mediated discourse over the next decade as to what constitutes success in Singapore.

Thus far we have positioned this paper as a cultural imperative for change with regard to increasing degrees of play and thinkering; at the same time, we recognise that remix also takes place at the level of the individual – this is manifested in one's interest-driven disposition to remix by thinking, making and performing, usually in dialogue with social others (Knobel and Lankshear 2008).

Discussion

The key issue is considering how it is possible for students in East Asian societies, in which examinations are seen as a leverage for social mobility (Cheng and Wong 1996), to engage in opportunities for play, thinkering and remix.

First, an excessive emphasis on qualification and credentialism as a yardstick for social mobility is potentially problematic. This leads to the zealousness of parents desiring to offer what they perceive to be the best for the children; with a rising middle class, children are sent for additional tuition.

Second, we recognise the importance of informal learning; the latter is aligned with 'messing around' and 'hanging out' with interest-driven groups and communities (Ito 2010). Although there may not be certifications arising from these activities, parents should take time to understand what is happening in these activities and groups instead of assuming that they are a waste of their children's time. In today's interconnected society, one can find many interest groups online and they are replete with opportunities for informal learning. Parental guidance is necessary and scaffolds can be provided to children and youths.

Third, parents and schools need to recognise that canonical approaches to content and skill sets are frequently framed from a paradigm of teaching rather than through that of encouraging students to experiment and ‘mess around’. Since the craft or trade has already been codified, the default approach is to teach such codifications. The methods for teaching canon are through pedagogies which are time efficient. More often than not, this leads to drill and practice. Moreover, canonical approaches are associated with accreditation and formal certification, and the latter are less aligned with the dispositions of play and remix. We are not suggesting that the canonical approaches are not good for society. We acknowledge their place, but we submit the argument that an excessive focus on these can be detrimental to the development of interest-driven learning in children, as well as to the cultivating of the dispositions for play and remix. These dispositions have been recognised to a greater degree in subjects such as home economics and design and technology.

Fourth, we want to reiterate the earlier point that dichotomies between academic and vocational training as traditionally conceived should be reconceptualised in the light that creating things (material and otherwise) and artefacts – as with the maker movement – is both a matter of mind and body as an integral coupling. Schools and society should not view vocational skills as less important and privileged compared to academic discourses. The dispositions of play and remix are central to the innovations of products which should equally emphasise hands and minds.

Fifth, considering the maker movement as discussed in the earlier part of this paper, there is a need for a cultural shift in East Asian societies for remix. The remix culture for cultivating these dispositions should not only be instilled when children are young but also sustained through school and after school (Pinkard et al. 2008). There is a need for society to recognise talents beyond the academics featured on credentialism and in the process gradually create the market and demand for products produced through remix.

Our sixth point is that opportunities for remix need to be provided by society – whether through governmental or private funding – for remix to productively occur (Ginsberg 2012). These could be similar infrastructure such as the Techshops and hackerspaces established where infrastructure (e.g. open spaces) and equipment and tools can be made available to all.

Conclusion

As they progress through the formal schooling system, students in East Asian societies typically learn to suppress the time and effort invested in exploring their interests because the rhetoric from the state and societal groups is that these exploratory diversions represent inefficient expenses of time and resources, which could be better invested in more direct, outcome-driven behaviours (Ng 2004). It is our contention that thinkering and the playful experimentative disposition are therefore not sufficiently valued in many societies throughout East Asia.

Home-grown examples of improvisation and remix – in a variety of fields – can help shape local understandings that the creative performance and innovations of such actors lie less and less at the periphery of a society’s overall cultural discourse.

Instead, their very domesticity demonstrates a transcending of historically defined binaries of core and periphery, academic success and vocational success and formal and informal learning.

The prevailing narrative on the city state of Singapore since postcolonial independence has been that she is a state with no natural resources (Quah and Chan 1987; Lee 1998; Grover 2000; Ganesan 2005). It is indeed true that by dint of her geopolitical context and her globalised economy, Singapore is particularly exposed to the vagaries of sociopolitical and economic forces external to the country (Quah and Chan 1987; Lee 1998; Grover 2000; Ganesan 2005). It will take time for both state and electorate to confidently mediate these edge interactions, but this will eventually broaden the definitions of success, painting a more textured, nuanced landscape of what it means to be successful, in an East Asian society such as Singapore.

It is important to make the point that we should not seek to merely recreate – or even nurture – a grassroots maker movement modelled almost entirely as a facsimile of the American model. Doing so would indeed be possible, but it would run the risk of not evolving into anything approaching a self-sustainable, self-funding model of entrepreneurial learning, adaptivity and innovation.

Instead we propose ‘RemixSG’ (‘SG’ as a reference to Singapore) – a maker movement that is uniquely and recognisably Singaporean. Such a maker movement would not completely shun the fabricative flavour that so characterises many American maker movements (as well as those burgeoning in the major cities of mainland China and South Korea) neither would it have such strong underground countercultural roots as those in Germany and other parts of Europe. Instead, RemixSG should leverage the fact that Singapore is essentially already a remixed, improvisational nation state, with its own viable and sustainable flavour, such as in terms of cuisine, stage and performance arts and architecture. In such a framing, spaces for more explicitly technological remix (as per the American model) would exist side by side with spaces where communities of interest can emerge and grow around thinkering centred around other manifestations of creativity and innovation.

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Chapter 10
Authentic Thinking with Argumentation: Putting on the Thinking Caps of Scientists and Designers

Jongho Baek, Eunjung Koh, Young Hoan Cho, and Dae Hong Jeong

Abstract A growing number of science educators make efforts to facilitate participation in authentic practices, such as scientific experiment and inquiry-based learning. In science education, integrating guided inquiry with engineering and technology can provide learners with opportunities to apply scientific concepts and principles to the design of artifacts and generate meaningful questions for scientific inquiry. Argumentation plays a crucial role in both science inquiry and design activities. Learners need to create, compare, and evaluate arguments so as to explain scientific phenomena and design an artifact for solving a real-world problem. This chapter provides a conceptual framework that can be used in the development of learning environments for authentic thinking with argumentation (ATA). The ATA model is carefully designed to promote students' competence in argumentation, in conjunction with the implementation of inquiry and design-based activities. The ATA consists of two main activities, POE (prediction-observation-explanation) and DOE (design-observation-evaluation), which reciprocally influence each other.

Keywords Argumentation • Inquiry • Design • Problem solving • Authentic task

Introduction

It is important that learners are able to use their knowledge to explain a phenomenon and to solve a real-world problem. However, we often see students who score high in science examinations, and yet express a lot of difficulty in applying what they have learned in school to real situations (Brown et al. 1989). In order to address this

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problem, science educators have encouraged learners to create and use their knowledge while carrying out an authentic task like scientific inquiry. Instead of memorizing scientific concepts and principles for examinations, learners need to explore diverse scientific phenomena, formulate their own hypotheses, collect evidence to support their claims, evaluate different viewpoints, and communicate scientific findings with other learners. To enhance the effectiveness of inquiry activities, science educators should provide novice learners with appropriate instructional supports like question prompts, scripts, examples, and feedbacks. Otherwise, learners may spend a lot of time in carrying out a demanding task, without constructive or reflective thinking (Kirschner et al. 2006). Through guided inquiry activities, learners can develop not only an in-depth understanding of scientific concepts and principles but also twenty-first-century skills like critical thinking, problem solving, collaboration, and self-regulated learning.

In addition to guided inquiry, a growing number of science educators emphasize the integration of science education with engineering and technology education. Science theories have been applied for the development of new technologies like smart phones, medical devices, and sustainable energy. New technologies also help scientists to pose new research questions. Scientists often collaborate with engineers to solve complex problems in the real world. In this point of view, science educators recognize that learners have to participate in science and engineering practices in order to apply their scientific knowledge. This view implies that learners need to develop integrated, rather than isolated, knowledge. This assertion is well reflected in the framework for K-12 science education in the U.S., which emphasizes integrating engineering and technology with natural sciences for two important reasons: "(1) to reflect the importance of understanding the human-built world and (2) to recognize the value of better integrating the teaching and learning of science, engineering, and technology" (National Research Council [NRC] 2012, p. 2). Science educators need to help learners not only to understand science concepts or principles but also to use their knowledge for designing and developing artifacts to improve their everyday lives.

This chapter intends to provide a conceptual framework for the design of a learning environment that allows learners to participate in authentic practices of the science and design communities. With respect to this approach, learners should be encouraged not only to carry out inquiry activities that involve formulating and testing hypotheses that explain scientific phenomena, as scientists do, but also to design and develop artifacts aimed at addressing practical needs or problems, as engineers do. For this purpose, scientific inquiry needs to be systematically integrated with design activities (Kolodner et al. 2003). The integration of science and design practices can provide opportunities for learners to act and think like scientists and engineers.

As both scientific inquiry and design tasks involve complex and ill-structured problems that do not have a single right answer, it is expected that learners will offer diverging solutions and engage in arguments to arrive at consensual solution. These processes also happen in the practice of science and engineering. Scientists create and justify hypotheses about particular phenomena. Engineers also need to negotiate with their colleagues to decide the design of their new products which is often supported with usability tests of prototypes, customer surveys, and expert opinions.

To efficiently carry out these processes, the application of key argumentation competencies, such as distinguishing scientific evidence from hearsay and evaluating opposing viewpoints (Jonassen 1997; Voss and Means 1991). However, many students were found to have weak argumentation competencies, particularly in distinguishing evidence from explanation and considering opposing viewpoints (Kuhn 1991; Voss and Means 1991; Wolfe et al. 2009).

Although it is increasingly recognized that students need to be provided more opportunities to develop their argumentation competencies, only a few educational interventions have been developed to this end (Kuhn and Katz 2009; Nussbaum and Schraw 2007). There is also little research focusing on the role of argumentation in the processes integrating scientific inquiry with design activities. Drawing upon the existing literature, this chapter presents a conceptual model of authentic thinking with argumentation (ATA) that promotes authentic thinking in scientific inquiry and design activities.

What Is Argumentation?

Argumentation is a "social, intellectual, and verbal activity serving to justify or refute an opinion, consisting of statements directed towards obtaining the approbation of an audience" (van Eemeren et al. 1987, p. 7). Its main aim is to produce a "rational resolution of questions, issues and disputes" (Siegel 1995, p. 162). An argument, which is considered as a product of argumentation, corresponds to a reasoned discourse or claims with evidences (Simon et al. 2006). In order to make a valid argument, learners should not only create a claim but also support it with evidence through deductive or inductive reasoning. Argumentation is a complex and iterative process whereby learners create, suggest, criticize, and evaluate diverse ideas until they reach a consensus about a controversial issue (Osborne et al. 2004).

Argumentation involves cognitive and social activities (Erduran and Jiménez-Alexandre 2008; Jonassen and Kim 2010). The cognitive aspect of argumentation involves an epistemic process in which individuals are engaged. Billig (1987, p. 44) considered the individual aspect of argumentation as "a piece of reasoned discourse", which requires making a connection between claims and data based on the viewpoints of individuals about a given phenomenon (Sandoval and Millwood 2005; Zohar and Nemet 2002). With respect to the social aspect, argumentation includes disputes and debates arising from conflicting stances on a given issue (van Eemeren and Grootendorst 2004; Fuller 1997). According to Nersessian (1995), the cognitive and social aspects of argumentation cannot be absolutely separated. As scientists do, learners need not only to create a scientific argument but they also need to convince other learners. In order to support a particular position, they should develop well-organized arguments and make rebuttals against alternative positions, which can be promoted through constant interaction with others. This collaborative interaction may, in turn, lead to the improvement of argumentation quality as well as the development of higher-order thinking skills (Kuhn 1993). Thus, both the cognitive and social aspects of argumentation should be sufficiently considered in learning to argue and arguing to learn. Through collaborative argumentation, learners evaluate the persuasiveness of claims and counterclaims, truthfulness of evidence, and validity of a conclusion. While learners synthesize different viewpoints to reach an agreement during the argumentation process, they can change their naïve beliefs and build new knowledge (Nussbaum 2008).

Argumentation also plays an important role in various domains such as science, engineering, and economics. There are multiple instances when practitioners need to persuade others to take different opinions about a controversial issue (Cohen et al. 2000; Jin and Lu 2004; Jonassen and Cho 2011; Erduran and Mugaloglu 2013). As a key competency required for solving open-ended, authentic problems in a knowledge society, argumentation has been highlighted in K-12 education as well as higher and professional education. In science education, "engaging in argumentation from evidence" (NRC 2012, p. 49) has been considered as an important learning activity for scientific thinking and knowledge building.

Argumentation in Scientific Inquiry

Researchers in the field of developmental psychology and science education have conducted comparative studies between children and scientists (Brewer and Samarapungavan 1991; Gopnik and Wellman 1992; Helm and Novak 1983). These studies reveal that children can make arguments, as scientists do, although their arguments are structured in naïve forms. As young scientists, children can evaluate scientific theories (Samarapungavan 1992) and coordinate theories and evidences (Karmiloff-Smith 1988). However, children tend to develop knowledge by themselves without taking part in social processes, such as persuasion (Brewer 2008), because they seldom have chances to share and debate their scientific knowledge. According to Erduran and Jiménez-Alexandre (2008), argumentation contributes to the development of scientific competencies, which are all important for authentic thinking in science education. These competencies include communication, critical thinking, scientific literacy through talking and writing, epistemic criteria, and reasoning. Thus, it is important to provide children with opportunities to share their scientific knowledge and engage in argumentation.

In scientific inquiry, argumentation plays important roles particularly for causal reasoning, evaluation of hypotheses, and communication. During science inquiry, learners need to predict the results of a scientific experiment and explain how or why a scientific phenomenon occurs. For example, Kuhn and Katz (2009) asked students to make inferences about the variables that can predict earthquakes and to justify their inferences after exploring several earthquake cases. The cases included information of earthquake risks and other variables like soil types, S-wave rates, and water quality. The validity of the claims was evaluated in terms of accuracy and quality of evidence provided to support the justifications. In this study, argumentation was used to promote causal reasoning, which is essential in scientific inquiry.

In carrying out scientific inquiry, learners should create multiple hypotheses to explain a scientific phenomenon based on the scientific literature and their own experiences; argumentation is also needed to evaluate different hypotheses. As learners investigate which among a list of hypotheses is the most valid, they conduct experiments and scientific research. In going through this process, learners also engage in creating diverse arguments and evaluating them with standards of scientific inquiry. Nussbaum and Schraw (2007) pointed out that people are not likely to consider counterclaims in their arguments although integrating diverse viewpoints makes an argument more persuasive. Instructional supports are necessary to help learners to justify their own hypotheses by comparing them with alternative hypotheses.

The social aspect of argumentation is closely related to collaborative activities in scientific inquiry (Driver et al. 2000; Sandoval and Reiser 2004). Just like scientists, learners should support their arguments with evidence to persuade others that their claims are valid and reliable. Scientific inquiry also leads to productive knowledge building when learners jointly contribute to scientific argumentation by elaborating or challenging opinions of other group members. In addition, taking part in collaborative argumentation can contribute to the development of learners' skills in communicating ideas with scientific language.

Argumentation in Design Activity

In engineering design process, a delivery of products that meet the needs of customers is a key component (Jin and Geslin 2010). The needs and criteria are not predetermined, and the way of solving the design problem has no pre-determined answer (Buchanan 1992). Thus, designers need to find the needs and the way to satisfy these needs. The quality of design can be evaluated in terms of diverse criteria such as performance, convenience, safety, creativity, competitive price, and whatever a market requires. In order to satisfy the needs and to improve the quality of design, engineers make efforts to articulate the needs of customers, explore multiple solutions with restricted resources, and develop and test prototypes. They also evaluate their design based on reasonable evidence, and explicate their reasoning to justify their artifact. In line with this, Shum and Hammond (1994) suggest argumentation-based design principles to justify design decisions and explain design processes. Design tasks require complex cognitive processes including "design thinking" (Brown 2008), which fosters a decision-making ability (Tang et al. 2010).

Kolodner and her colleagues (2003) described the requirements of design tasks as follows:

> Understanding the challenge and the environment in which its solution must function well; generating ideas; learning new concepts necessary for its solution (through a variety of means, ranging from asking an expert to reading to carrying out an investigation); building models and testing them, analyzing, rethinking, and revising; and going back to any of the previous steps to move forward, repeating until a solution is found. (p. 504)

A complex design task requires collaboration with other engineers for a better solution. It is essential in this collaborative work to gather opinions from various experts and discuss with collaborators to reach the goal because such collaboration needs to overcome the limitation of resources, expand the technological accessibility, and resolve conflicts among diverse opinions. The discussion and negotiation involved in these processes necessitate effective argumentation skills among engineers (Jin and Geslin 2010; Jonassen and Kim 2010). Collaborative decision making with argumentation can help engineers to establish reasonable principles to guide their design process (Suh 2006).

Design Principles for Authentic Thinking with Argumentation

The ATA refers to an instructional model that involves argumentation, with both its cognitive and social aspects, to promote authentic thinking in real-world problem-solving. On the basis of a literature review, we described the ATA design principles in terms of (a) ATA process, (b) problems and tasks, (c) resources, and (d) instructional support (see Table 10.1).

ATA Process

The ATA process involves cognitive, social, and metacognitive activities pertaining to argumentation. Argumentation activities occur in an iterative way because learners tend to generate, share, evaluate and modify arguments in complex and nonlinear ways. In order to promote these activities, instructors can provide an authentic problem-solving situation in which learners are able to produce a variety of products or answers (Jiménez-Alexandre and Pereiro-Munhoz 2002; Kelly et al. 1998). Learners are encouraged to justify why the problem is important, what constraints the problem involves, what causes the problem, and why a solution is appropriate. Moreover, in this problem-solving situation, learners are asked to compare their own opinions with those of others and evaluate different perspectives based on shared standards so as to generate more valid solutions or synthesize varied perspectives (Siegel 1995). This process can enable learners to articulate their assumptions underlying different solutions and identify limitations of their arguments (Sandoval and Reiser 2004). Lastly, learners also need to reflect on the ill-structured problem-solving process along with the quality of their arguments. By reflecting on the argumentation experience, learners can recognize the weakness of their argumentation skills and domain-specific knowledge, which provides learning opportunities for advanced argumentation.

In addition, ATA can be promoted through collaborative and social interaction in which learners elaborate or challenge opinions of other group members (Nussbaum 2008). It is important that all learners equally participate in the collaborative

Table 10.1 Design principles for authentic thinking with argumentation

Category	Design conjecture for promoting argumentation	Reference
ATA process	The process of generating arguments to solve authentic problems	Jiménez-Alexandre and Pereiro-Munhoz (2002), Kelly et al. (1998)
	The process of evaluating and synthesizing different arguments	Sandoval and Reiser (2004), Jiménez-Alexandre and Pereiro-Munhoz (2002)
	The process of collaboration between learners	Krajcik et al. (1998), Nussbaum (2008)
Problems and tasks	Ill-structured problems	Clark and Sampson (2008), Kolodner et al. (2003)
	Tasks in the context of daily life	Jiménez-Alexandre and Pereiro-Munhoz (2002), Sadler and Donnelly (2006), Mork (2005), Zohar and Nemet (2002)
Resources	Visualization tools	Nussbaum and Schraw (2007), Osborne et al. (2004), Suthers et al. (2008), Cho and Jonassen (2003)
	Database	Kuhn and Katz (2009), Kolodner (1997)
	Simulation	Clark and Sampson (2008), Crawford and Cullin (2004)
	Portfolios	Land and Zembal-Saul (2003)
	Communication tool	de Vries et al. (2002), Kirschner et al. (2003), Scardamalia and Bereiter (2006)
Instructional support	Cognitive support	Wolfe et al. (2009), Osborne et al. (2004), Mork (2005)
	Metacognitive support	Quintana et al. (2005), Davis and Linn (2000), Cho and Jonassen (2012), Voss and Means (1991)
	Social support	Garrison and Arbaugh (2007), Mork (2005), Weinberger and Fischer (2006), Stegmann et al. (2007)
	Adaptive support	Graesser et al. (2005), Pinkwart et al. (2009), Cho and Schunn (2007)

argumentation process. If learners simply agree or disagree with each other without in-depth discussion, peer interaction may not lead to effective knowledge building and collaborative problem solving. To promote collaborative argumentation, instructors can provide the learners with different roles that stimulate consideration of diverse perspectives on a problem or topic. Moreover, collaborative argumentation can be enhanced when learners individually prepare their own arguments ahead of the collaborative activity. This preparatory activity can help build the learners' confidence and reduce thinking time, thereby making it easier for them to participate in the activity.

The ATA process, which incorporates science inquiry and design principles, includes two sub-processes: Prediction-observation-explanation (POE) and the

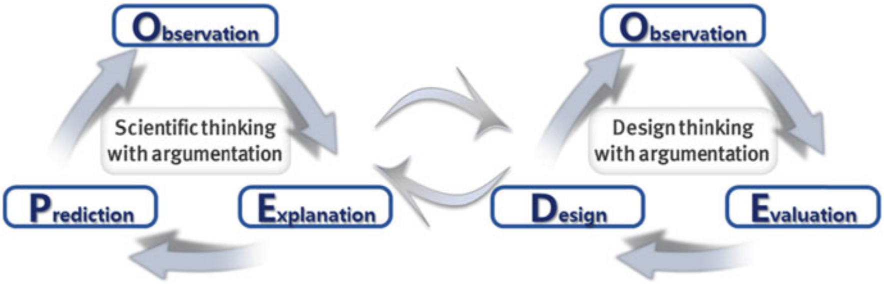

Fig. 10.1 Process of learning by authentic thinking with argumentation (ATA)

design-observation-evaluation (DOE) activities (see Fig. 10.1). The POE allows learners to generate their arguments on the basis of known scientific principles and compare these arguments using a list of questions as a guide. In a real-world context, learners make predictions or formulate arguments in relation to a particular issue or phenomenon, justify their predictions or arguments, make observations or collect information, compare their predictions with their observations, and maintain or modify their initial ideas through evaluating their initial arguments with evidence (Osborne et al. 2004). In DOE, learners generate their arguments and designs to solve an authentic design problem, observe how people use the designed artifacts, and evaluate their initial arguments and artifacts in regard to how well they meet design objectives and constraints, which is often followed by iterative redesign process (Jonassen 2011; Kolodner et al. 2003). Learners should generate, justify, compare, plan, monitor, reflect on, share, negotiate, and challenge their arguments while carrying out scientific inquiry and design activities.

Problems and Tasks

In designing ATA tasks or problems, it is deemed that argumentation play a more crucial role in solving ill-structured problems than well-structured ones. Ill-structured problems can be supported by competing theories and interpreted and solved in multiple ways. They require learners to compare diverse perspectives and collect evidence to support their own solution or reject alternative ones (Driver et al. 2000; Jonassen 1997). Argumentation in relation to solving ill-structured problems was applied in studies focusing on science education or design education. For example, Clark and Sampson (2008) introduced a problematic situation in which the temperature of objects set in the same room was felt differently and asked students to establish their own principles for explaining this phenomenon. In relation to design education, Kolodner et al. (2003) asked secondary school students to design a low-friction coaster car that can go farthest after running on a ramp.

Another useful element that ATA problems and tasks may include would be realistic contexts. Framing problems in authentic settings can encourage learners to be actively engaged in argumentation activities. In realistic contexts, learners can easily make sense of the purpose of argumentation and activate their prior experience and knowledge as source of argumentation. For example, social-scientific issues like environmental pollution can be useful to promote argumentation based on ethical perspectives as well as scientific principles (Jiménez-Alexandre and Pereiro-Munhoz 2002; Sadler and Donnelly 2006). This approach was used by Mork (2005), who used TV debates between politicians about a controversial issue of the wolf population in Norway. Zohar and Nemet (2002) also provided students with a realistic dilemma situation about human genetics in order to encourage students to use biological knowledge and ethical principles to support their opinions.

In addition to the use of realistic contexts, argumentation tasks can also focus on presenting controversial issues that are familiar to the learners. The inclusion of controversial issues can serve as a fertile ground for learners to create arguments by considering different viewpoints of stakeholders within a problem (Mork 2005). Argumentation competencies can be facilitated when it is easier for the learners to generate diverse perspectives. On top of these, learners should be able to understand and evaluate the merits of different opinions or competing theories to explain a phenomenon (Keogh and Naylor 1999) and support alternative arguments with evidence (Osborne et al. 2004).

The ATA model, thus, requires ill-structured problems that involve realistic contexts and feature contentious scenarios that are within the grasp of the learners. In secondary school, for instance, a *Swimsuit Design* task can be used for developing students' understanding of the principles of buoyancy. A teacher provides students with an authentic problem situation that requires them to design a swimsuit for paraplegic patients. After assigning the students to work in groups, they are required to generate some arguments about the design of the swimsuit and to support their design ideas by considering the diverse needs of the patients, available resources, and the principles of buoyancy.

To help the students develop the target scientific principles, which are necessary for the swimsuit design, the teacher can provide the POE tasks shown in Fig. 10.2. The teacher can show a video clip in which a researcher puts dry ice within a balloon, ties it, and puts it on an electronic scale. The teacher asks the students to predict what would happen to the weight of the balloon. Students need to think of their own predictions and reasons for their predictions, and to share their ideas with other

Fig. 10.2 An example of problems given in video clips

group members. Next, the teacher can also show a video clip in which the dry ice changes from solid to gas, which makes the tied balloon expand while the weighing scale indicates a decreasing value in the balloon's weight. Students need to record what they observe in the video and compare it with their initial prediction. Lastly, students discuss with their group mates about the reasons why their observation is consistent or inconsistent with their initial prediction.

The POE tasks are followed by DOE tasks, which require students to develop and test a prototype of the swimsuit. At the design stage, students independently draw a swimsuit and justify why their swimsuit design is appropriate for the paraplegic patients. In crafting their design, the students are also asked to identify the suitable materials (e.g., cotton fabric, plastic, aluminum foil, and bubble wrap). In small groups, students can compare their design ideas and discuss which would be the most satisfactory design solution. Then, students make a swimsuit prototype using agreed materials. Alternatively, they can make different prototypes using different materials. In the observation stage, students test how well their swimsuits work in water (see Fig. 10.4). Lastly, students evaluate their swimsuits based on a list of multiple evaluation criteria, which include functionality, aesthetics, and convenience for the target user. In order to improve the swimsuits, students can modify their design ideas or use different materials. The DOE cycle can be repeated until students are satisfied with their swimsuits.

Resources

There are a variety of resources to support argumentation, which include visualization tools, databases, simulations, portfolios, and communication technologies. Visualization tools can help learners to articulate the relationships between argumentation components or between arguments and counterarguments. Nussbaum and Schraw (2007) found that a graphic organizer was beneficial for integrating arguments with counterarguments to formulate a conclusion because the graphic organizer explicitly represented the relationships among arguments, counterarguments, supporting reasons, and a final conclusion. By visualizing arguments, learners can be engaged in reflective thinking and evaluating the validity of their arguments (Osborne et al. 2004; Nussbaum and Schraw 2007). Moreover, visualization tools can also aid learners to communicate with each other by explicitly representing abstract concepts, invisible objects, and relationships between data and hypotheses. Suthers et al. (2008) found that an online knowledge-mapping tool effectively encouraged learners to integrate information distributed between learning partners and to reach a common conclusion. Cho and Jonassen (2003) also found that *Belvedere*, a synchronous constraint-based system which enabled students to collaboratively visualize an argument with pre-defined argumentation constraints and links, contributed to generating coherent arguments in group problem-solving activities.

For novice learners, databases can be useful when exploring possible solutions to a problem or developing hypotheses to explain a phenomenon. Databases, which include multiple files of information, allow learners to store, organize, and retrieve information in a systematic way, and to compare and contrast different perspectives. Moreover, learners can develop their own database by collecting data and organizing them according to key factors or ideas, and then use the developed database to support or rebut arguments. Databases on earthquakes were used in Kuhn and Katz's study (2009) to help children compare multiple cases of an earthquake and construct an argument about which variables influence the earthquake among soil types, S-wave rates, water quality, snake activities, and gas levels.

Another way to compensate for the lack of experience of novice learners in dealing with problems is to present problem-solving stories of more experienced learners or experts (Kolodner 1997). Experts' stories can be used by novice learners as evidence or examples and as guides to comprehend the process of generating valid arguments (Lawson 2003). For the *Swimsuit Design* activity, the teacher can provide students with problem-solving stories of more experienced groups of students who generated efficient swimsuit designs (see Fig. 10.3), for paraplegic patients.

Simulations allow learners to test different arguments or predictions. Recently, computers are often used as tools to develop simulations that imitate real-world phenomena and allow learners to manipulate key variables of a system. Learners can make inferences about causal relationships between multiple variables before testing their arguments with simulations. In addition, learners can support or reject

Database 6

The news article in Korean daily paper **2013. 01. 10**
A development of special swimsuit by undergraduates in an industrial engineering department, Seoul National University.

Undergraduates in an industrial engineering department developed a special swimsuit for Mr. Yun who suffers from paralysis of the lower half body, using a scuba diving suit and swimming kickboards. Their story showed some constraints, such as maintenance of balance in water, satisfaction of design shape. There were barriers, such as an expense of air bags in designing the swimsuit.

← *Special swimsuit developed by undergraduates*

Fig. 10.3 Example of a problem-solving story alternative arguments by collecting data from simulations. For example, Clark and Sampson (2008) had learners collect empirical data about temperatures of objects by manipulating variables about heat transfer, thermal sensation, and thermal conductivity using an interactive simulation. Based on the simulation results, learners can justify their claims, modify their initial thoughts, or challenge other group members' claims (Crawford and Cullin 2004). In addition to the computer simulation, a model can be used to test scientific hypotheses and design ideas. For the *Swimsuit Design* activity, the teacher can provide a doll that represents a paraplegic patient who cannot move his or her legs (see Fig. 10.4). The students can make a model of the swimsuit for the doll, using materials (e.g., cotton fabric, plastic, bubble wrap) that can affect the buoyant force. While testing the model, students can collect data to support their arguments about the relationship between materials and buoyant force.

Portfolios are beneficial for promoting metacognition during argumentation. In order to monitor and reflect on the argumentation process, learners need to record their decisions about claims and evidence as they conduct an argumentation task. Land and Zembal-Saul (2003) used *Progress Portfolio*, which is a software for recording inquiry process and managing a variety of claims and evidence. The *Progress Portfolio* allowed students to record, revisit, and monitor their research procedures, evidence, findings, and claims through various experiments. The software can be beneficial for supporting metacognitive activities when learners iteratively generate, monitor, and revise their arguments in scientific inquiry or design activities.

Lastly, communication tools are helpful in supporting the social aspects of argumentation. In online learning environments, learners can synchronously or asynchronously negotiate meanings with each other and collaboratively develop arguments. Asynchronous online technologies (e.g., discussion boards, e-mail) allow learners to have enough time to construct and elaborate arguments and reflect on different perspectives (de Vries et al. 2002), whereas synchronous online technologies (e.g., video conferencing, chat) enable learners to co-construct arguments with immediate responses of other group members (Kirschner et al. 2003). Moreover, the use of knowledge-building technology, such as *Knowledge Forum*,

Fig. 10.4 Test of products for assistance of swim using a model

can enable a community of learners to collectively develop their understanding by creating and sharing notes, which may include arguments, information, and other resources (Scardamalia and Bereiter 2006). Learners can link new notes to existing ones and create a graphic organizer of the notes in the *Knowledge Forum*. This knowledge-building technology can be helpful in collaboratively synthesizing a variety of claims and evidence.

Instructional Support

Instructional supports like prompts, hints, scaffolds, and feedback are necessary for novice learners who lack ATA experience. Learners can get instructional supports pertaining to the cognitive, metacognitive, and social aspects of argumentation. For instance, Mork (2005) described how a teacher helped his or her students to achieve the learning objectives for an activity by challenging the students' ideas, asking for elaboration, introducing sub-topics, switching focuses, rephrasing content, encouraging participation, and managing the order of speakers. These instructional supports can promote constructive and interactive argumentation and prevent students from debating off track and using wrong concepts or information.

To facilitate effective argumentation, instructional supports are also necessary to help learners to support a claim with valid evidence and relate a claim with alternative viewpoints (Jonassen and Cho 2011; Nussbaum and Schraw 2007). Students tend to have difficulties in interpreting complex data, supporting a claim with evidence, and explaining the meanings of evidence even though they understand the importance of evidence in argumentation (Sandoval 2003; Sandoval and Millwood 2005). In addition, many students fail to consider a variety of perspectives and integrating counterarguments with their own arguments (Nussbaum and Schraw 2007). As cognitive supports, a teacher can explain key components of a high-quality argument and demonstrate how to create the argument with specific examples (Wolfe et al. 2009). It is also beneficial for the development of argumentation skills to contrast an exemplar argument with student-constructed arguments so as to explain what students should (not) do and why they should (not) do it (Osborne et al. 2004). In addition, a teacher can provide argumentation guide prompts (e.g., "Justify your claim or design using as many reasons as possible", "What will others say to oppose your claim or design?"), challenge students' perspectives with alternative ones, and provide comments on students' arguments along with suggestions about how to modify them (Mork 2005; Osborne et al. 2004). In the *Swimsuit Design* activity, the teacher can provide instructional supports via a website as shown in Fig. 10.5.

Students should be engaged in metacognitive activities in order to improve the quality of arguments. Quintana et al. (2005) suggested a framework of instructional supports for metacognitive activities, which include (1) task understanding and planning, (2) monitoring and regulation, and (3) reflection. For instance, a teacher needs to encourage learners, who lack argumentation experience, to articulate the purpose of argumentation, monitor data collection and interpretation, and reflect on

Please submit your swimsuit design with specific reasons, evidence, and scientific explanation. Please consider what others may argue against your design idea.
→ *Task prompt*

Student work of swimsuit design

Instructional support: Example of constructing valid argument with detailed description

Fig. 10.5 Task prompts and examples in a website

argumentation process and final outputs. These activities can be supported through metacognitive prompts (Davis and Linn 2000) such as "Thinking ahead: To generate a high-quality argument, I need to …," and "Checking my argument: Perspectives I did not consider included …" In addition, reflection on arguments can be fostered with meta-level feedback that prompts learners to compare their own argument with an instructor-provided argument (Cho and Jonassen 2012). In the meta-level feedback, a teacher can encourage learners to focus on whether all reasons are acceptable, how strongly reasons support a claim, and what counterarguments are considered (Voss and Means 1991).

Regarding the social aspect of argumentation, a few learners experience difficulty in actively sharing their opinions with others due to the fear of losing their faces. There are social barriers that prevent active and equal participation in argumentation, lack of social presence among group members, disagreement with other group members, counterarguments not being viewed as helpful, and discussion dominated by a few group members. To overcome these social barriers, a teacher needs to encourage learners to develop social bonds, communicate openly around a controversial issue, and establish a sense of community (Garrison and Arbaugh 2007). In addition, it can be beneficial for a teacher or a student, who takes the role of a group moderator, to prompt passive group members to express their opinions and to provide equal opportunities of argumentation to all group members (Mork

2005). Moreover, collaborative argumentation should go beyond simply sharing opinions with others in a group. It is necessary that learners jointly develop a group argument through integration-oriented and conflict-oriented consensus-building processes (Weinberger and Fischer 2006). Integration-oriented consensus-building occurs when learners modify their own argument by integrating it with other arguments. In conflict-oriented consensus-building, learners compare and contrast alternative perspectives and judge which argument is more acceptable and valid. To facilitate collaborative argumentation, a teacher can provide learners with collaboration scripts that guide the sequence of arguments (e.g., argument-counterargument-integration; Stegmann et al. 2007). It is also helpful to divide a class into pro and con groups and ask them to support their positions in a debate, which may promote conflict-oriented consensus building.

Teachers need to provide the instructional supports in a flexible manner because learners may have different needs depending on their argumentation skills, prior knowledge, and values. In a real-classroom situation, however, it is hard for a teacher to provide all students with personalized instructional supports due to limited time and resources. To overcome this limitation, teachers can use advanced technologies (e.g., intelligent tutoring system), which can interact with and adapt to learners. For example, Graesser et al. (2005) introduced computer-based learning environments (e.g., *AutoTutor, iSTART*) with animated agents that model, coach, and scaffold cognitive and metacognitive strategies through dialogues with individual learners. Like a teacher, the computer agents can ask questions, give hints, and provide feedback based on what learners say. Pinkwart et al. (2009) showed that an intelligent tutoring system, which provided adaptive feedback on students' graphical representations of legal arguments, was beneficial for the development of argumentation skills. In addition to the adaptive learning technologies, reciprocal peer reviewing can be helpful to complement instructional supports for ATA. Cho and Schunn (2007) showed that receiving feedback from multiple peers was more effective for the improvement of writing quality than receiving it from a single expert. It is possible that students better understand and use peer feedback for revising arguments than expert feedback. In addition, they can learn by explaining the strengths and weaknesses of peer arguments during reciprocal peer reviewing (Cho and Cho 2011).

Conclusion

In this chapter, we asserted that argumentation plays a crucial role to facilitate authentic thinking in both scientific inquiry and design activities. In line with this notion, this chapter described a conceptual framework that underscores key ATA features and principles that were drawn from the existing literature and showed diverse examples that illustrate the application of these principles. This conceptual framework would be beneficial for educators who intend to design a learning environment for the development of twenty-first-century competencies like collaboration, problem solving, and critical thinking. It is necessary to investigate the strengths and weaknesses of the ATA model in integrating scientific inquiry and design activity in diverse educational contexts. ATA principles can be further elaborated and modified through future design-based research.

Future studies are necessary not only for elaborating the ATA model but also for investigating what students learn from the ATA activities. It is also important to determine whether the ATA model can help learners to generate arguments with evidence; synthesize alternative perspectives; use scientific concepts and principles as tools to solve real-world problems; collaboratively build knowledge; and plan, monitor, regulate, and reflect on their learning progress. These competencies are crucial in the twenty-first century in which knowledge and technology keep changing constantly and rapidly.

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Chapter 11
Using an Immersive Environment to Address Problems Associated with the Learning of Geography

Kenneth Y.T. Lim and Habibah Ismail

Abstract In its historical trajectory as a discipline in the formal curriculum, geography teachers have sought to mediate the learning experiences of students through the use of a diversity of interventions – from scale models to fieldwork. Because of the way much of formal schooling is operationalised, geography as it is experienced from the point of view of novices to the discipline can be potentially decontextualised when compared to how the discourse is dialogued about and practised by professionals. This chapter suggests how the affordances of fictive worlds and virtual environments might be leveraged to help novice geographers appropriate the epistemic frames of professionals in the craft.

Using examples from an immersive environment, the chapter describes a curricular intervention as enacted by a team of geography teachers at a state-funded school in Singapore. The chapter begins by introducing the concept of geographical intuition and relating it to problems potentially faced by students of geography; a framework for curriculum design in immersive learning environments is then used to elaborate on how the environments were used to mediate these learning difficulties, leveraging the spatiality and authenticity inherent in such environments. Finally, the impact of the intervention on the school is described.

Keywords Geography • Virtual environments • Curriculum design

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Problems Associated with the Learning of Geography

The inherent spatial and systemic nature of many areas of geographical investigation has meant that geographical problems in understanding space and the importance of time, providing authentic and contextualised examples and experiences, have been challenging to represent meaningfully within the spatial and temporal confines of a classroom. Such representations are important in learning because they form the substrate upon which the embodied experience of learners is built; in turn, continual embodied experience helps learners derive enduring disciplinary understandings through the development of intuition (Lim, 2015).

The Nature of Geographical Intuition

Kong (1999, 2000) has argued that children and adolescents in highly urbanised Singapore view nature as something which is orderly and well maintained. She continues that this rather limited perception arises from the fact that nature is

> a 'waste of time'. All the teenage members of the school group acknowledged that nature was not very much a part of their consciousness. When bored and thinking about places to visit and what things to do, the tendency was not to think of activities associated with nature. When thoughts about the natural world did surface in their minds, it was often in the context of school work, for example, their geography lessons, during which nature was more about conceptual issues and scientific processes than everyday environments of potential fun and enjoyment (Kong, 1999, p. 3).

It is our considered position that such 'everyday environments of potential fun and enjoyment' constitute the substrate upon which intuitions about geography – intuitions about the nature of the man-land relationship – are formed and developed. Such intuitions, in turn, shape geographical ways of knowing and are thus critical to informing how novice geographers (such as students in school) approach and understand the world. This theoretical construct of disciplinary intuitions is elaborated upon in a book published in 2015.

In the context of the present chapter, it suffices to frame disciplinary intuitions as a lens through which to understand a 'missing link' in some instances of curriculum design. The design of curriculum for formal learning environments often presumes upon (whether explicitly or implicitly) the intuitions that learners bring to the table. These intuitions – to the extent that they exist in the first place – may have been developed through personal experience and prior knowledge, often through non-formal learning such as play. Such intuitions are, however, tacit by definition, and their qualities would vary from learner to learner. Both this tacit nature and this heterogeneity work against the explicit recognition of the role that such intuitions play in the curriculum design of more formalised learning environments; yet they are of critical importance – at the very least in terms of shaping the pre- and misconceptions that learners have and consequently the likelihood of what is learnt enduring beyond the immediate formalised experience. Further, the nature of such intuitions varies by discipline – intuitions about geography are likely different from intuitions about physics, for instance – and that such variations across disciplines need to be recognised, investigated and elaborated upon if learning environments in particular – and curricular designs as a whole – are to be truly effective.

In this regard, geographical intuitions would include prototypical and/or nascent understandings about a range of phenomena in the earth sciences as well as in human geography, such as on types of rain, on relief and on the relationship between climate and vegetation. Because the discipline of geography foregrounds the man-land relationship, such geographical intuitions are contextually bound and would vary from biome to biome.

Disciplinary intuitions are thus distinct from prior knowledge, in that such intuitions are often developed through non-formal learning (including play) and have not yet been formally codified (let alone verified) by the learner or significant others. Further, these intuitions are 'disciplinary' in the sense that a primary focus area of the proposed book would be to initiate debate with regard to the nature of intuitions as varying across traditional subject domains (e.g. from the 'hard sciences' to the social sciences).

Disciplinary intuitions therefore represent a provocation into contemporary understandings of curriculum design, in that the present authors argue that such understandings have somewhat overlooked the tacit sensings that learners bring to each discipline and/or obfuscated such sensings with prior knowledge. To this end, it is hoped that the debate precipitated will go some way towards the design of curricula and learning environments which go beyond paying lip service to more enduring understandings.

Designing for Epistemological Appropriation

To the extent that one of the aims of formal curricula in school is to help novices to the discipline (in the case of this chapter, namely, students of geography) appropriate the epistemology of professionals in the field, enactments of the curriculum are obliged to address the related problems of a schooling experience decontextualised from disciplinary practice, with a consequent lack of authenticity. In addition, a primary problem that curriculum designers in geography apply themselves to is the understanding of scale – both in terms of space and time (such as, but not limited to, the passage of geologic time). This chapter describes the use of the open-source version of the immersive environment known as Second Life, to afford the study of both physical and human landscapes. Through explorations and interactions with both types of landscape, students in a state-funded school in Singapore were better able to appreciate the complementary role that each plays in shaping the everyday world.

Addressing the Problem of Spatial Scale: An Example from River Studies

A key element which differentiates geography from other disciplines is its study of scale – primarily scale over space, but also across time. The difficulty of appreciating geomorphological processes as they unfold over space and across time is universal for many novices to the discipline and is particularly acute for students in the city-state of Singapore – which has a land area of only 710 km^2 (equivalent to approximately eight times the size of Manhattan).

Traditionally, geomorphological features and processes have been taught primarily through the textbook, but even if videos and scale models are used – from the perspective of cognition – the learner would still be consciously aware of the fact that he or she is viewing or interacting with a model, a facsimile. When operating as an avatar in an immersive environment, however, the work of Gee (2007) on Projective Identity describes a coherent identification with the persona of the avatar in the mind of the learner, such that when, for example, the avatar of the latter is walking along a river delta in the immersive environment (see, e.g. Fig. 11.1), the learner takes it that he or she is actually there – in person – on the mudflats. This extremely powerful affordance enhances the experience of the learner as he or she explores the hydrological landscape.

Fig. 11.1 Exploring a true-to-scale river basin in its entirety

Addressing the Problem of Temporal Scale: An Example from Environmental Education

The discipline of geography concerns itself not only with investigations of spatial scale but also of temporal scale. Be it in terms of the passage of geologic time or of something such as seasonal or diurnal cycles, grappling with the issue of time can be potentially as vexing as that of space. In collaboration with teachers in Singapore, the authors have constructed within the immersive environment simulations depicting various forms of pollution, including reef health (see Fig. 11.2) and acid rain. Not only do the simulations afford explorations into processes of degradation across accelerated spans of time, but the manipulability of the environment permits an 'on-demand' nature to the activities, giving the learners a greater sense of ownership as they are able to trigger events and manipulate landscapes in a way not possible in their more familiar, everyday world.

Addressing the Problem of Authenticity: An Example from Map Literacy

Apart from the disciplinary-specific problematic of scale, geography teachers also face problems of bridging the relatively decontextualised renditions from a much curricular material to more authentic and enduring understandings. The immersive environment has been used in nurturing map literacy, from a first-principle perspective which foregrounds the development of intuition about the language of maps (see Fig. 11.3). This approach contrasts with the more traditional post hoc strategy of *map reading* (as opposed to *map literacy*) in which students are required to memorise the symbolic language of maps without sufficient care being given to why exactly the symbols are the way they are in the first place. For example, again with

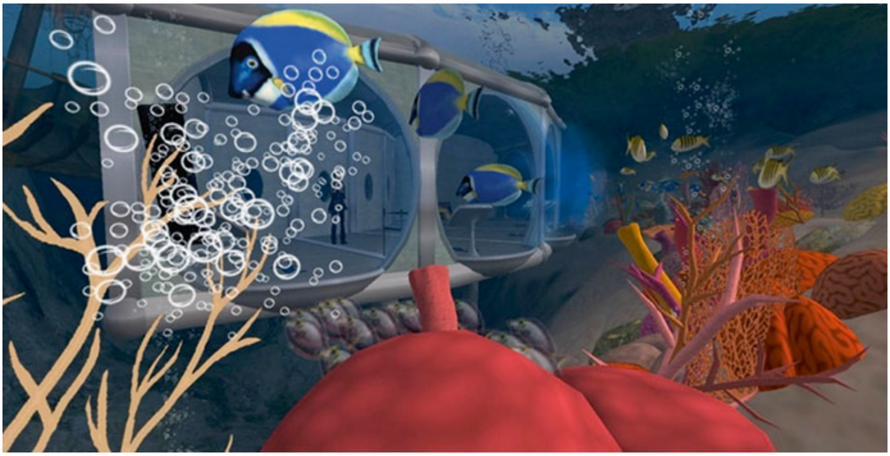

Fig. 11.2 On-demand reef-health/reef-hazard simulation

Fig. 11.3 Map literacy from the first principles

the help of fellow geography teachers, the authors have codesigned learning activities in which students – through their operation as avatars exploring within a true-scale immersive environment – manually generate terrain plots on graph paper of their relative position and altitude. By literally connecting the dots on their plots, they see the contour map appearing before their eyes, by their own hand, and depicting a landscape that they themselves are exploring in real time. By doing so, they are also developing the epistemological understandings of professional geographers, as they seek to transpose their two-dimensional paper-based renditions vis-à-vis the three-dimensional landscapes that their minds are stitching.

Addressing the Problem of Context: An Example from Tourism Studies

As a final example – this time of how the authors have used the immersive environment to address the problem of decontextualised learning – geography students were assigned different regions of the immersive world to study, in terms of the respective potentials of each field site for the development of tourism (see Fig. 11.4). The field sites differed in terms of their level of existing infrastructural development and in terms of the degree of planning/spontaneity of existing structures and land uses. Through their exploration, they were able to better understand and apply their knowledge of tourism through gathering ‘real-world’ evidence to support their arguments on the various factors and impacts of tourism.

Importantly, the immersive environment allowed them to articulate and manifest their understanding of the concepts – such as the negative impact of tourism – through their screen captures or enactment of significant events at the respective field site, by collaborating with their peers.

Fig. 11.4 Studying tourism in context

Learning Geography in a Troubled and Turbulent World

In the light of geopolitical developments over the past decade, school systems everywhere are much more cautious about organising fieldtrips. Notwithstanding this, fieldwork is very much an integral component of geographical inquiry. In addition, tectonic events – both regionally and globally – such as the Indian Ocean tsunami event of 2004, have given even the most gung-ho geography teachers a little more cause for circumspection when planning fieldtrips overseas. Together, these developments have meant that the changes in the physical landscape affecting geological and geomorphological conditions of countries make it difficult for teachers to conduct river and coastal studies related to the syllabus.

The authors have worked with fellow geography teachers not so much to use immersive environments as replacements for regular fieldtrips, but as complementary constructs (either *pre* or *post facto*) to fieldtrips, with particular emphasis on tapping the affordance of such environments for unpacking the decision-making behind the design and enactment of *fieldwork* (as opposed to *fieldtrips*). Together, we have found that the immersive environment provides a suitably authentic platform upon which to design for explorations into, for example, climate and weather studies, without the need to conduct an overseas trip (with its attendant logistical, administrative and financial costs).

Furthermore, the hyperreal nature of the immersive environment (see Fig. 11.5) might be tapped in geographical inquiry which might ordinarily be difficult or almost impossible to be conducted because of these same attendant challenges, costs and hazards. For example, students might feasibly explore the entirety of a river course and conduct underwater exploration of the river and seabed as they document and analyse the characteristics and processes associated with a littoral environment.

Fig. 11.5 Adding a hyperreal dimension to fieldwork

Developing Disciplinary Intuitions Through the Six-Learning Curricular Framework

Given the preceding concerns, the authors used an immersive learning environment to address the challenges, making particular use of the spatiality inherent in such environments as a means of contextualising the activities designed for the students. Such contextualisation of spatially mediated learning in the physical world – through an immersive environment – reinforces opportunities for learners to vicariously have embodied experiences through which their own geographical intuitions are developed.

In this way, immersive environments afford both a rich resource as well as flexibility in implementing the principles of learning which have been suggested by Saphier et al. (2008). Working with fellow geography teachers, the authors have conceptualised and designed a series of curricular enactments with specific focus on cognitive, motivational and technical principles, as well as on impacting attention and engagement for efficient and effective learning experiences.

The learning activities within the immersive environment were designed according to a curriculum design framework developed by Lim (2009) – the six learnings. The framework consists of six lenses through which curricular interventions designed for immersive environments might be analysed and critically evaluated, during the early planning stages.

Briefly, the six learnings are:

- Learning by exploring
- Learning by collaborating
- Learning by being

- Learning by building
- Learning by championing
- Learning by expressing

Learning by Exploring

As learners find their way around installations within the immersive environment, they potentially appropriate information and construct understandings. Thus, for example, geography students might collect weather data from various parts of a topographically authentic landscape and subsequently plot their findings as charts and graphs.

Learning by Collaborating

There is an extensive literature (e.g. Johnson and Johnson 1994) advocating collaborative learning over a more competitive stance. By 'learning by collaborating' is meant structuring learning tasks to foreground co-dependence, negotiation and consensus building. By dint of the affordance of allowing many learners to potentially share a common space, even though the learners themselves may not be physically co-present, learning by collaborating is a potentially powerful way of structuring learning tasks within immersive environments.

Learning by Being

Identity construction is another potential affordance of immersive environments, because such environments often facilitate avatar customisation and role play. By this is meant 'learning by being', and such learning is akin to Brown's and Duguid's (2000) understandings of 'learning to be'. When successfully designed, 'learning by being' is a powerful conduit through which the epistemic frames described by Shaffer (2007) may be appropriated by learners.

Learning by Building

When learners build or modify objects and/or learn to script interactivity into such objects, they are experiencing what is meant by 'learning by building'. Such activities could potentially involve the terraforming of landscapes, such as to surface nascent intuition about orogenic processes and other tectonic forces. For example, when learners are tasked to build a representation of a geographically authentic landscape in an immersive environment, the manner in which they go about such terraforming tasks can potentially make more explicit their developing and malformed prototypical understandings of the geomorphological processes undergirding similar landscapes in the physical world.

Learning by Championing

'Learning by championing' indicates the many initiatives by various communities in massively multiplayer online role playing games (MMORPGs) to adopt, champion and evangelise real-world causes. Especially active in this regard are groups to do with health and environmental education, such as the *Abyss Observatory*.

Learning by Expressing

The preceding five learnings describe dimensions of learning which are potentially afforded by immersive environments, as the learner interacts within the environment; there is a sixth learning, namely, 'learning by expressing'. In contrast to the preceding five, 'learning by expressing' highlights to the curriculum designer that the representation of in-world activity to an audience who is not necessarily in world (e.g. through social media and machinima) can be just as valuable a mode of learning to explicitly design for.

Enacting the Six-Learning Framework into Design Principles Within a School-Based Setting

The remainder of this chapter focuses on the specific case of the implementation of a curriculum around leveraging an immersive environment to support the learning of geography at a state-funded school – Ang Mo Kio Secondary School – in Singapore. The intervention was inspired by the beliefs that learning should be fun, that knowledge from the texts can and should be deepened and that a collaborative spirit of learning should be cultivated.

Translating these beliefs into an enacted curriculum, the geography teachers at the school took care to deconstruct complex tasks into simpler parts. Lessons were scaffolded, such as beginning from simple exploration of a river within the immersive environment to collaborating and building a simulated river landscape. In addition, lessons included reference to the textbook and extra-curricular research (homework assignments) to ensure better understanding of the topic. Guidance was given by the teacher through examples, and students learned in a collaborative environment to ensure positive outcomes.

Framing the Learning

At the beginning of each lesson, the rationale, objectives, tasks, processes and outcomes of the lesson were clearly delineated. The criteria for success for the product and performance were included in the lesson.

The three-dimensional visuals afforded by the immersive environment provided a rich resource as explanatory devices. Students' thinking was also made visible when they explained their answers, through maps, diagrams and terraformed landscapes to their peers. They had to offer plausible and convincing arguments to support their respective stances when questioned by their peers, teachers and/or independent assessors.

In reviewing the answers to the worksheets and examining the product or performance of the students, the teacher was able to check for understanding and provide immediate feedback and clarify misconceptions – this was a critical step towards developing disciplinary intuition among the learners – with respect to geography.

Developing a Sense of Ownership

Through the landscapes that they themselves designed and crafted within the immersive environment, students were able to compare and to make connections with real-world examples and infer implications of anthropogenic actions, thereby enriching their recommendations for remediation to authentic case studies beyond rote recitation and towards a more multi-perspectival nuanced appreciation of the context.

In this way, the use of the immersive environment as part of the regular geography curriculum afforded a sense of ownership. In the study of river processes, the landscape created was tailored to the specifications of the teacher, through the articulation of the focus questions.

Anchoring Learning Through Empathy

The nature of immersive environments lends themselves naturally to role play. Through such role appropriation, students were able to develop empathy towards victims of natural disasters, such as the Indian Ocean tsunami of 2004.

In addition, environmental awareness was developed when students explored sites depicting various forms of pollution, in the immersive environment. They were able to observe and analyse how both flora and fauna were affected by oil spillage and industrial pollutants.

Aligning the Six-Learning Framework with Twenty-First-Century Competencies and Literacies

Within the context of the formal education system in Singapore, teachers are encouraged to design and enact a curriculum which might foster the development of dispositions such as cross-cultural appreciation and critical thinking. It was therefore very helpful to be able to align the six-learning curriculum design framework with such so-called twenty-first-century competencies. Table 11.1 illustrates the coherence of the curriculum design framework with the skills and dispositions (as the latter have been defined by the Ministry of Education in Singapore).

Impact of the Curricular Intervention

The intervention has inculcated a sense of ownership among students for their respective trajectories of learning; this was especially the case when lesson units included specific time set aside for students to craft their own landscapes to

Table 11.1 Aligning the six-learning framework with twenty-first-century competencies

Six-learning framework	Twenty-first-century competencies	Learning activity
Learning by exploring	Information and communication skills and cross-cultural skills	Students learn to gather information from the immersive environment based on concepts learned in class
Learning by collaborating		Students terraform a river landscape; this requires collaboration and communication to complete the river course
Learning by being		Many different teaching and learning strategies can be adopted in the immersive environment
		Cooperative-learning lessons designed with role differentiation and contexts allow students to gain insights and different perspectives. In a Structured Academic Controversy lesson, students assume different roles in support of different perspectives of an issue
Learning by building	Critical and inventive thinking	Terraforming lessons, e.g. in building a river landscape, enables deep learning of the river processes as they require the learner to visualise, create or build through understanding the concepts learned in the classroom
Learning by championing	Global awareness	The sharings done by the students to external stakeholders enable them to be more confident and more inventive and creative
Learning by expressing	Civic literacy, global awareness and cross-cultural skills; communication skills	Students develop a variety of communicative skills to convince their audience with different learning strategies in support of their cause or stance

represent their nascent intuitions about geographical interactions and geomorphological processes.

In support of our own Action Research programme within the school, in 2012, we administered a simple questionnaire to four classes of seventh grade students ($n = 160$) after their 3-week lesson unit on map literacy. Students have shown high levels of engagement, understanding, interest in the subject and collaborative effort (see Appendix A).

Assessment for Learning

In order to successfully attempt the learning activities designed, students were encouraged to make reference to their regular texts and paper-based resources. However, unlike in more traditional pen-and-paper-based assessment designs, having students craft their own landscapes through which to express their nascent intuitions and evolving understandings resulted in a more effectively secure learning environment in which the adolescents were less circumspect about sharing their yet-incomplete work with their peers and teachers for critique.

This resulted in greater motivation and self-directed learning as students were able to set goals for themselves while they discussed each others' efforts. In addition, the open-ended nature of the immersive environment boosted confidence as it imparted a sense of control over their own learning trajectories.

An example of such extension and deepening of learning was the aforementioned map literacy activity in which students plotted their own contour map – not from an abstract series of dots or coordinates (as would normally be the case), but from their own careful observations and recordings as they explored the three-dimensional landscape in the immersive environment.

By doing so, they not only cultivated the disposition of precision, but they were also appropriating the epistemology of professional geographers in their decision-making as to whereabouts in the landscape to record the data from. This activity afforded the students to learn from first-principle deductions through their own transpositional cartographic endeavours around the landscape which they themselves had earlier terraformed.

Clearer Visualisations Through Active Participation

The immersive environment afforded a clearer visualisation of many concepts in geography. Instead of being obliged to visualise a river in their mind or passively observing a scale model or passively viewing it through a video, they are able to actively conceptualise, design and collaboratively create the river in true scale. This gave students a better view and understanding on how river systems impact upon the man-land relationship through landscapes which they themselves created. Such better understandings were – in turn – reflected in a higher quality in the diagrams drawn by the students during their traditional pen-and-paper-based assessment.

Indeed, while initial feedback from students was that they felt it did not really benefit them as there were few textual signposts within the immersive environment itself (this was, in fact, a deliberate decision taken by the members of the design team), after the passage of a year, the same students admitted that, with hindsight, they realised that it was not necessary to have accompanying notes as their repeated participation in authentic activities within the environment over time afforded them the epistemological wherewithal to synthesise a diversity of topics across the entire discipline of geography.

The Enhancement of Collaborative Effort

The curricular intervention which the authors codesigned with fellow geography teachers incorporated deliberate design principles for co-dependence among learners, in order to help the latter develop skills of negotiation and consensus building.

For example, students were assigned designated areas to map out or specific courses along a river to terraform. In order for each group of students to complete the drainage basin, the student in charge of terraforming, say, the upper course, had to interact with the person in charge of the middle course in order to link up the different parts of the river system in a coherent and hydrologically authentic manner. Active discussion and clear communication were necessary to enable the students to complete the task. Such activities afforded greater collaborative effort and bonding among members of the respective groups.

Projective Identity, Resilience and the Negotiation of Hazard

Avatars in the immersive environment were resilient, in the sense that even after facing a setback (such as slipping off a steep slope), it would simply pick itself up, dust itself off and continue walking. Likewise, the avatar would not drown even when exploring ocean depths in the immersive environment. Through Gee's (2007) notions of projective identity, we understand that although the learner's human identity would be well aware of the hazard represented by the on-screen depiction of ocean depths, for example, the resilience of the avatar identity would – through projective identity – contribute to building resilience and a 'can-do' attitude in the students themselves.

Concluding Remarks

The use of immersive environments as a signature information and communications technology (ICT) initiative at the state-funded school constituting the case study in this chapter complements the overall direction set by the school management team towards harnessing technology for teaching and learning. In its 6 years of implementation thus far, challenges were faced, just as workarounds have been found.

For example, first, although lessons designed to leverage the immersive environment take time to plan and enact, teachers have been willing to invest this time, because they understand that dividends would be reaped subsequent to these lessons as the students would have developed stronger intuitions and more enduring understanding as they would have learned about the topics in holistic and authentic settings, as opposed to having learned about them in the decontextualised silos of chapters. Second, the team of teachers has also been careful to design for lessons which might be enacted within regular classrooms – in which only one computer is installed – as opposed to being purely reliant on the booking and use of computer labs in school.

As for the challenges to novice geographers described at the beginning of the chapter, these have also been addressed to the extent that the programme has allowed teachers and learners to understand the relationship between space and time in an immersive environment which bears authenticity to the physical world. These learning environments have enabled the learner and teacher to explore a field study area as a complementary experience to field-based study in the physical world. Because the field study can be instantiated at any time, it has the advantage of allowing all the students to participate in the field activities.

The programme is presently in its sixth year of enactment and has grown from its origins in the geography curriculum to a diversity of subject disciplines, grade levels and academic cohorts, as well as to other schools in Singapore. The programme has also been represented – often by the students themselves – at various fora both locally and overseas. Professionals in the audience, as well as the steady stream of visitors to the school, have come away impressed by how students on the programme – regardless of gender and age – have been able to represent their learning experiences authentically in spontaneous, confident and unscripted ways.

Schools in Singapore which participate in the six-learning/disciplinary intuition curricular programme have received strong support from both the National Institute of Education and the Ministry of Education. This augurs well for the schools as they embark on their respective journeys to include collaborative and self-directed learning through the use of ICT. As the use of immersive environments becomes widely accepted by the teaching fraternity, the programme can only grow as new ways are continually discovered by school-based practitioners as to how to leverage it to address problems in a diversity of academic disciplines.

Appendix A: Results of Post-intervention Survey

	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)	Disagree (%)	Strongly disagree (%)
(a) The virtual world lessons give me more opportunities to share my views	29	46	14	4	4
(b) The lessons in the virtual world give me a deeper understanding of my learning	46	39	11	0	0
(c) I am able to gain more knowledge of the subject through virtual world lessons	25	64	7	0	0
(d) I am able to gain more understanding of the subject through virtual world lessons	36	46	14	0	0
(e) I find that it is easier for me to understand content that I was not exposed to through usual lessons	39	46	11	0	0
(f) I am able to interact more (e.g. texting, IM, sharing of opinion, items) with my classmates in the virtual world lessons	32	54	11	0	0
(g) It is easy to collaborate with my classmates	29	57	11	0	0
(h) I find that lessons through virtual world help me to be more actively engaged in my learning	43	39	14	0	0
(i) The virtual world lessons have increased my interest in the subject	36	43	11	7	0
(j) The 'river trip' provided a good visualisation of the geographical features along the river	39	46	11	0	0
(k) I have a better understanding of the different features of the river through virtual world IT lesson	43	46	4	4	0
(l) I have a better understanding of the relationship between human activities and the physical landscape along the river course	39	43	14	0	0
(m) I enjoyed my time spent learning in the virtual world	36	46	11	4	0
(n) I would like to have more lessons in the virtual world	46	32	14	4	0
(o) Learning in virtual world is more exciting than my normal lessons	50	36	11	0	0

	Strongly agree (%)	Agree (%)	Neither agree nor disagree (%)	Disagree (%)	Strongly disagree (%)
(p) Learning in the virtual world is more effective than my normal lessons	54	25	11	7	0
(q) The virtual world lessons allow for learning through self-discovery and self-exploration	43	36	14	4	0
(r) The virtual world lesson has increased my interest in the subject	46	29	18	4	0
(s) I would visit the virtual world outside of my lessons	36	36	14	7	4

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Part V

Authentic Practice Through Productive Failure

Chapter 12
Learning from Productive Failure

Manu Kapur and Leslie Toh

Abstract Situating our work within the constructivist debate about effective ways of designing for learning, we describe our program of research on productive failure (PF). The PF learning design affords students opportunities to engage in authentic mathematical practice where they start by generating and exploring solutions to a novel design problem followed by consolidation and knowledge assembly. In doing so, PF affords students opportunities to activate and differentiate their prior knowledge, so that they are better prepared to attend to and learn the critical conceptual features of the targeted concepts during the subsequent instruction. Our findings show that the PF learning design is more effective in developing conceptual understanding and transfer than a direct instruction design. Follow-up studies are described in brief wherein key aspects of the productive failure design were tested over multiple classroom-based studies in Singapore public schools and how these studies helped us interrogate and understand the criticality of key mechanisms embodied in the PF design.

Keywords Productive failure • Authentic practice • Mathematics

Introduction

Proponents of direct instruction bring to bear substantive empirical evidence against unguided or minimally guided instruction to claim that there is little efficacy in having learners solve problems that target novel concepts and that learners should receive direct instruction on the concepts before any problem-solving (Sweller 2010; Kirschner et al. 2006). Kirschner et al. (2006) argued that "Controlled experiments almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it" (p. 79). Commonly cited problems with unguided or minimally guided instruction include increased working

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memory load that interferes with schema formation (Sweller 1988), encoding of errors and misconceptions (Brown and Campione 1994), lack of adequate practice and elaboration (Klahr and Nigam 2004), as well as affective problems of frustration and de-motivation (Hardiman et al. 1986).

Consequently, this has led to a commonly held belief that there is little efficacy in having learners solve novel problems that target concepts they have not learned yet. Perhaps this belief is best captured by Sweller (2010), “What can conceivably be gained by leaving the learner to search for a solution when the search is usually very time consuming, may result in a suboptimal solution, or even no solution at all?” (p. 128). The basis for this belief comes from a large body of empirical evidence that has compared some form of heavily guided direct instruction (e.g., worked examples) favorably with unguided or minimally guided discovery learning instruction (Kirschner et al. 2006). It is of course not surprising that learners do not learn from unguided or minimally guided discovery learning when compared with a heavily guided direct instruction. However, the conclusion that there is little efficacy in having learners solve problems that target concepts they have not learned yet—something that they have to do in unguided discovery learning—does not follow.

To determine if there is such an efficacy, a stricter comparison for direct instruction would be to compare it with an approach where students first generate representations and methods to novel problems on their own followed by direct instruction. It can be expected that the generation process will likely lead to failure. By failure, I simply mean that students will not be able to develop or discover the canonical solutions by themselves. Yet, what is critical is not the failure to develop the canonical solution per se but the very process of generating and exploring multiple representations and solution methods, which can be productive for learning *provided* that direct instruction on the targeted concepts is subsequently provided (Kapur and Bielaczyc 2012; Kapur and Rummel 2009; Schwartz and Martin 2004).

This chapter reports on a program of research that explores the possibility of affording learners the opportunity to engage in a process of generating solutions to novel problems and shows how this process invariably leads to suboptimal solutions (i.e., failure to generate the canonical solutions) but can still be a productive exercise in failure provided that some form of direct instruction follows (Kapur 2010, 2011, 2012, 2014, 2015). Thus argued, instead of reporting experiments comparing discovery learning with direct instruction, the work presented herein seeks to understand whether combining the two—as instantiated in the learning design called *productive failure* (Kapur and Bielaczyc 2012)—can be more effective than direct instruction alone.

We start with a brief review of research that supports the case for productive failure and points to an efficacy of learner-generated solutions provided that an appropriate form of direct instruction builds upon it. Next, we provide a brief description of the mechanisms embodied in the design principles of productive failure. Following this, we describe a program of design research wherein key aspects of the productive failure design were tested over multiple classroom-based studies in Singapore public schools. Our aim is not to describe each study in detail. Instead, it is to articulate the underlying logic of how the various studies help us test and understand some of the critical design decisions of PF.

The Case of Failure in Learning and Problem-Solving

Research on *impasse-driven learning* (Van Lehn et al. 2003) with college students in coached problem-solving situations provides strong evidence for the role of failure in learning. Successful learning of a principle (e.g., a concept, a physical law) was associated with events when students reached an impasse during problem-solving. Conversely, when students did not reach an impasse, learning was rare despite explicit tutor explanations of the target principle. Instead of providing immediate or direct instruction upfront, e.g., in the form of feedback, questions, or explanations, when the learner demonstrably makes an error or is "stuck," Van Lehn et al.'s (2003) findings suggest that it may well be more productive to delay that instruction up until the student reaches an impasse—a form of failure—and is subsequently unable to generate an adequate way forward.

Building on this, Mathan and Koedinger (2003) compared learning under two different feedback conditions on student errors. In the immediate feedback condition, a tutor gave immediate feedback on student errors. In the delayed feedback condition, the tutor allowed the student to detect their own error first before providing feedback. Their findings suggested that students in the delayed feedback condition demonstrated a faster rate of learning from and on all the subsequent problems. Delayed feedback on errors seemed to have resulted in better retention and better preparation to learn from subsequent problems (Mathan and Koedinger 2003).

Further evidence for such *preparation for future learning* (PFL; Schwartz and Bransford 1998) can be found in the *inventing to prepare for learning* (IPL) research by Schwartz and Martin (2004). In a sequence of design experiments on the teaching of descriptive statistics with intellectually gifted students, Schwartz and Martin (2004) demonstrated an existence proof for the hidden efficacy of invention activities when such activities preceded direct instruction, despite such activities failing to produce canonical conceptions and solutions during the invention phase. However, the proponents of direct instruction have criticized PFL and IPL studies because of a lack of adequate control and experimental manipulation of one variable at a time, which makes it difficult to make causal attributions of the effects (Kirschner et al. 2006).

Earlier experiments in *productive failure* (Kapur 2008) provide evidence from randomized-controlled experiments for the role of failure in learning and problem by delaying structure. Kapur (2008) examined students solving complex problems without the provision on any external support structures or scaffolds. 11th-grade student triads from seven high schools in India were randomly assigned to solve either ill- or well-structured physics problems in an online, chat environment. After group problem-solving, all students individually solved well-structured problems followed by ill-structured problems. Ill-structured groups generated a greater diversity of representations and methods for solving the ill-structured problems. However, ill-structured group discussions were found to be more complex and divergent than those of their well-structured counterparts, leading to poor group performance (Kapur et al. 2005, 2006, 2007). Notwithstanding, findings suggested a hidden efficacy in the complex, divergent interactional process even though it seemingly led to failure. Kapur argued that delaying the structure received by students from the ill-structured groups (who solved ill-structured problems collaboratively followed by well-structured problems individually) helped them discern how to structure an ill-structured problem, thereby facilitating a spontaneous transfer of problem-solving skills. Findings from this study have since been replicated (Kapur and Kinzer 2009).

These findings are consistent with other research programs that suggest that conditions that maximize performance in the shorter term are not necessarily the ones that maximize learning in the longer term (Clifford 1984; Schmidt and Bjork 1992). Collectively, it is reasonable to reinterpret their central findings as all of them point to the efficacy of learner-generated processing, conceptions, representations, and understandings, even though such conceptions and understandings may not be correct initially and the process of arriving at them not as efficient. The above findings, while preliminary, underscore the implication that by delaying instructional support—be it explanations, feedback, direct instruction, or well-structured problems—in learning and problem-solving activities so as to allow learners to generate solutions to novel problems can be a productive exercise in failure (Kapur 2008).

More than simply indicating a delay of instructional structure, these studies also underscore the presence of desirable difficulties and productive learner activity in solving problems. It is this interest in what is present, that is, the features of productive learner activity (even if it results in "failure"), that forms the core of our work. Based on the literature and our own studies in PF, we have begun to develop a design theory of what needs to be present in student problem-solving contexts in which instructional structure is delayed. We are interested in testing our theoretical conjectures by investigating their embodiment in the design of problem-solving experiences that, although leading to short-term performance failure, are efficacious in the longer term. We briefly describe these design principles and the theoretical conjectures they embody next (for a fuller description, see Kapur and Bielaczyc 2012).

Designing for Productive Failure (PF)

There are at least two problems with direct instruction in the initial phase of learning something new or solving a novel problem. First, students often do not have the necessary prior knowledge differentiation to be able to discern and understand the affordances of the domain-specific representations and methods underpinning the targeted concepts given during direct instruction (e.g., Kapur and Bielaczyc 2012; Schwartz and Bransford 1998; Schwartz and Martin 2004). Second, when concepts are presented in a well-assembled, structured manner during direct instruction, students may not understand why those concepts, together with their representations and methods, are assembled or structured in the way that they are (Chi et al. 1988; Schwartz and Bransford 1998).

Cognizant of these two problems, PF engages students in a learning design (for a fuller explication of the design principles, see Kapur and Bielaczyc 2012) that embodies four core, interdependent mechanisms: (a) activation and differentiation of prior knowledge in relation to the targeted concepts, (b) attention to critical conceptual features of the targeted concepts, (c) explanation and elaboration of these features, and (d) organization and assembly of the critical conceptual features into the targeted concepts. These mechanisms are embodied in a two-phase design: a generation and exploration phase (Phase 1) followed by a consolidation phase (Phase 2). Phase 1 affords opportunities for students to generate and explore the affordances and constraints of multiple representations and solution methods (RSMs). Phase 2 affords opportunities for organizing and assembling the relevant student-generated RSMs into canonical RSMs. The designs of both phases were guided by the following core design principles that embody the abovementioned mechanisms:

1. Create problem-solving contexts that involve working on complex problems that challenge but do not frustrate, rely on prior mathematical resources, and admit multiple RSMs (mechanisms a and b).
2. Provide opportunities for explanation and elaboration (mechanisms b and c).
3. Provide opportunities to compare and contrast the affordances and constraints of failed or suboptimal RSMs and the assembly of canonical RSMs (mechanisms b–d).

The PF design also undertakes a commitment that there is more to learning mathematics than just *learning about* mathematics, which is necessary but not sufficient. Part of learning mathematics, and arguably the more important part perhaps, is to engage in the *authentic* practice of mathematics akin to that of mathematicians. This involves *learning to be* like a member of the mathematical community (Thomas and Brown 2007). But what does authentic mathematical practice entail? Inventing representational forms, developing domain-general and specific methods, flexibly adapting and refining or inventing new representations and methods when others do not work, critiquing, elaborating, explaining to each other, and persisting in solving problems define the epistemic repertoire of authentic mathematical practice (Bielaczyc and Kapur 2010; Bielaczyc, Kapur and Collins 2013; diSessa and Sherin 2000). Learning to be like a mathematician is to learn and do what mathematicians do; it involves a "mathematical" way looking at the world, understanding the constructed nature of mathematical knowledge, and persisting in participating in the construction and refinement of mathematical knowledge. Learning to be, therefore, clearly foregrounds the epistemological aspects of authentic mathematical practice. Needless to say, both learning about and learning to be are important commitments, but the latter remains much neglected in comparison to the former. The epistemological commitments of PF aim to redress this imbalance and thus engage the learner in authentic learning and practice of mathematics.

Examining the PF Design in the Real Ecologies of Singapore Classrooms

Having articulated the mechanisms embodied in the design principles of PF, we now describe the implementation in a series of classroom-based experiments. To bring about change in classroom practice and pedagogy, especially in a system of high-stakes testing such as Singapore, it was important to compare a new learning design (e.g., PF) with a design most prevalent in practice (e.g., DI). Thus, we started by comparing learning from PF with DI.

Comparing PF with DI

We illustrate a comparison of learning from PF and DI through a pre-posttest, quasi-experimental study (hereinafter referred to as Study 1) with 133, ninth-grade mathematics students (14–15-year-olds) from a public school in Singapore (for fuller details, see Kapur 2012). The targeted concept was standard deviation (SD), which is typically taught in the tenth grade, and therefore, students had no instructional experience with the targeted concept prior to the study. All students, in their intact classes, participated in four, 50-min periods of instruction on the concept as appropriate to their assigned condition. The same teacher taught both the PF and DI conditions.

In the PF condition, students spent the first two periods working face-to-face in triads to solve a complex data analysis problem on their own (see Appendix A). The data analysis problem presented a distribution of goals scored each year by three soccer players over a 20-year period. Students were asked to design a quantitative index to determine the most consistent player. During this generation phase, no cognitive guidance or support was provided. In the third period, the teacher first consolidated by comparing and contrasting student-generated solutions with each other and then modeled and worked through the canonical solution. In the fourth and final period, students solved three data analysis problems for practice, and the teacher discussed the solutions with the class.

In the DI condition, the teacher used the first period to explain the canonical formulation of the concept of variance using two sets of "worked example followed by problem-solving" pairs. The data analysis problems required students to compare the variability in 2–3 given data sets, for example, comparing the variability in rainfall in two different months of a year. After each worked example, students solved an isomorphic problem, following which their errors, misconceptions, and critical features of the concept were discussed with the class as a whole. To motivate students to pay attention and remain engaged, they were told that they will be asked to solve isomorphic problems after the teacher-led worked examples. In the second period, students were given three isomorphic data analysis problems to solve, and the solutions were discussed by the teacher. In the third period, students worked in triads to solve the same problem that the PF students solved in the first two periods, following which the teacher discussed the solutions with the class. DI students did not need two periods to solve the problem because they had already learned the concept. The DI cycle ended with a final set of three data analysis problems for practice (the same problems were given to the PF students), which the students solved individually, and the teacher discussed the solutions with the class.

Process findings suggested that PF groups generated on average six solutions to the problem. Elsewhere (see Kapur 2012), we have described these student-generated solutions in greater detail. For the present purposes, we only briefly describe the four categories of solutions:

(a) *Central tendencies* (e.g., using mean, median, mode)
(b) *Qualitative methods* (e.g., organizing data using dot diagrams, frequency polygons, line graphs to examine clustering and fluctuations' patterns)
(c) *Frequency methods* (e.g., counting the frequency with which a player scored above, below, and at the mean to argue that the greater the frequency at the mean relative to away from the mean, the better the consistency)
(d) *Deviation methods* (e.g., range; calculating the sum of year-on-year deviations to argue that the greater the sum, the lower the consistency; calculating absolute deviations to avoid deviations of opposite signs canceling each other; calculating the average instead of the sum of the deviations).

None of the PF groups were able to generate the canonical formulation of SD. In contrast, analysis of DI students' classroom work revealed that students relied *only* on the canonical formulation to solve data analysis problems. This was not surprising given that they had been taught the canonical formulation of SD, which is also easy to compute and apply. All DI students were accurately able to apply the concept of SD to solve the very problem that the PF students tried to generate a solution to.

Furthermore, the solutions generated by PF students suggested that not only were students' priors activated (central tendencies, graphing, differences, etc.) but that students were able to assemble them into different ways of measuring consistency. After all, PF students could only rely on their priors—formal and intuitive—to generate these solutions. Therefore, the more they can generate, the more it can be argued that they are able to conceptualize the targeted concept in different ways, that is, their priors are not only activated but also differentiated in the process of generation. In other words, these solutions can be seen as a measure, albeit indirect, of knowledge activation and differentiation; the greater the number of such solutions, the greater the knowledge activation and differentiation.

On the day immediately after the intervention, all students took a posttest comprising three types of items: procedural fluency, conceptual understanding, and transfer (for the items, see Kapur 2012). Analysis of pre-post performance suggested that PF students significantly outperformed their DI counterparts on conceptual understanding and transfer without compromising procedural fluency. Further analyses revealed that the number of solutions generated by PF students was a significant predictor of how much they learned from PF. That is, the more solutions the students generated, the better they performed on the procedural fluency, conceptual understanding, and transfer items on the posttest. We refer to this effect as the *solution generation effect*.

Discussion

These findings are consistent with the seminal studies on productive failure (Kapur 2008; Kapur and Kinzer 2009) and also with other studies described earlier (e.g., Schwartz and Bransford 1998; Schwartz and Martin 2004). These findings suggest that there is in fact a utility in having students solve novel problems first. To explain these findings, we argued that the PF design invoked learning processes that not only activated but also differentiated students' prior knowledge as evidenced by the number of student-generated solutions. Whereas PF students were afforded opportunities to work with not only the solutions that they generated but also the canonical solutions that they received during direct instruction, DI students worked with only the canonical ones. Hence, DI students worked with a smaller number of solutions, and consequently, their knowledge was arguably not as differentiated as their PF counterparts.

What prior knowledge differentiation affords in part is a comparison and contrast between the various solutions—among the student-generated solutions as well as between the student-generated and canonical solutions. Specifically, these contrasts afford opportunities to attend to the following critical features of the targeted concept that are necessary to develop a deep understanding of the concept. Granted that student-generated solutions are at best an indirect measure of prior knowledge activation and differentiation, it was nonetheless a critical difference between the two conditions by design. Importantly, this difference needs to be situated in the argument made by the proponents of DI in their questioning of the utility of getting students to generate solutions to solve novel problems on their own. They argue that students should be given the canonical solutions (either through worked examples or direct instruction) before getting them to apply these to solve problems on their own (Sweller 2010).

Further Studies Examining the PF Design

On the one hand, the finding that the more solutions students generate, the more they learn from PF on average—the solution generation effect—evidenced one of the key mechanisms of the PF design of prior knowledge activation and differentiation. On the other hand, the solution generation effect also raised important questions for further inquiry. In this section, we describe four such lines of inquiry, each testing a critical aspect of the PF design. Once again, fuller descriptions of these studies can be found in our published work, and therefore, our intention here is to briefly describe and summarize the findings and their implications for the PF design.

The Role of Math Ability

A key assumption in the PF design is that students have the formal and intuitive resources for generation and exploration prior to learning a new concept. In the light of the solution generation effect, an obvious and immediate question given was to examine the role of math ability. After all, one could expect math ability to influence what and how much students generate and consequently how much students learn from PF.

Testing the efficacy of PF over DI across different math ability profiles was precisely the aim of the studies reported in Kapur and Bielaczyc (2012). Students were purposefully sampled from three public, coeducational schools with significantly different math ability profiles—75 high ability, 114 medium ability, and 113 low ability—on the national standardized examinations in Singapore. In each school, students in their intact classes were assigned to the PF or the DI condition taught by the same teacher.

Several key findings were demonstrated: (a) the relative efficacy of PF over DI was replicated, (b) the solution generation effect was replicated, and (c) students with significantly different math ability were not as different in terms of their capacity to generate solutions during the generation and exploration phase. Consequently, students across different ability profiles were able to learn better from PF than DI. Taken together, these findings provided a strong evidence for the design principles of PF and demonstrated the tractability of PF across a range of math ability provided that one is able to design according to the design principles of PF.

The Role of Guided Versus Unguided Generation

A critical design decision for PF is to not provide cognitive guidance or support during the generation and exploration phase. The solution generation effect showed that students of different math abilities are in fact able to leverage their formal and intuitive resources to generate solutions even in the absence of any cognitive guidance or support. However, this only begged the question: might not guiding students during the generation and exploration phase result in an even better production of solutions, which in turn may help students learning even more from PF? In other words, what is the marginal gain of providing students with guidance during the generation and exploration phase?

In Kapur (2011), we addressed this question. Participants were 109, secondary 1 (grade 7) students from a coeducational public school in Singapore. Students were from three mathematics classes taught by the same teacher. The participating school was a mainstream school comprising average-ability students on the grade six national standardized tests. The same study design as in Study 1 was used except that in addition to the PF and DI conditions, a third condition—the guided-generation condition—was added. One class was assigned to each condition. The guided-generation condition was exactly the same as the PF condition but with one important exception. Whereas students in the PF condition did not receive any form of cognitive guidance or support during the generation and exploration phase, students in the guided-generation condition were provided with cognitive support and facilitation throughout that process. Such guidance was typically in the form of teacher clarifications, focusing attention on significant issues or parameters in the problem, question prompts that engendered student elaboration and explanations, and hints toward productive solution steps.

Findings suggested that students from the PF condition outperformed those from the DI and guided-generation conditions on procedural fluency, conceptual understanding, and transfer. The differences between guided-generation and DI conditions were not significant, though students from the guided-generation condition performed marginally better than those from the DI condition. Overall, the descriptive trend PF > guided-generation > LP seemed consistent across the different types of items. We argued that giving guidance too early or in the process of generation does not add to the preparatory benefits of generation in part because students may not be ready to receive and make use of the guidance provided.

The Role of Generating Versus Studying and Evaluating Solutions

A critical mechanism embodied in the PF design is one of generation and exploration of solutions relying only on students' formal and intuitive resources. However, it was not clear from the solution generation effect whether what was critical is the generation of solutions or simply an exposure to these solutions. Simply put, is it really necessary for students to generate the solutions or can these solutions be given to students to study and evaluate, that is, the opportunity to learn from the failed problem-solving efforts of their peers? We refer to learning from the failed problem-solving efforts of others as learning from *vicarious failure* (VF). If productive failure is a design where students have an opportunity to learn from their own failed solutions, then vicarious failure is a design where students have an opportunity to learn from the failed solutions of their peers.

In Kapur (2013), we compared the effectiveness of learning from PF and VF. Participants were one hundred and thirty six ($N = 136$) grade eight mathematics students (14–15-year-olds) from two coeducational public schools in Singapore. Sixty four students from School A and seventy two students from School B participated in the study. In both schools, students came from two intact classes taught by the same teacher. As per the PF design, PF students experienced the generation and exploration phase followed by the consolidation and knowledge assembly phase. VF students differed from the PF condition only in the first phase: The generation and exploration phase was replaced with a study and evaluation phase, where instead of generating and exploring solutions, students worked in small groups to study and evaluate student-generated solutions (available from earlier work, e.g., Kapur 2012; see Kapur 2013 for examples of solutions). VF students then received the same consolidation and knowledge assembly as PF students. In the study and evaluation phase for VF students, students first read the complex problem (see Appendix A) and were then presented with the student-generated solutions one-by-one counterbalanced for order with the prompt: “Evaluate whether this solution is a good measure of consistency. Explain and give reasons to support your evaluation.” The number of solutions was pegged to the average number of solutions produced by PF groups, that is, six. The most frequently generated solutions by the PF students were chosen for VF condition.

Findings suggested that, after controlling for prior knowledge, school, and ability differences, PF students significantly outperformed VF students on conceptual understanding and transfer, without compromising procedural fluency. These findings underscored the primacy of generation over mere exposure, thereby evidencing a key mechanism of the PF design. In more recent work (Kapur 2014), we have compared PF, VF, and DI and shown the findings to be consistent with Kapur (2013).

The Role of Attention to Critical Features

As discussed earlier, the contrasts among and between the student-generated solutions and the canonical solutions afford students the opportunities to attend to the critical features of the targeted concept. However, if what is essential is that students attend to the ten critical features, then why not simply tell students these critical features? Why bother having them generate and compare and contrast the solutions? Simply put, do students really need to generate before receiving the critical features, or would telling the critical features without any generation work just as well? Addressing this question would help understand a critical mechanism of PF that the generation and exploration of solutions better prepares students to understand the critical features during for instruction than simply telling them those features.

In Kapur and Bielaczyc (2011), we addressed this question. Participants were 57, ninth-grade mathematics students (14–15-year-olds) from two intact classes in an all-boys public school in Singapore. One class was assigned to the PF condition, and the other class to the “Strong-DI” condition. Both classes were taught by the same teacher. The PF condition was exactly the same as in Study 1. The Strong-DI condition was the same as the DI condition in Study 1 except that the teacher drew attention to the ten critical features during instruction (e.g., why deviations need to be taken from the mean, why they must be positive, why divide by *n*, etc.). While explaining each step of formulating and calculating SD, the teacher explained the appropriate critical features relevant for that step. For example, when explaining the concept of “deviation of a point from the mean,” the teacher discussed why deviations need to be from a fixed point, why the fixed point should be the mean, and why deviations must be positive. During subsequent problem-solving and feedback, the teacher repeatedly reinforced these critical features throughout the lessons.

Findings suggested that PF students significantly outperformed their Strong-DI counterparts on conceptual understanding without compromising on procedural fluency. There were no differences in terms of transfer. These findings suggested that although telling students that novel information can be effective, the generation and exploration phase is nonetheless better in preparing students to receive these features.

Conclusion

Contrary to the commonly held belief that there is little efficacy in having learners solve novel problems that target concepts they have not learned yet, our work suggests that there is indeed such an efficacy even if learners do not formally know the underlying concepts needed to solve the problems and even if such problem-solving leads to failure initially. Our work also demonstrates how engaging students in the process of generating, exploring, critiquing, and refining solutions affords them with the opportunity to engage in authentic practice. Authenticity refers not so much to the actual task or problem but the context and culture within which such problem-solving occurred that afforded students opportunities to not only learn about mathematics but also be like a mathematician (Thomas and Brown 2007).

In this chapter, we traced the developmental trajectory of PF from its inception to a learning design. We started by describing the mechanisms embodied in the PF design, as well as the principles guiding the design. Our initial work in the schools compared the PF design with the most prevalent design in classroom instruction, that is, DI. Findings from an initial comparison between PF and DI were encouraging yet raised further lines of inquiry that necessitated a closer examination of some critical aspects of the PF design, namely, (a) the role of math ability, (b) the role of guidance during the generation, (c) the role of learning from vicarious failure, and (d) the role of attention to critical features. Each of these lines of inquiry was pursued through classroom-based quasi-experimental studies.

Thus far, our work has focused on a closer interrogation of the design to more systematically unpack and examine its design assumption and decisions. Through such an "iterative" examination in real ecologies, our goal for the PF learning design is to become more "ecologically valid and practice-oriented" (Confrey 2006, p. 144). More importantly, the iterative examination of the design further generates theoretical conjectures that in turn drive future work. In other words, the continuous examination of the design enables the development of possible design principles that direct, apprise, and advance educational research and practice (Anderson and Shattuck 2012). Therefore, our future work would continue to interrogate the PF design and all its constituent mechanisms, design principles, and design decisions, while at the same time iterate and refine the PF design.

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in accordance with the publishing agreement, from a chapter (Kapur and Toh 2013) that was contributed to a handbook of educational design cases.

Appendix A: The Complex Problem Scenario

Mr. Ferguson, Mr. Merino, and Mr. Eriksson are the managers of the Supreme Football Club. They are on the lookout for a new striker, and after a long search, they short-listed three potential players: *Mike Arwen*, *Dave Backhand*, and *Ivan Right*. All strikers asked for the same salary, so the managers agreed that they should base their decisions on the players' performance in the Premier League for the last 20 years. Table 12.1 shows the number of goals that each striker had scored between 1988 and 2007.

The managers agreed that the player they hire should be a *consistent* performer. They decided that they should approach this decision mathematically and would want a *formula* for calculating the consistency of performance for each player. This formula should apply to all players and help provide a fair comparison. The managers decided to get your help.

Please come up with a formula for consistency and show which player is the most consistent striker. Show all working and calculations on the paper provided.

Table 12.1 Number of goals scored by three strikers in the Premier League

Year	Mike Arwen	Dave Backhand	Ivan Right
1988	14	13	13
1989	9	9	18
1990	14	16	15
1991	10	14	10
1992	15	10	16
1993	11	11	10
1994	15	13	17
1995	11	14	10
1996	16	15	12
1997	12	19	14
1998	16	14	19
1999	12	12	14
2000	17	15	18
2001	13	14	9
2002	17	17	10
2003	13	13	18
2004	18	14	11
2005	14	18	10
2006	19	14	18
2007	14	15	18

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Chapter 13
Discussing Student Solutions Is Germane for Learning when Providing or Delaying Instruction

Katharina Loibl and Nikol Rummel

Abstract Recent studies have shown benefits of problem-solving prior to instruction (cf. productive failure) for learning. These findings seem to contradict well-established assumptions of cognitive load theory. However, there are two possible mechanisms in line with cognitive load theory that may explain these beneficial effects: the activation of prior knowledge and intuitive ideas during the problem-solving phase to generate solution approaches and the focusing of attention on relevant components of the canonical solution by comparing and contrasting typical student solutions to the canonical solution during the instruction phase. It is unclear whether the reported benefits originate from the activation of prior knowledge and intuitive ideas during the problem-solving phase or from the specific form of instruction in which student solutions are compared and contrasted to the canonical solution. To investigate this question, we compared three conditions in a quasi-experimental study: standard instruction prior to problem-solving (I – PS), instruction in which typical student solutions are contrasted to the canonical solution prior to problem-solving ($I_{contrast}$ – PS), and problem-solving prior to instruction in which typical student solutions are contrasted to the canonical solution (PS – $I_{contrast}$). I – PS was outperformed by the other two conditions on conceptual knowledge. This finding suggests that student solutions are fruitful learning resources. We argue that the comparison of student solutions and the canonical solution focuses attention on the relevant components of the solution, which leads to deeper processing. Indeed, our cognitive load measures suggest that comparing and contrasting typical student solutions during instruction is germane for learning.

Keywords Cognitive load • Intuitive ideas • Inventing • Prior knowledge • Productive failure

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Productive Failure in the Light of Cognitive Load Theory

Can learning be best promoted by providing or by withholding instructional support? This so-called assistance dilemma (Kapur and Rummel 2009; Koedinger and Aleven 2007) targets the question of how and when to support learners most effectively. Cognitive load theory (e.g., Sweller 1988) suggests that withholding instruction increases the demands imposed on the learners' cognitive capacity and thus may have a negative impact on learning. If their cognitive capacity is exceeded, learners cannot process the information given and in consequence cannot learn the new information (Cook 2006). Therefore cognitive load theory favors instruction on the required solution procedure right at the beginning of the learning process (Kirschner et al. 2006). The instruction aims at establishing relevant knowledge for subsequent problem-solving activities (Roelle and Berthold 2012; Wittwer and Renkl 2008). Against the predictions of cognitive load theory, the benefits of problem-solving prior to instruction over direct instruction (i.e., without previous problem-solving) shown in recent studies (e.g., Kapur 2011, 2012; Roll et al. 2009, 2011; Schwartz and Martin 2004) seem surprising. These studies indicate that attempting to solve problems, which require the application of a yet unknown concept, prepares students for understanding the concept in the subsequent instruction. While at first glance these findings seem to contradict cognitive load theory, there are two possible mechanisms in line with cognitive load theory that may explain these beneficial effects: the activation of prior knowledge and intuitive ideas during the problem-solving phase and the focusing of attention on the relevant components of the canonical solution by contrasting typical student solutions to the canonical solution during the instruction phase. In the following, we will discuss these two mechanisms in detail to derive specific hypotheses concerning their impact on cognitive load and on learning. Finally, we will present a quasi-experimental study that tests those hypotheses.

Activation of Prior Knowledge and Intuitive Ideas by Delaying Instruction

Cognitive load theory is based on the assumption of a limited working memory and an unlimited long-term memory (Sweller 1988). Information is processed in working memory by taking recourse to knowledge retrieved from long-term memory. In long-term memory, knowledge is stored and organized in schemas (Chi et al. 1982). A schema is constructed by linking knowledge elements together so that all knowledge elements within one schema can then be processed as one unit in working memory (Sweller et al. 1998). According to cognitive load theory, a delay of instruction will increase the cognitive load imposed on the learner's working memory and thereby hamper schema formation (Sweller 1988). Moreover, letting students invent mostly non-canonical and incomplete solutions without correcting them at the beginning entails the risk of manifesting misconceptions (Brown and Campione 1994). How can problem-solving prior to instruction then still be productive? Cognitive load theory argues that successful learners will relate new concepts to their prior knowledge stored in long-term memory by linking new information to existing schemas (e.g., Kirschner et al. 2006; Sweller 1988). This process is more likely to occur if prior knowledge is activated in working memory. Studies on cognitive load commonly focus on canonical, formally learned prior knowledge (e.g., Kirschner et al. 2006) and rarely take intuitive ideas into account (Kapur and Bielaczyc 2011). Intuitive ideas are ideas that students have prior to formal instruction based on their real-life experiences. These intuitive ideas do not necessarily match the curricular norm. In addition to formal prior knowledge, intuitive ideas might also provide resources for future learning (Kapur and Bielaczyc 2011) as the intuitive ideas are part of the schemas stored in memory. When students solve problems prior to instruction, they have to activate their prior knowledge and intuitive ideas to generate solution attempts (Kapur and Bielaczyc 2012; Schoenfeld 1992). During subsequent instruction, students can then connect the new information to the activated prior knowledge and intuitive ideas and thereby integrate the new information in existing schemas.

Students' prior knowledge and intuitive ideas are reflected in the solution attempts generated during the problem-solving phase. Depending on the quality of students' prior knowledge and intuitive ideas, these student solutions may or may not be partly correct. In other words, even though the overall solutions are usually incorrect or incomplete (Kapur and Bielaczyc 2012), they may already include some canonical components. The more canonical components are already represented in the students' solutions, the less cognitive load is required to learn and integrate the remaining components during instruction. Thus, solution quality during problem-solving prior to instruction should affect the learning outcome. Kapur (2012) found a positive correlation between the diversity of invented solutions that reflect different knowledge components and learning outcome (for similar results, see Kapur and Bielaczyc 2012; Wiedmann et al. 2012). While this finding is a first indicator for an existing relation between invented solutions and learning, diversity does not necessarily reflect the quality of the solutions. Diversity counts the number of different solutions regardless of their quality. Wiedmann et al. (2012) attempted to include quality in their coding by dividing the solutions in two categories regarding quality. They found a higher correlation between the number of high-quality solutions and learning outcome than between the number of low-quality solutions and learning outcome. However, a more detailed investigation is required as to whether the quality of student solutions as evidenced by the number of canonical components represented in the student solutions relates to learning.

Focusing Attention During Instruction

As students usually fail to invent the canonical solution themselves during the problem-solving phase, instruction is necessary to ensure that students learn the canonical solution in the end. However, most research on problem-solving prior to instruction has focused on designing the problem-solving phase (e.g., with or without collaboration, Sears 2006; with or without support, Loibl and Rummel 2014; Roll et al. 2012; Westermann and Rummel 2012), while the instruction phase that follows the problem-solving phase has received less attention (Collins 2012). Upon closer inspection of the instruction provided in the studies by Kapur (e.g., 2011, 2012), it becomes apparent that the form of instruction might be a relevant aspect: In the instruction prior to problem-solving control condition (called direct instruction, DI), the teacher directly presented the canonical solution of the task at hand. In the problem-solving prior to instruction condition (called productive failure, PF) however, the teacher compared and contrasted typical student-generated solutions to the canonical solution in a classroom discussion focusing on the structurally relevant components of the solution. Kapur and Bielaczyc (2011) attempted to align the instruction in problem-solving prior to instruction and instruction prior to problem-solving settings: They implemented an instruction prior to problem-solving condition where the teacher explained the structurally relevant components of the canonical solution (called strong DI). However, the strong-DI condition still did not include typical student-generated (i.e., non-canonical) solutions. Despite this remaining difference in the instruction of both conditions, the alignment reduced the learning differences between problem-solving prior to instruction and instruction prior to problem-solving, indicating that the instruction indeed plays a crucial role.

Roll and colleagues (2011) claim that during the instruction that follows a problem-solving phase, students focus their attention on the structurally relevant components that did not occur in their invented solution attempts. Against this background, we argue that the comparison of non-canonical student solutions to the canonical solution during instruction supports students to detect differences between their own prior ideas and the canonical solution. Further, detecting these differences guides students' attention to the structurally relevant components (cf. Durkin and Rittle-Johnson 2012) and to the aspects of their existing schemas that have to be modified to match the canonical solution. Focusing on the most important components enables students to process these components deeply (Renkl and Atkinson 2007) as the load arising from processing irrelevant aspects is reduced (cf. Mayer et al. 2001). The deep processing of the relevant components in turn fosters students to integrate these components in their existing schemas.

If the comparison of non-canonical student solutions with the canonical solution during instruction helps students to focus their attention on the structurally relevant components of the canonical solution, a classroom discussion about typical non-canonical solutions may also be beneficial in instruction prior to problem-solving settings: In such a classroom discussion, the teacher can meet students at their level of knowledge and understanding (for the importance of meeting students at their level of understanding, see Wittwer and Renkl 2008) and make discrepancies between the canonical solution and possible erroneous, intuitive ideas explicit (Smith et al. 1994). Accordingly, two studies by Große and Renkl (2007) showed that erroneous worked-out examples can enhance transfer performance of more advanced learners by fostering reflection about the problem-solving process. Durkin and Rittle-Johnson (2012) found that comparing common mathematical errors to correct examples increases learning in comparison to comparing only correct examples. Further research demonstrated that students process the canonical solution more deeply when they realize impasses and errors (van Lehn et al. 2003) and that the realization of an impasse can be triggered by the warning of possible errors before presenting the instructional explanation (Acuña et al. 2010; Sánchez et al. 2009). Taking these findings together, it seems promising to investigate the role of typical student-generated, non-canonical solutions in instruction prior to problem-solving approaches.

In summary, problem-solving prior to instruction prompts students to activate their prior knowledge and intuitive ideas. Subsequent instruction can build on the activated prior knowledge and intuitive ideas that help students to connect the new information to their existing schemas. Therefore the cognitive load to learn the new concept should be reduced. Furthermore, comparing and contrasting student solutions that reflect students' prior knowledge and intuitive ideas to the canonical solution during instruction should enable students to focus their attention on the structurally relevant components of the new concept. This attention focusing should promote deeper processing and reduce the cognitive load caused by processing irrelevant information not only in instruction that follows a problem-solving phase but also in instruction building on typical student solutions prior to a problem-solving phase. Both mechanisms (activating prior knowledge and focusing attention) can provide possible explanations of the beneficial effect of problem-solving prior to instruction within the frame of cognitive load theory. Both mechanisms foster students' understanding of the new concept. Thus, these mechanisms are in line with the findings of the cited studies on problem-solving prior to instruction showing beneficial effects on conceptual knowledge and transfer but not on procedural skills (e.g., Kapur 2011, 2012; Roll et al. 2009, 2011; Schwartz and Martin 2004). The acquisition of procedural skills requires practicing the application of the learned procedure to isomorphic problems (Rittle-Johnson et al. 2001). Therefore problem-solving prior to instruction might be less effective for fostering procedural skills in comparison to instruction prior to problem-solving as it reduces the time available for practice (Klahr and Nigam 2004).

Research Question and Hypotheses

The literature cited above proposes two possible mechanisms to explain the beneficial effect of problem-solving prior to instruction found in recent studies: activating prior knowledge and intuitive ideas prior to instruction and focusing attention by comparing and contrasting typical non-canonical solutions to the canonical solution during instruction. While the first explanation clearly favors problem-solving prior to instruction, the latter suggests that an instruction prior to problem-solving condition that compares typical student solutions and contrasts them to the canonical solution should outperform a regular direct instruction condition on conceptual knowledge just as well as a problem-solving prior to instruction condition. To approach this question, we implemented three conditions in a quasi-experimental study: standard instruction prior to problem-solving (I – PS), instruction in which typical student solutions are compared and contrasted to the canonical solution prior to problem-solving ($I_{contrast}$ – PS), and problem-solving prior to instruction in which typical student solutions are compared and contrasted to the canonical solution (PS – $I_{contrast}$). Analogously to most of the cited studies on problem-solving prior to instruction, in all conditions, students worked in small groups of three students during the problem-solving phase:

1. In the first set of hypotheses, we focus on the differences between the PS – $I_{contrast}$ condition (i.e., students who *activate their prior knowledge and intuitive ideas* during problem-solving prior to instruction) and both instructions prior to problem-solving conditions (i.e., I – PS and $I_{contrast}$ – PS):

   - *Hypothesis 1a:* Learning the new concept during instruction will impose less cognitive load on students in the PS – $I_{contrast}$ condition than on students in both instructions prior to problem-solving conditions (I – PS and $I_{contrast}$ – PS).
   - *Hypothesis 1b:* Students in the PS – $I_{contrast}$ condition will outperform students in both instructions prior to problem-solving conditions (I – PS and $I_{contrast}$ – PS) on items testing for conceptual knowledge.
   - *Hypothesis 1c:* Students in both instructions prior to problem-solving conditions (I – PS and $I_{contrast}$ – PS) will outperform students in the PS – $I_{contrast}$ condition on items testing for procedural skills.

2. In the second set of hypotheses, we focus on the differences between the I – PS condition and the $I_{contrast}$ – PS condition:

   - *Hypothesis 2a:* Learning the new concept during instruction will impose less cognitive load on students in the $I_{contrast}$ – PS condition than on students in the I – PS condition.
   - *Hypothesis 2b:* Students in the $I_{contrast}$ – PS condition will outperform their counterparts in the I – PS condition on items testing for conceptual knowledge.

3. In the third set of hypotheses, we focus on the effects of the quality of solution approaches generated by students in the PS – $I_{contrast}$ condition:

   - *Hypothesis 3a:* The number of correct components represented in the student solutions generated during problem-solving prior to instruction in the PS – $I_{contrast}$ condition will correlate negatively with reported cognitive load during instruction.
   - *Hypothesis 3b:* The number of correct components represented in the student solutions generated during problem-solving prior to instruction in the PS – $I_{contrast}$ condition will correlate positively with the acquisition of conceptual knowledge.

Methods

Participants

Participants were 107 10th graders (5 classes) recruited from two secondary schools in Germany. The study took place at the schools. Classes were randomly assigned to one of the three conditions as a whole. Only the 98 students who were present during both learning phases were included in the analyses. Descriptive statistics of the final sample are shown in Table 13.1.

Learning Materials

The learning materials were the same as described in Loibl and Rummel (2014). It addressed the same mathematical concept, namely, the concept of variance, as in other studies on problem-solving prior to instruction (e.g., Kapur 2012; Roll et al. 2009; Schwartz and Martin 2004). This enabled us to compare our results to the results found by others. By grade 10 of German secondary schools, students have not yet covered the concept of variance. This topic contains the formula for mean absolute deviation ($\text{MAD} = \sum |x_i - \text{mean}|/N$) and for standard deviation ($\text{SD} = \sqrt{(\sum (x_i - \text{mean})^2/N)}$). Both formulae include the following four functional components: (1) Sum up deviations including all numbers to get a precise result, (2) take absolute or squared deviations (positive values) to prevent positive and negative deviations from canceling out, (3) take deviations from a fixed reference point (the mean) to avoid the impact of sequencing, and (4) divide by the number of data points to account for sample size. The learning task was adopted from the task used by Kapur (2012). It was the same in all conditions: At the beginning of the first learning phase, students were told the number of goals three soccer players scored

Table 13.1 Descriptive statistics of the final sample

		Sample	I – PS	$\text{I}_{\text{contrast}}$ – PS	PS – $\text{I}_{\text{contrast}}$
N (classes)		98 (5)	19 (1)	40 (2)	39 (2)
Age	*M*	15.80	15.63	15.78	15.90
	(*SD*)	(0.48)	(0.50)	(0.53)	(0.38)
Male		43	6	14	23
Female		55	13	26	16
Math score[a]	*M*	3.04	2.87	2.97	3.22
	(*SD*)	(0.92)	(0.85)	(0.84)	(1.03)

Note. [a]In the German system, 1 is the best score and 6 is the worst score. A score of 4 or better counts as a pass

Reprinted from Learning and Instruction, 34, Loibl, K. & Rummel, N., Knowing what you don't know makes failure productive, 74–85, Copyright (2014), with permission from Elsevier in the last 10 years and were asked who the most consistent goal scorer is. In order to force students to think about strategies beyond their formal prior knowledge, the range and the mean were the same for all three players. Thus, students were unable to answer the question by calculating descriptive statistics which they might have learned prior to the study.

Measures and Covariates

Learning Outcomes

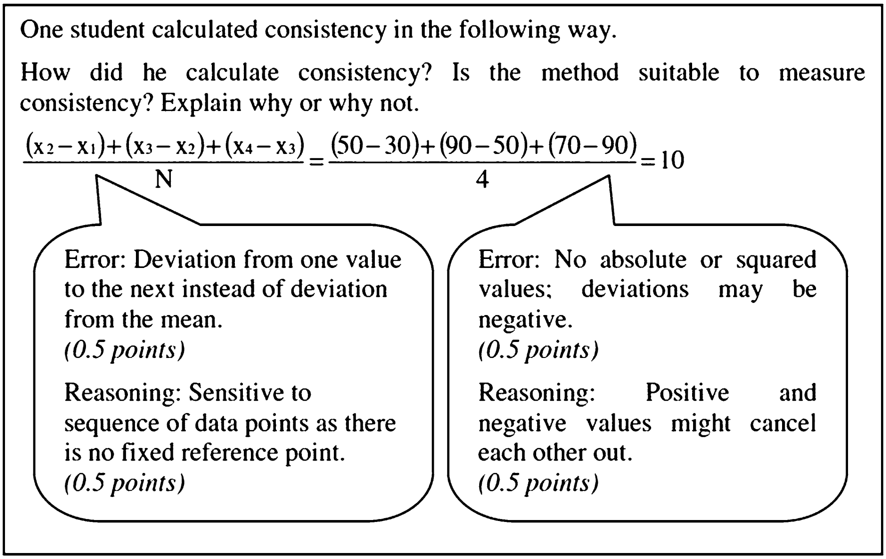
We assessed learning outcomes with a posttest after the second learning phase. The posttest was the same as the one described in Loibl and Rummel (2014). It included items which tested for procedural skills and for conceptual knowledge:

The *procedural skill* items asked students to solve problems isomorphic to the one discussed during instruction. For each correct calculation of the mean absolute deviation or the standard deviation, students received 1 point. 0.5 points were subtracted for computation errors. When students were asked to compare two deviations, they could receive 1 additional point. In total, students could achieve 4 points (i.e., 1 item required a single calculation and 1 item required the calculation of two deviations including a comparison). A second rater coded 10 % of the tests. Inter-rater reliability was high ($\text{ICC}_{\text{random,absolute}} = .97$).

The *conceptual knowledge* items required students to reason mathematically and to translate between graphical and algebraic strategies: Two items presented incorrect solution approaches. Students had to detect the errors and to reason mathematically about the adequate functional component of the formula. Students received 0.5 points for the correct detection of each error and an additional 0.5 points per detected error for correct reasoning about the functional components. Figure 13.1 presents an example. Two other items required sense making using both graphical representations and the canonical decomposed formula. Students received 0.5 points for each correct match of a functional component and a graphical representation. In total, students could achieve 7 points (3 points for the first type of items, 4 points for the second type of items). A second rater coded 10 % of the tests. Inter-rater reliability was high ($\text{ICC}_{\text{random,absolute}} = .97$).

Process Data

In the $\text{PS}-\text{I}_{\text{contrast}}$ condition, students used tablet PCs to invent their solutions. Students used the tablet PCs in a paper-and-pencil fashion: They had a blank space where they could write or draw on with a stylus. All other functionalities were blocked. The use of tablet PCs enabled us to collect synchronized audio, video, and screen recordings of students' collaborative problem-solving prior to instruction. To test the assumption that the more functional components are included in the invented



One student calculated consistency in the following way.

How did he calculate consistency? Is the method suitable to measure consistency? Explain why or why not.

$$\frac{(x_2 - x_1) + (x_3 - x_2) + (x_4 - x_3)}{N} = \frac{(50 - 30) + (90 - 50) + (70 - 90)}{4} = 10$$

Error: Deviation from one value to the next instead of deviation from the mean.
(0.5 points)

Reasoning: Sensitive to sequence of data points as there is no fixed reference point.
(0.5 points)

Error: No absolute or squared values; deviations may be negative.
(0.5 points)

Reasoning: Positive and negative values might cancel each other out.
(0.5 points)

Fig. 13.1 Example of one item testing for conceptual knowledge with solution (Reprinted with minor modification from Learning and Instruction, 34, Loibl, K. & Rummel, N., Knowing what you don't know makes failure productive, 74–85, Copyright (2014), with permission from Elsevier)

solution approaches, the easier should be the acquisition of the new concept, we coded how many of the four functional components (see "Learning materials") were included in each solution approach. This coding of the *quality* assessed the accordance of each generated solution with the canonical solution (with 0 points meaning no functional component was included and 4 points indicating a canonical solution). We only focused on the best solution of each group, that is, the solution including the most functional components. This way quality and quantity was not confounded. Previous studies have found an effect of the diversity (Kapur 2012) or of the number (Wiedmann et al. 2012) of different solution approaches on learning. To account for these findings, we additionally counted how many different solution approaches (i.e., the *quantity* of solutions) were invented by each group regardless of the quality of these approaches. Each solution idea counted only once, even if it was discussed several times.

A second rater coded 20 % of the data; three groups were randomly selected for this coding. The inter-rater reliability was good with an agreement of 67 % concerning the number of invented solutions and an agreement of 100 % concerning the quality of the best solution. Disagreements concerning the number of solutions arose because the coding included solution ideas that were actually carried out and calculated, as well as solution ideas that were discussed during the problem-solving phase but not carried out. The latter were more difficult to detect correctly.

Cognitive Load

To test the hypotheses that better solutions facilitate learning the new concept during instruction (hypothesis 3a) and that instruction in the different learning conditions differs in the amount of cognitive load imposed on the students (hypotheses 1a and 2a), we measured cognitive load. According to Paas (1992), cognitive load includes mental effort and mental load. We operationalized mental load as perceived task difficulty (cf. Bratfisch et al. 1972 in Paas 1992; Moreno 2007). We asked students to rate their invested mental effort and the perceived difficulty on a 9-point Likert scale at three occasions: after each learning phase and after the posttest.

Covariate

Generating solutions to a new problem likely depends on prior knowledge. Thus, we assessed students' formal prior knowledge as covariate: Prior to the study, students indicated their score in mathematics from the last academic year.

Experimental Conditions and Procedure

As mentioned above, we implemented three conditions. Within the instruction prior to problem-solving conditions, we varied the form of instruction during the first learning phase: In the regular I – PS, condition students received direct instruction on the canonical solution. The experimenter, who was teaching the class, first presented the problem of the three soccer players and discussed the meaning of consistency with the class. This introduction was followed by a presentation of several canonical approaches (graphical approaches, range, mean absolute deviation, and standard deviation). The class discussed the advantages and disadvantages of the different approaches (e.g., graphical approaches might be imprecise and range is sensitive to outliers). Finally the experimenter explained the functional components of the canonical formulae (mean absolute deviation and standard deviation). In the I_{contrast} – PS condition, prior to explaining the canonical solution, the experimenter presented and compared typical student solutions (e.g., number of times the soccer player scored at the mean, deviation from 1 year to the next with or without absolute values) during instruction and discussed whether each approach is suitable to solve the problem. It should be stressed that the solutions were not the very solutions generated by students during the problem-solving phase in this study. Rather, the solutions were *typical* student-generated solutions (taken from pilot studies and studies from other researchers on the same content, e.g., Kapur 2012) that match the most often generated solutions during problem-solving prior to instruction. Afterward the experimenter contrasted the student solutions to the canonical solution and explained the functional components of the canonical formulae, following the same procedure as in the I – PS condition. In both instructions prior to problem-solving conditions (i.e., I – PS and $I_{contrast}$ – PS), students solved practice problems in small groups with several isomorphic problems during the second learning phase.

In the PS – $I_{contrast}$ condition, students tried to solve the problem by generating several solution approaches in small groups without instruction or support. During this process, they only received motivational prompts encouraging them to persist in solving the task (e.g., "you are doing a good job together, keep going"). They did not receive any guidance on the concept or concerning problem-solving strategies. During instruction in the following learning phase, the experimenter compared typical student solutions (the same solutions as in the $I_{contrast}$ – PS condition, i.e., not students' own solutions but solutions taken from pilots and previous studies) and contrasted them to the canonical solution. The instruction was exactly the same as in the $I_{contrast}$ – PS condition, but took place in the second learning phase.

The same experimenter gave the instruction in all conditions. As mentioned above, students worked in groups during the problem-solving phase in all conditions. To safeguard external validity, the groups were formed following the normal process in schools: Usually students worked together with their seat neighbors. Most groups had three members. Due to organizational reasons and absenteeism, some groups had two or four members. The study took place during regular mathematics periods. In the first 5 min, students filled in a pre-questionnaire including their math score from the previous academic year. Learning phase 1 according to each condition followed. Learning phase 1 took 45 min. Afterward students rated their cognitive load for the learning phase. Learning phase 2 of 45 min took place about 2 days later during the next mathematics lesson. After a short break, students completed a posttest of 30 min in length. Students rated their cognitive load for the learning phase 2 prior to the posttest and they rated their cognitive load for the posttest after the test.

Results

Learning Outcomes

To assess differences between the experimental conditions, we calculated a MANCOVA with the factor condition and the covariate prior knowledge (i.e., math score) that revealed significant differences between conditions for both scales (procedural skills: $F[2, 94] = 4.86$, $p = .01$; conceptual knowledge: $F[2, 94] = 17.50$, $p < .01$). Table 13.2 provides the means and standard deviations for the posttest scores.

Table 13.2 Means and standard deviations of posttest results

Condition	*N*	Procedural skills (max. 4 points)	Conceptual knowledge (max. 7 points)
I – PS	19	3.68 (0.95)	1.05 (1.21)
$I_{contrast}$ – PS	40	3.56 (0.62)	3.11 (1.71)
PS – $I_{contrast}$	39	2.90 (1.32)	3.46 (2.04)

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In line with our hypotheses, we calculated two a priori contrasts: First, we compared the problem-solving prior to instruction condition ($PS - I_{contrast}$) to both instructions prior to problem-solving conditions (hypothesis 1b and 1c). Second, we compared I – PS and $I_{contrast} - PS$, that is, the different forms of instruction (hypothesis 2b).

Regarding *procedural skills*, the a priori contrasts revealed one significant difference: The instruction prior to problem-solving conditions (I – PS and $I_{contrast} - PS$) significantly outperformed the $PS - I_{contrast}$ condition ($F[1, 94] = 9.57$, $p = .003$, $\eta_p^2 = .09$). The form of instruction in the instruction prior to problem-solving conditions ($F[1, 94] = .13$, $p = .72$) had no significant effect.

For *conceptual knowledge*, the a priori contrasts revealed two significant differences with medium effect size: First, the $PS - I_{contrast}$ condition outperformed the instruction prior to problem-solving conditions ($F[1, 94] = 21.18$, $p < .001$, $\eta_p^2 = .184$). Second, $I_{contrast} - PS$ outperformed I – PS ($F[1, 94] = 22.09$, $p < .001$, $\eta_p^2 = .19$). That is, students who received instruction in which typical student solutions are compared and contrasted to the canonical solution outperformed their counterparts receiving regular instruction on items testing for conceptual knowledge.

To compare the two conditions that included instruction with comparing and contrasting typical student solutions ($I_{contrast} - PS$ and $PS - I_{contrast}$) to each other, we additionally calculated an a posterior comparison (LSD) that revealed significant differences for procedural skills ($p = .01$) but not for conceptual knowledge ($p = .15$).

Process Data and Their Correlation with Learning Outcomes

We tested whether quantity (mean: 5.67 [2.13]) and quality (mean: 2.53 [0.92]) of the generated solutions in the $PS - I_{contrast}$ condition is related to learning (hypothesis 3b). As quantity and quality is assessed on a group level, we analyzed the correlation on a group level, using the mean posttest scores of each group. We found no significant correlation with the learning outcomes for the *quantity* of solution ideas (procedural skills, $r = .39$, $p = .15$; conceptual knowledge, $r = -.22$, $p = .43$). The correlation between *quality* and learning outcomes was significant for conceptual knowledge ($r = .55$, $p = .03$), but not for procedural skills ($r = .26$, $p = .35$). There was no significant correlation between prior knowledge and the quality of solution approaches, neither with individual prior knowledge ($r = -.13$, $p = .43$) nor on the group level ($r = -.25$, $p = .37$).

Cognitive Load

Students rated their cognitive load three times which allows for multiple comparisons: We compared mental effort and perceived task difficulty across conditions after the posttest as this is the usual timing of measuring cognitive load. We further compared mental effort and perceived task difficulty after the first learning phase (i.e., after the problem-solving phase for $PS-I_{contrast}$ and after the instruction phase for I–PS and $I_{contrast}-PS$) to test the prediction of cognitive load theory that problem solving prior to instruction increases cognitive load in comparison to direct instruction. To test whether instruction can be easier processed after activating prior knowledge by problem-solving activities (hypothesis 1a) and/or when the attention is focused on the structurally relevant components by comparing and contrasting non-canonical and canonical solutions (hypothesis 2a), we compared mental effort and perceived task difficulty after instruction across all three conditions. Note that the timing of measuring cognitive load imposed during instruction differs across conditions: We measured cognitive load for instruction after the first learning phase for I–PS and $I_{contrast}-PS$ and after the second learning phase for $PS-I_{contrast}$. Thus, the foci of the analyses differ: For the first comparison (i.e., after the posttest) the timing of the measurement and the previous task are the same for all conditions. For the second comparison (i.e., after the first learning phase), the timing of the measurement is the same for all conditions, but the previous task differs (i.e., instruction or problem solving). For the third comparison (i.e., after the instruction), the previous task is the same for all conditions, but the timing of the measurement differs (i.e., after the first learning phase or after the second learning phase). We calculated three MANCOVAS with math score as covariate. Math score correlated with mental effort (posttest, $r=.21$, $p=.04$; learning phase 1, $r=.37$, $p<.001$; instruction, $r=.40$, $p<.001$) and perceived task difficulty (posttest, $r=.28$, $p=.01$; learning phase 1, $r=.42$, $p<.001$; instruction, $r=.43$, $p<.001$) and was therefore included as covariate. Where the MANCOVAs revealed significant differences across conditions, we calculated the same a priori contrasts as for learning outcomes. Table 13.3 provides the means and standard deviations of the cognitive load ratings.

After the posttest, the MANCOVA did not reveal any significant differences across conditions (mental effort, $F[2, 92]=1.17$, $p=.32$; task difficulty, $F[2, 92]=1.80$, $p=.17$).

After the first learning phase, the MANCOVA revealed significant differences across conditions for mental effort ($F[2, 94]=12.79$, $p<.001$) and perceived task difficulty ($F[2, 94]=14.14$, $p<.001$). Students in the $PS-I_{contrast}$ condition reported significantly higher mental effort ($F[1, 94]=22.84$, $p<.001$, $\eta_p^2=.20$) and higher perceived task difficulty ($F[1, 94]=28.27$, $p<.001$, $\eta_p^2=.23$) than students in

Table 13.3 Means and standard deviations of mental effort and task difficulty

	Learning phase 1: instruction for I–PS and $I_{contrast}-PS$		Learning phase 2: instruction for $PS-I_{contrast}$		Posttest	
	Mental effort	Task difficulty	Mental effort	Task difficulty	Mental effort	Task difficulty
I–PS	2.53 (0.70)	2.47 (0.90)	2.47 (0.61)	1.74 (0.73)	4.05 (1.27)	4.84 (1.54)
$I_{contrast}-PS$	3.63 (1.46)	2.95 (1.48)	2.90 (1.26)	2.00 (1.06)	4.62 (1.18)	4.44 (1.33)
$PS-I_{contrast}$	4.64 (1.68)	4.41 (1.58)	3.41 (1.80)	3.36 (1.69)	4.71 (1.68)	5.11 (1.50)

both instructions prior to problem-solving conditions. Students in the $I_{contrast}-PS$ condition reported significantly higher mental effort than students in the I – PS condition ($F[1, 94]=7.52$, $p=.01$, $\eta_p^2=.07$). This difference was not significant for perceived task difficulty ($F[1, 94]=1.26$, $p=.27$).

After instruction, the MANCOVA revealed significant differences across conditions for mental effort ($F[2, 94]=3.58$, $p=.03$), but not for perceived task difficulty ($F[2, 94]=1.44$, $p=.24$). The a priori contrasts for mental effort revealed only one significant difference: Students in the $I_{contrast}-PS$ condition reported significantly higher mental effort than students in the I – PS condition ($F[1, 94]=7.13$, $p=.01$, $\eta_p^2=.07$). The mental effort of students in both instructions prior to problem-solving conditions did not differ significantly from the mental effort reported by students in the $PS-I_{contrast}$ condition ($F[1, 94]=2.1$, $p=.65$). A posteriori comparisons (LSD) revealed that students in the $PS-I_{contrast}$ condition reported marginally significant higher mental effort than students in the I – PS condition ($p=.098$); the ratings of students in the $PS-I_{contrast}$ condition and students in the $I_{contrast}-PS$ condition did not differ significantly ($p=.23$).

To test hypothesis 3a that better solution ideas reduce the load imposed on the learner during instruction, we calculated correlations between solution quality and cognitive load during instruction for the $PS-I_{contrast}$ condition. The correlation was significant for both aspects: mental effort (individual level, $r=-.40$, $p=.01$; group level, $r=-.48$, $p=.07$) and perceived task difficulty (individual level, $r=-.49$, $p=.002$; group level, $r=-.66$, $p=.01$).

Discussion

Previous studies have shown benefits of problem-solving prior to instruction approaches (e.g., Kapur 2011, 2012; Roll et al. 2009, 2011; Schwartz and Martin 2004). At first glance, these findings seem to contradict well-established findings in the light of cognitive load theory that usually favor instruction prior to problem-solving approaches (Kirschner et al. 2006). However, there are two possible mechanisms in line with cognitive load theory that may explain these benefits: activating prior knowledge and focusing attention on the structurally relevant components. While the first mechanism clearly favors problem-solving prior to instruction approaches, the second mechanism could also be reached by comparing and contrasting typical student solutions in instruction prior to problem-solving settings. To test these assumptions, we implemented three conditions in a quasi-experimental study: standard instruction prior to problem-solving (I – PS), instruction in which typical student solutions are compared and contrasted to the canonical solution prior to problem-solving ($I_{contrast}-PS$), and problem-solving prior to instruction in which typical student solutions are compared and contrasted to the canonical solution ($PS-I_{contrast}$).

Regarding *conceptual knowledge*, the a priori contrast comparing the $PS-I_{contrast}$ condition to both instructions prior to problem-solving conditions ($I_{contrast}-PS$ and

$\mathrm{I}-\mathrm{PS}$) (hypothesis 1b) replicated the positive effect of problem-solving prior to instruction found by others (e.g., Kapur 2011, 2012; Roll et al. 2011; Schwartz and Martin 2004). However, upon closer inspection, only the $\mathrm{I}-\mathrm{PS}$ condition showed weak performance on the conceptual knowledge items, resulting in a significant difference between $\mathrm{I}-\mathrm{PS}$ and $\mathrm{I}_{\mathrm{contrast}}-\mathrm{PS}$ (hypothesis 2b). The descriptive difference between $\mathrm{I}_{\mathrm{contrast}}-\mathrm{PS}$ and $\mathrm{PS}-\mathrm{I}_{\mathrm{constrast}}$ favoring the problem-solving prior to instruction condition was rather small. Indeed, the a posteriori comparison indicated that the difference in conceptual knowledge outcome between $\mathrm{I}_{\mathrm{contrast}}-\mathrm{PS}$ and $\mathrm{PS}-\mathrm{I}_{\mathrm{constrast}}$ did not reach statistical significance. In contrast to our finding, Kapur (2014) found significant differences on conceptual knowledge and transfer items when comparing two conditions with instruction in which typical student solutions were contrasted to the canonical solution during the second learning phase: a problem-solving prior to instruction condition (i.e., productive failure) and a so-called vicarious failure condition in which students evaluated typical student solutions in small groups during the first learning phase. Comparing both findings, it seems that students do not benefit from evaluating typical student solutions on their own, but do benefit from it when the evaluation is led by the teacher during instruction. With regard to the instruction phase, our finding is in line with findings by Kapur and Bielaczyc (2011): They implemented an instruction prior to problem-solving condition where the teacher explains the structurally relevant components of the canonical solution (called strong-DI condition). When comparing a problem-solving prior to instruction condition to this strong-DI condition, the learning differences between the problem-solving prior to instruction condition and the instruction prior to problem-solving condition were reduced. In contrast to our study, Kapur and Bielaczyc still found significant differences between conditions on specific conceptual items of their posttest. This might be due to the fact that (unlike the instruction in their problem-solving prior to instruction condition) the instruction in their strong-DI condition did not build on non-canonical student solutions. In the $\mathrm{I}_{\mathrm{contrast}}-\mathrm{PS}$ condition and the $\mathrm{PS}-\mathrm{I}_{\mathrm{constrast}}$ condition of our study, instruction did compare typical student solutions and contrasted them to the canonical solution. In comparison to the weaker performing $\mathrm{I}-\mathrm{PS}$ condition, our results suggest that this process of comparing and contrasting solutions fosters conceptual knowledge. How might this comparing and contrasting during instruction support learning? Most likely, comparing and contrasting typical student solutions during instruction triggered active and focused processing of the concept (cf. Renkl and Atkinson 2007) and its structurally relevant components (cf. Durkin and Rittle-Johnson 2012). Our mental effort results for the instruction phase support this notion: Students in the $\mathrm{I}_{\mathrm{contrast}}-\mathrm{PS}$ condition and in the $\mathrm{PS}-\mathrm{I}_{\mathrm{contrast}}$ condition reported higher mental effort than students in the $\mathrm{I}-\mathrm{PS}$ condition indicating that the instruction was more deeply processed in the conditions that compared and contrasted solutions during instruction. Note that we had hypothesized that cognitive load would be highest in the $\mathrm{I}-\mathrm{PS}$ condition as students in this condition do not activate their prior knowledge and intuitive ideas (hypothesis 1a), and they are not supported in connecting the new concept to their prior knowledge and intuitive ideas by focusing the attention on the distinguishing components (hypothesis 2a). This notion of cognitive load as excessive demand underlies the measurement of perceived task difficulty. However, the perceived task difficulty as indicator for cognitive load did not differ across conditions. In contrast, the measurement of mental effort can reflect germane load. The fact that the conditions with higher reported mental effort for processing the instruction performed better on items testing for conceptual learning suggest that the invested effort was indeed germane for learning (cf. Paas and van Gog 2006). Kapur (2014) found a similar pattern regarding the relation of posttest results and mental effort. In his study, students in a problem-solving prior to instruction condition (i.e., productive failure) reported higher mental effort *and* achieved better posttest results than students in a so-called vicarious failure condition who evaluated typical student solutions in small groups during the first phase.

We additionally compared cognitive load after the first learning phase (i.e., after the instruction phase for $I - PS$ and $I_{contrast} - PS$ and after the problem-solving phase for $PS - I_{contrast}$). Cognitive load theory predicts that a delay of instruction as in the $PS - I_{contrast}$ condition increases the cognitive load imposed on the learner's working memory (Sweller 1988). Indeed, our ratings indicate that cognitive load was highest for the $PS - I_{contrast}$ condition (both mental effort and perceived task difficulty). However, the differences in cognitive load did not hold true for the load imposed during the posttest (which is the usual timing of measuring cognitive load). More importantly, the load did not influence the posttest results for conceptual knowledge negatively. We can therefore conclude that while problem-solving activities prior to instruction increases cognitive load at first, this effect does neither persist throughout the test nor does it have a negative impact on learning.

As indicated in the introduction, the cognitive load to learn the new concept should be smaller if students' prior knowledge and intuitive ideas are closer to the canonical concept, which may ease learning. Indeed, we found a negative correlation between solution quality and cognitive load (both mental effort and perceived task difficulty), indicating that the closer the invented solutions are to the canonical solution, the less cognitive load is imposed to learn the canonical solution (hypothesis 3a). Furthermore, the solution quality correlated with conceptual knowledge (hypothesis 3b). In this context, it is interesting that we did not find a correlation between the quality of solutions and prior knowledge, suggesting that students of all competence levels may benefit from problem-solving prior to instruction approaches (cf. Kapur and Bielaczyc 2012). In contrast to other researchers (Kapur 2012; Kapur and Bielaczyc 2012), we found no correlation between the number of invented solution approaches and learning. This divergent finding might be due to different operationalization: The coding of diversity by Kapur and colleagues might include aspects of quality (they only counted a solution idea if it was substantially different), while our coding strictly referred to quantity. For example, mean and median would count as one idea for diversity (both measure central tendency), but as two ideas for quantity.

Taking the findings on conceptual knowledge and cognitive load together, prior knowledge and intuitive ideas can be considered as valuable learning resources: The more similar the prior knowledge and the intuitive ideas are to the yet to be learned concept, the smaller the cognitive load to acquire the new concept during instruction as fewer components have to be modified or integrated in the existing schemas. Instruction that builds upon students' prior knowledge and intuitive ideas prompts students to focus their attention on the most relevant components of the canonical solution, that is, they focus on those components that differ from their existing schemas. The mental effort ratings in our study support the notion that focusing the learners' attention on differences between their schemas (intuitive ideas and prior knowledge) and the canonical solution is germane for learning as it leads to deeper processing. Deeper processing in turn fosters the acquisition of conceptual knowledge. However, building on students' prior knowledge and intuitive ideas requires identifying them first. Delaying instruction seems to be an effective approach for triggering students to externalize their prior knowledge and intuitive ideas by inventing solution approaches prior to instruction. In the subsequent instruction, the teacher can build on these student solutions and contrast them to the canonical solution. Only if students' prior knowledge and intuitive ideas are known beforehand, it is possible to implement an instruction that builds on students' prior knowledge and intuitive ideas by comparing typical student solutions to the canonical solution without previous problem-solving.

The finding that both instructions prior to problem-solving conditions ($I_{contrast} - PS$ and $I - PS$) outperformed the $PS - I_{contrast}$ condition on items testing for *procedural skills* (hypothesis 1c) is not surprising: Students in both instructions prior to problem-solving conditions solved up to eight practice problems in the problem-solving phase following instruction. This high amount of practice problems was due to the fact that applying a learned procedure to isomorphic problems is straightforward and requires less time than figuring out solutions to a problem targeting a yet unknown concept. In comparison, students in the $PS - I_{contrast}$ condition worked only on one problem during the problem-solving phase prior to instruction as they invented different (non-canonical) solution approaches for this problem. This lack of practice in the $PS - I_{contrast}$ condition was necessary to hold time constant for all conditions without allowing for too much time to learn the concept. We further aimed at limiting the danger of over-practice for the instruction prior to problem-solving conditions as much as possible. Studies that found no difference on items testing for procedural skills between the instruction prior to problem-solving condition and the problem-solving prior to the instruction condition usually allowed additional problem-solving practice for students in the problem-solving prior to instruction condition after students received the canonical solution (e.g., Kapur 2011, 2012; Roll et al. 2009). Thus, our finding confirms that after learning the canonical solution, students still need time to practice their procedural skills.

Although our study yields interesting results, we have to acknowledge some limitations and needs for future research. First of all, we have to acknowledge that the conditions of our study had different sample sizes, with fewer students in the $I - PS$ condition. This difference in the sample sizes may affect the homogeneity of variance. Indeed, the Levene test was significant for procedural skills ($p < .01$), but it was not significant for conceptual knowledge ($p = .06$). Thus, despite the different sample sizes, our results seem robust concerning conceptual knowledge, but they can only be interpreted with caution concerning procedural skills. Inspired by the in vivo research paradigm advocated by the Pittsburgh Science of Learning Center (Koedinger et al. 2012), we conducted our study in the field with real learners and real learning content, which promotes the external validity of the study. However, this also yields some limitations: The implementation in schools forced us to conduct a quasi-experimental study. Prior differences between conditions cannot be completely excluded due to the randomization of classes as a whole. Furthermore, it should be noted that the solutions used in the instruction phase of $I_{contrast} - PS$ and $PS - I_{contrast}$ were *typical* student-generated solutions (taken from pilot and previous studies). These matched the solutions most often generated in the $PS - I_{contrast}$ condition. From a total of 85 solutions generated by all groups in the $PS - I_{contrast}$ condition (same ideas generated by several groups were counted once for each group), only 11 solution ideas did not match the solutions discussed during instruction. Thus, the discussed solutions were indeed typical student solutions. It seems that it is not necessary to use students' own self-generated solutions in order to successfully build on their (typical) prior knowledge and intuitive ideas. Yet, until this date, it has not been systematically investigated whether using the very own solutions of students in comparison to typical student-generated solutions would further increase the impact. Using their very own solutions could support students to map the presented solutions to their prior knowledge and intuitive ideas. In addition, picking the very own solutions might foster students' motivation during the problem-solving phase (cf. diSessa et al. 1991), especially if instruction is delayed on a regular basis.

To conclude, we propose two mechanisms in line with cognitive load theory that may account for the beneficial effects of problem-solving prior to instruction approaches: During problem-solving prior to instruction, students activate their prior knowledge and intuitive ideas and represent them in their solutions. While this activation may increase cognitive load at first, this increased load does not persist. More importantly, the activation may increase the likelihood that students integrate the new information in existing schemas during instruction. Our findings indicate that the higher the quality of the existing schemas, the smaller the cognitive load to learn the canonical solution during instruction. During instruction, student solutions can be compared and contrasted to the canonical solution. This comparison focuses students' attention on the relevant components of the new concept that differ from their solutions. Focused attention is germane for learning as it leads to deeper processing and thereby fosters the acquisition of conceptual knowledge. Even without previous problem-solving activities, comparing non-canonical and canonical solutions increases conceptual knowledge. Future research is needed to determine whether the two proposed mechanisms are independent from each other.

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Chapter 14
Mathematical Skills and Learning by Invention in Small Groups

Michael Wiedmann, Ryan C. Leach, Nikol Rummel, and Jennifer Wiley

Abstract The purpose of the present research was to investigate how the effectiveness of learning-by-invention activities may be influenced by the composition of the small groups that engage in them in terms of the mathematical skills of their members. Undergraduates engaged in an "inventing standard deviation" activity. Groups that included both high- and low-skill members generated a broader range of solution attempts and more high-quality solution attempts during the activity. Both the range and quality of solution attempts that were generated related to better uptake of the standard deviation formula from a later lesson. These results suggest that the composition of the small groups that work together may have an impact on the effectiveness of learning-by-invention activities.

Keywords Collaborative learning • Collaborative problem solving • Learning by invention • Group composition • Mathematical skill

Mathematical Skills and Learning by Invention in Small Groups

One approach for teaching new mathematical procedures is to provide direct instruction with a lesson that introduces the new problem-solving method (c.f. Anderson et al. 1995; Rosenshine and Stevens 1986). After the lesson, students are encouraged to practice using the new formula. This approach makes sure that students have the prior knowledge necessary to solve problems with the new formula. But does presenting the lesson first lead to the best understanding of the formula? Or are students

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able to come up with useful attempts for solving new problems on their own? In an alternative approach to mathematics instruction, *learning by invention*,[1] students (generally working in small groups) attempt to invent their own solution methods before being taught the canonical formula. Learning by invention has now repeatedly been shown to be just as effective as instruction where the canonical solution is taught first (e.g., Belenky and Nokes-Malach 2012; DeCaro and Rittle-Johnson 2012; Kapur 2009, 2012; Kapur and Bielacyzc 2011; Loibl and Rummel 2013; Roll et al. 2009; Schwartz and Martin 2004; Westermann and Rummel 2012). This chapter takes a closer look at the question of whether diversity in math skills among the members of the small groups might play a role in learning by invention.

As an example of the efficacy of learning by invention for teaching statistics, Schwartz and Martin (2004) compared two instructional conditions. In the experimental condition, students engaged in learning by invention. Their invention task was to compare data across different distributions in order to develop standardized scores. Following the invention activity, students then received a worked example teaching them about this concept. Thus, the learning-by-invention condition involved both an invention phase and an instruction phase. In a comparison condition, students were first taught how to standardize scores before practicing the procedure. Students in the learning-by-invention condition outperformed the control condition on a transfer test that required applying standardized scores in a new context. Schwartz and Martin argued that the invention phase served as *preparation for future learning* from the worked example. The invention process was suggested to activate prior knowledge that facilitated learning from the following direct instruction. The creation and careful consideration of solution attempts during the invention phase may be a mediator of this effect.

Kapur (2009, 2012) has also shown benefits from learning by invention on conceptual and procedural learning. In his work, he proposes that invention may lead to productive failure; that is, students may fail at generating a formula, but, similarly to Schwartz and Martin (2004), that this will be productive for future learning. Kapur's instructional approach combines the invention phase with a class lecture and discussion in which students' solution attempts are compared and contrasted with each other and with the canonical solution. This may help students recognize the critical constraints and affordances of these solutions. Kapur (2012) showed that, non-surprisingly, students in an invention condition generated a more diverse set of solutions than the control condition that was taught canonical solutions. However, students in the invention condition also outperformed the control condition on conceptual understanding items and performed just as well as the control

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[1] In the literature, there are several similar approaches that explore the learning opportunities that can result from having students engage in problem solving before having received instruction. VanLehn referred to this as impasse-driven learning (1988). Schwartz and Martin (2004) have argued that an initial invention phase can provide "preparation for future learning." Kapur frames generation and exploration (Kapur 2012), or elicitation phases (Kapur and Bielaczyc 2011), as ways to encourage *productive failure*. In the present paper, we adopt the terminology and instructional sequence of Schwartz and Martin (2004) where an invention phase is followed by instructional support in the form of a worked example.

condition on procedural fluency items. In addition, Kapur and Bielaczyc (2011) also found that the diversity of solutions generated during invention predicted posttest performance. This empirical link between the invention process and learning suggests that the consideration of multiple solution approaches during invention activities may be one key to students' preparation for future learning.

The Present Study

The previously reported results suggest that learning by invention may be an effective instructional approach for promoting conceptual understanding of formulas as well as procedural knowledge of how to use them (following Mayer and Greeno 1972). The main question of the present study is *under which conditions* this approach may be most effective. In particular, we are investigating how the small groups engaging in invention activities may be best composed in order to optimally support individual student learning. Since the problem-solving task is mathematical, it seems likely that the mathematical skill of individual group members may have an effect on group interaction. Roll (2009) was only able to show benefits from invention activities in high school students that took college-level (Advanced Placement) courses, but not for more typical students. Kapur and Bielaczyc (2011) investigated benefits of productive failure in three schools of varying student profiles in mathematical skill. The effect of productive failure activities was stronger in schools of higher mathematical skill profiles. Therefore, one prediction might be that learning by invention is only effective for students with higher mathematical skill.

However, it may also be sufficient that *each group* has at least one member with higher mathematical skill (Wiley et al. 2009). Many researchers (Paulus 2000; Strobe and Diehl 1994; Wiley and Jensen 2006; Wiley and Jolly 2003) have suggested that diversity in the background of group members may be beneficial for problem solving. Dunbar (1995) showed that in laboratories where scientists came from different disciplines, unexpected findings led to many more alternate hypotheses and analogies, which in turn led to more scientific breakthroughs. Gijlers and de Jong (2005) found that dyads engaging in discovery learning generated more hypotheses when they were heterogeneous in prior knowledge than when they were homogeneous. And Canham et al. (2012) found that dyads were better at solving transfer items when their members were trained in different ways of solving probability problems than when both members had received the same training.

Heterogeneous group composition in terms of the math skills of the members may also influence the interaction of the group. Webb (1980), for instance, found that when high- and low-skill students work together, they often form teacher-student relationships. This peer tutoring can not only be beneficial for the tutee but also for the high-skill tutor. Webb also found that working in mixed groups seemed to promote the most explanation-giving during group discussion. Given these advantages of heterogeneous group composition, it may also be that in invention activities, mixed groups will have the most productive discussions. However, it is also possible that the high-skill members will show poorer learning outcomes when having to work with low-skill students than when working in homogeneous, high-skill groups (Fuchs et al. 1998). It is therefore an interesting question whether mathematical skill of each group member, and group composition in terms of mathematical skill of the members, may have an effect on learning by invention.

To test whether the composition of groups in terms of their math skills might matter, the present study explored differences in the effects of learning by invention in performance among three group types: all-low-skill groups, all-high-skill groups, and mixed groups. The target content was the standard deviation formula, and mathematical skill was measured using scores on a standardized college admission test (the Math ACT). Data was collected in two contexts. Some groups participated as part of an undergraduate course in Research Methods in Psychology. For these students, dependent measures included written artifacts of the invention process and an online quiz to assess learning. A second sample was collected from a subject pool of undergraduates enrolled in Introduction to Psychology. These students participated in a laboratory study using parallel procedures, but additionally recordings were collected that allowed for a more complete accounting of the group discussion.

The main hypotheses to be tested were (1) whether groups needed at least one high math member to take advantage of learning by invention and (2) whether heterogeneous group composition (i.e., participating in mixed groups) would positively affect the variety and quality of solution approaches generated during the invention activity, which would in turn affect learning. Thus, the main analyses of interest were ANOVAs testing for the main effect of group composition on both solution variety and quiz performance, with planned comparisons among the three different group types. Subsequent analyses tested whether solution variety and quality would predict quiz scores, acting to mediate the effect of group composition on performance.

Method

Participants

Research Methods Sample

Students who enrolled in an undergraduate Research Methods course in Psychology at the University of Illinois at Chicago participated in the experiment as a class activity. This course is usually taken in the second year of university. Students who take this course generally intend to declare psychology as their major.

The original sample consisted of 149 students, taught in six sections and assigned to groups of three based on their Math ACT scores so that there would be groups in each category of group type. Students were unaware that ACT scores were used to assign them to groups. Assigning students to groups also prevented established groups from working together, to make this study more similar to the randomly assigned groups obtained in the subject pool sample. Students had to be excluded for several reasons: Because Math ACT scores were not available for all students, 66 students from groups where some members' Math ACT scores were unknown were excluded from both group-level and individual-level data analyses. Another 15 students did not complete the final quiz. Those students, but not the other members of their groups, were excluded from learning outcome analyses resulting in a final sample size of 68 individuals for individual-level analyses. There was data from members of 25 groups available for group-level analyses.

Participants received credit for participating in the activity and completing the homework assignment, as they did for all recitation and homework activities in their class. They were unaware that the quiz would not count toward their grade. The homework assignment, which included the quiz, was announced after the invention activity.

Introduction to Psychology Sample

Sixty undergraduate students from the Introduction to Psychology course at the University of Illinois at Chicago were recruited to participate in the experiment as part of a subject pool. Introduction to Psychology is typically taken during the first or second semester of university. Groups were comprised of students who signed up individually for the same time slot. Skill profiles of the groups were ascertained after the data was collected. Groups of friends who signed up together were excluded from further analysis. There were 59 students with complete data that could be included in the individual analyses, and data from members of 20 groups were available for group-level analyses.

Math Skill Level

For both samples, math skill level was based on a median split derived from historical data from this student population. Students with Math ACT scores of 24 or below were considered to have lower skill, and those with scores of 25 or above were considered to have higher skill. A score of 25 puts students in the 80th percentile in national norms. Of the 127 individuals available for individual analyses, 64 were classified as low math skill and 60 as high math skill. Students categorized as having high versus low math skill differed significantly on the Math ACT, $t(122) = 14.46$, $p < .001$. Of the 45 groups, all students were considered to have low math skill in 11 groups, all students were considered to have high skill in 9 groups, and 25 groups had a mix of high- and low-skill members.

Materials

Invention Activity

The invention activity used in this study is included in Appendix A of Wiedmann et al. (2012). This activity was based on prior invention activities developed by Kapur (2012) and Schwartz and Martin (2004) in which students are tasked with comparing three data sets. In this study, the invention activity used a cover story about the amount of antioxidants found in tea coming from three tea growers. Students were told that "a company wished to buy tea from the grower with the most consistent levels of antioxidants from year to year and the company has asked for the students' help." They are asked to propose a formula for calculating the consistency of antioxidant levels for each tea grower.

Quiz

The quiz contained three items: two in which the formula for standard deviation needed to be applied to a new problem about the weather and one in which students needed to invent standardized scores in order to compare two students' test performances across different courses. Students were asked to explain the mathematical reasoning behind their answers. This quiz served as the assessment of learning outcomes for the activity and is based on items used in Kapur (2012).

Procedure

Research Methods Sample

The study took place as part of a course in Research Methods, during the weekly recitation section meeting. At the start of the meeting, the teaching assistant gave a short (10 min) introduction that began with an example research question and two data sets. For each data set, the teaching assistant demonstrated how to draw a histogram and defined and calculated the mean and median. While the means were the same in both data sets, the medians were not. To help the student notice the variance among scores, students were then asked to describe the other big difference they could see between the two data sets.

Students then worked in groups for 30 min with the goal of inventing a formula to describe "consistency" in three data sets.

They were given a group worksheet with three data sets. The worksheet asked them to generate as many invented formulas as they could to describe consistency in the three data sets, and provided additional space for their solution attempts. The group worksheets were collected at the end of the discussion.

After class, students completed an online homework assignment through the university's e-learning (Blackboard) system. As usual, they completed the homework individually at a time of their choosing before the next class meeting. This assignment included a short lesson about the standard deviation formula and asked students to compute standard deviations from a worked example before the quiz (following Schwartz and Martin 2004).

Introduction to Psychology Sample

The procedure was largely the same, except that the small groups were run one group at a time in a laboratory room and recorded. The introduction given by the experimenter was similar except median was not mentioned. Because students sometimes are overwhelmed with the demand to create a formula (Roll et al. 2009), in this sample, it was clarified that instead of a formula, they could also write step-by-step instructions for how they would compute consistency.

The remainder of the procedure was similar. After working on the invention activity together for 30 min, the group members were separated to work individually for the remainder of the study. Each student was given the overview of the standard deviation formula and worked example to read before taking the quiz.

Coding Schemes

Coding of Solution Attempts

The group worksheets from the invention activity were coded for both variety and quality of solutions. A coding scheme was established post hoc based on the range of solutions that were actually obtained such that each distinct solution type had its own subcategory. A list of the 22 final codes appears in Appendix B of Wiedmann et al. (2012). Coders assigned each solution attempt to one of the 22 subcategories. The total number of different solution approaches was computed for each group by adding the number of subcategories that had at least one instance present in the group worksheet (i.e., the total of the 0, 1 codings across the 22 codes).

To code for differences in quality of solution attempts, a task analysis of understanding the standard deviation formula identified several critical insights that students might reach during their discussions. The first insight is that methods such as making histograms or bar graphs, noticing an individual high or low score, or summing or averaging scores will not help to quantify consistency. Alternatively, noticing differences in the range of values across data sets is an important first step toward understanding variance. A second key insight is that somehow variations in positive and negative directions need to be handled in some way so that they do not cancel each other out. A third key insight is that variance needs to be computed in relation to some reference point (such as the mean). Based on this analysis, solution attempts that included recognition of range, deviations from the mean, and the need to consider absolute values were all categorized as being of higher quality, and a subtotal of higher-quality solution approaches was computed in addition to the overall variety of solution approaches.

Coding for the Research Methods sample relied on the worksheets. Coding for the Introduction to Psychology sample was also based on ideas mentioned in discussion when transcripts of the discussions were available. Two individuals coded all groups for the presence or absence of solution attempts in each subcategory (Krippendorff $\alpha = .81$). Differences were resolved by a third rater.

Coding for Quiz Responses

Each of the three problems was scored using the same basic concepts and point values, giving the student the point value assigned to the most advanced concept that was referenced in each explanation:

Central tendency, sum, or maximum score (1 point)

Examples: The average of February is higher than January, so they should go with January. Alicia was only 1 point away from a perfect score. Alicia had a higher score.

Ranges and deviations: differences between scores, subtracting smallest from largest score, differences from the mean (2 points)

Examples: The difference from the temperature for February by month is 2, 2, 1, 3, 4 and that is very consistent. January has a lower range. Chemistry has more of a spread. Alicia is further from the mean.

Vague or incorrect formula or reasoning about *SD* (3 points)

Examples: A higher deviation means the classes were harder, making Alicia more deserving.

Correct use of *SD* (4 points)

Examples: January has a lower standard deviation. Kelvin should receive the award because his score has a greater number of standard deviations above the average.

Two individuals scored all posttest items. A maximum score of 12 points was possible across the 3 items. Final explanation quality composite score was computed as a proportion of that total. Cronbach's α among the three quiz items was .80. Krippendorff's α indicated good interrater reliability on all three items (item 1 = .84, item 2 = .81, item 3 = .77).

Results

Learning Outcomes

Before proceeding to test the main questions, we explored the independency of the individual learning data since it was obtained in a group setting. Kenny et al. (1998) suggest the calculation of intra-class correlations to test for consequential nonindependence. Because the intra-class correlation for group members' quiz scores was not significant in the Research Methods sample, ICC = .08, $p = .55$, CI = 95%, and the Introduction to Psychology sample, ICC = .12, $p = .36$, CI = 95%, it was appropriate to analyze learning outcomes on an individual level.

In a next step, differences between the two samples were explored. Participants from the Research Methods sample, who were more advanced in their studies, were found to outperform the Introduction to Psychology sample on the quiz, $F(1, 125) = 5.90$, $p < .02$, $\eta^2 = .05$. Importantly, this did not interact with the group composition factor, $F < 1.07$, which meant the two samples could be collapsed in order to increase power, while the sample variable was retained as a covariate in all aggregated analyses reported below (for more complete analyses of this data, including descriptive statistics and analyses for the separate samples, see Wiedmann et al. 2012).

The top panel of Fig. 14.1 presents average quiz performance as a function of group composition (entered as a nominal variable) and math skill. An ANCOVA with sample entered as a covariate showed a significant effect of group composition

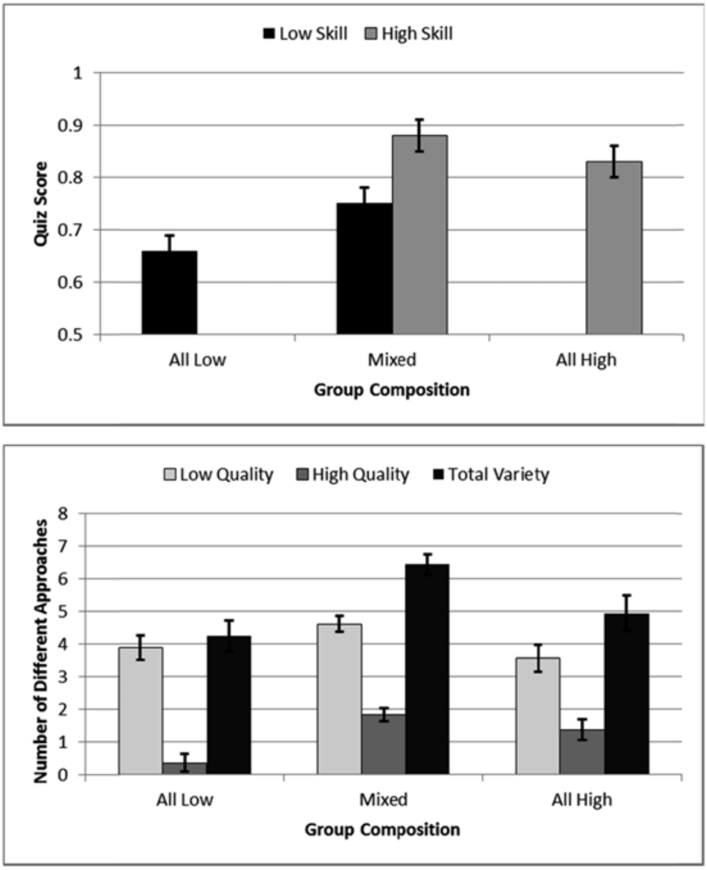

Fig. 14.1 Adjusted means for quiz scores (*top*) and solution variety (*bottom*) by group composition

on quiz performance, $F(2, 123) = 12.41$, $p < .01$, $\eta^2 = .17$. Planned comparisons indicated that students in the all-low math groups had lower scores on the quizzes than students in either the mixed or all-high groups, who did not differ in quiz performance.

A follow-up analysis was performed to see if group heterogeneity affected low-skill and high-skill students differently. As shown in the top panel of Fig. 14.1, both high- and low-skill members seemed to benefit from participation in mixed groups. A 2×2 ANCOVA (math skill × group heterogeneity) with sample entered as a covariate revealed two significant main effects. As might be expected, high-skill students did better than low-skill students, $F(1, 122) = 28.44$, $p < .01$, $\eta^2 = .19$. In addition, the main effect for group heterogeneity, $F(1, 122) = 6.29$, $p = .01$, $\eta^2 = .05$, and the lack of a significant interaction, $F < 1$, indicated that both high-skill and low-skill students benefited from working in heterogeneous (mixed) groups.

Variety of Solution Approaches

Average totals of different solution approaches as a function of group composition are shown in the bottom panel of Fig. 14.1. An ANCOVA on the total number of different solution approaches with sample entered as a covariate showed a significant effect of group composition, $F(2, 41) = 8.55$, $p = .001$, $\eta^2 = .29$. Planned comparisons indicated that the mixed groups documented significantly more different solution approaches than the all-low-skill, $p < .001$, and all-high-skill groups, $p = .02$, who did not differ, $p = .33$.

When only higher-quality solution approaches were considered, a different pattern emerged. An ANCOVA on the number of higher-quality representations included in the group worksheets showed a significant effect of group composition, $F(2, 41) = 9.47$, $p < .001$, $\eta^2 = .32$. Planned comparisons indicated that the all-low groups documented fewer different high-quality solution approaches than the all-high, $p = .02$, and mixed groups, $p < .001$, who did not differ, $p = .23$. Although the mixed groups also tended to include higher numbers of low-quality solution approaches, this effect did not reach significance, $F(2, 41) = 2.76$, $p < .08$, $\eta^2 = .12$.

Relation of Solution Variety to Learning Outcomes

The partial correlations among the total number of different solution approaches, high-quality solution approaches, low-quality approaches, and students' quiz scores (controlling for sample) are presented in Table 14.1.

Two final analyses were then performed to test whether the discussion of a broad variety of representations was responsible for the better performance that was observed as a function of group heterogeneity. To investigate this mediational hypothesis, the test of indirect effect procedure and corresponding macro (Preacher

Table 14.1 Correlations between number of solutions and quiz performance

	Low quality	High quality	Total variety
Quiz score	.15	.34**	.31**
Low quality		.14	.81**
High quality			.70**

Note: $N = 127$, $df = 124$, $^{**}p < .01$

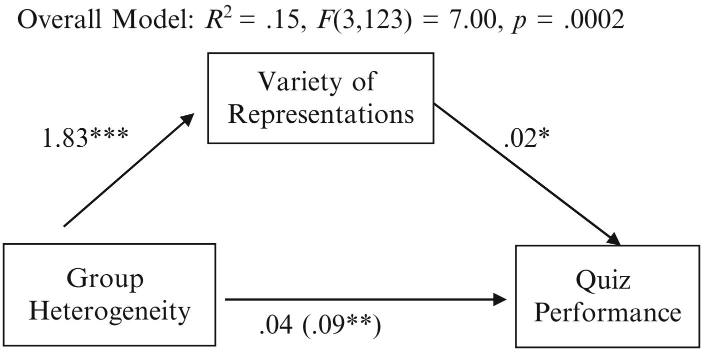

Fig. 14.2 Mediational model. Note: the value in parentheses indicates the total effect before accounting for mediation. $^{*}p < .05$, **p<.01, ***p<.001

and Hayes 2008) was employed using 5,000 resamples. For these analyses, bootstrapping tests are generally preferred to the more traditional Sobel test because they do not assume a normal distribution of the product terms which are usually normally distributed only in large samples (Preacher and Hayes 2004, 2008; Shrout and Bolger 2002). Mixed groups were coded as "1" for heterogeneity, and the remaining groups were coded as "0" for this analysis. Results indicated that heterogeneity predicted the variety of representations, $B = 1.83$ ($SE = .27$), $t(126) = 6.61$, $p < .05$, and that variety of representations predicted quiz performance, $B = .02$ ($SE = .01$), $t(126) = 2.47$, $p < .05$. The total effect of heterogeneity on quiz performance was also significant, $B = .09$ ($SE = .03$), $t(126) = 2.84$, $p < .05$. However, this relationship decreased to non-significance when the mediating influence of the variety of representations was included in the analysis, $B = .04$ ($SE = .04$), $t(126) = 1.23$, $p = .22$ (see Fig. 14.2).

In addition, the indirect effect (the mediated effect) of heterogeneity on quiz performance through representation variety was 0.05 ($SE = 0.02$), and the 95% bias-corrected confidence intervals for the size of the indirect effect did not include zero (.01, .08), which shows that the indirect effect was significant at a $p = .05$ level (Preacher and Hayes 2004, 2008; Shrout and Bolger 2002). Taken together, these findings provide evidence for full mediation. This analysis suggests that heterogeneity in groups led to better quiz performance because it affected the variety of solutions that were discussed during the learning-by-inventing activity.

Of course, another critical aspect of group composition as defined in this study was that it was based in math skill (all low, mixed, and all high). Clearly math skill can have a direct effect on learning about math for any individual, so it is interesting to ask if the discussion of a variety of representations during the learning-by-inventing activity might have a significant effect on performance unique from the effect of group composition on performance through math skill.

To address this concern, we performed a second regression analysis using both representation variety and math ACT scores as mediators. This analysis showed that group composition significantly predicted the variety of representations produced by the group, $B = .56$ ($SE = .23$), $t(123) = 2.45$, $p < .05$, and math ACT scores, being the basis upon which group composition was defined, were significantly related to composition, $B = 3.72$ ($SE = .54$), $t(123) = 6.89$, $p < .05$. Both representation variety, $B = .02$ ($SE = .01$), $t(123) = 2.72$, $p < .05$, and math ACT scores, $B = .02$ ($SE = .00$), $t(123) = 4.76$, $p < .05$, significantly predicted quiz performance. The total effect of group composition on quiz performance was also significant, $B = .10$ ($SE = .02$), $t(123) = 4.33$, $p < .05$, but was reduced to non-significance when including the mediating influences of representation variety and math skill, $B = .03$ ($SE = .02$), $t(123) = 1.04$, $p = .30$. The indirect effect through variety of representations was 0.01 ($SE = 0.01$), and importantly, the 95% bias-corrected confidence intervals for the size of the indirect effect did not include zero (.003, .03). Taken together, these results indicate full mediation by variety of representations even when the effects of math skill are included in the analysis.

When these same two mediational analyses were performed using the number of high-quality solutions instead of total variety measures, identical patterns of results were found. The discussion of more high-quality solution approaches also mediated the group homogeneity and composition effects and contributed to performance independently of math ACT scores.

Taken together, these mediational analyses suggest that it is the discussion of a wide range of solution approaches during learning-by-invention activities (including a number of higher-quality solution attempts) that mediates the effects of group composition. More diverse groups documented a broader variety of solution approaches, and when more solution approaches were documented, that improved performance on later quizzes. Further, the benefits of solution diversity during group discussion were demonstrated to contribute to a better quiz performance even when the math skill of the students was taken into account.

Discussion

The results of this study suggest that group composition in terms of math skill affects whether students are able to benefit from mathematical learning-by-invention activities. Students who worked in mixed groups were better at explaining their understanding of standard deviation on a quiz following the activity than students who worked in homogeneous groups. Significant effects of group composition were seen in both variety and quality of solution approaches. Interestingly, it was the mixed groups who generated the widest variety of solution attempts, suggesting that they seem to be in a particularly good position to make the most of invention exercises. This result converges with several other findings in suggesting that diversity in expertise among group members can contribute to more adaptive, flexible, and creative problem solving (Canham et al. 2012; Gijlers and De Jong 2005; Goldenberg and Wiley 2011). Additionally, the consideration of a wider variety of solution approaches during the invention phase, including a number of higher-quality approaches, predicted the uptake of a later lesson about the standard deviation formula and mediated the effects of group composition and diversity on learning.

These results show a significant benefit of working in mixed groups for learning-by-invention activities. Yet, more research is needed to fully understand the affordances of this instructional context. It is possible that even more robust effects could be found with a longer invention activity, a conjecture that could be explored in future research. The invention activity used here was of a fairly short duration, and a number of the groups seemed to be approaching some critical insights when time ran out (Wiedmann et al. 2012). In previous studies, students generally engaged in their invention discussions for more than one class period (Kapur 2012; Schwartz and Martin 2004).

Another limitation of the present study was the lack of a pretest-posttest design to demonstrate that better quiz scores reflected improved learning from the activity. Also, because the present studies did not include a direct instruction comparison condition, these results cannot speak to whether low-skill students may benefit more from learning by invention in mixed groups than they would have from direct instruction.

One recommendation for future studies would be to consider using an instruction that does not prompt for a formula at all. In a number of groups, arbitrary formulas were contributed during the discussion. These formulas were not attempts to quantify a particular solution approach that was being discussed qualitatively. Instead, students just brought up simple formulas that students knew like distance = rate × time. We suspect this problematic behavior may have been a consequence of giving the instruction "to create a formula" in these studies. It may be better to instruct students to give step-by-step descriptions of how to compute consistency (Roll et al. 2009) or to prompt students to generate a method (Schwartz and Martin 2004). For the Introduction to Psychology sample, we included requests for both formulas and step-by-step descriptions as part of our task instruction; however, many students still seemed to focus on the formula goal.

Because the benefits of learning by invention over direct instruction may be less robust for low-skill students (Kapur and Bielaczyc 2011; Kroesbergen et al. 2004; Roll 2009), all of the above points represent important issues for future research. Further, while these results represent some of the first demonstrations of learning by invention for low-skill students, an important observation is that previous attempts have used much younger samples. We suspect all college students will have the capacity to engage in the demands of this learning-by-inventing task, even if the low-skill students are less proficient at math tests. Given this, it is possible that the present findings will not generalize to younger samples where the demands of a learning-by-invention activity may present too much of a challenge for low-skill learners. It is an interesting question for future research whether the benefits of working in mixed groups can be seen in younger samples, which would be consistent with other work (i.e., Webb 1980) showing learning benefits when students with different ability levels work together.

Another important direction for this line of research is the further exploration of what is happening during these collaborative discussions that is critical for effective learning from invention. The analyses so far have shown that a broader variety of representations are discussed and a larger number of higher-quality solution attempts are considered, but how are these brought into the conversation? The really interesting questions of how the interactive discourse and dynamics of mixed groups may facilitate learning from invention have yet to be answered.

We have only just begun the task of analyzing the discussion protocols of groups, starting with the three most successful mixed groups of the Introduction to Psychology sample (Wiedmann et al. 2012). Some initial impressions suggest that there are multiple ways in which groups can engage in invention activities. In our preliminary analysis (reported in Wiedmann et al. 2012), we found that the first group discussed fewer solution approaches than the other two groups, but they seemed to engage in discussion on a more conceptual level. They also engaged in more evaluation of the proposals and in more reflection on their progress. On the other hand, the two other groups generated more solution approaches, but this activity seemed to be accompanied by less discussion. A very preliminary speculation could be that generating a wide variety of approaches to the problem may be one important factor. In addition, a richer discussion around fewer alternatives can also lead to successful learning-by-invention activities as seen in the first group, especially if the discussion leads to key insights. Alternatively, two of the three groups seemed to benefit from the visual affordances of line graphs. It is possible that some specific kinds of solution attempts may be particularly helpful toward preparation for future learning (i.e., more visual ones or more abstract ones; Ainsworth 2006; Schwartz 1995). Although no universal pattern could be identified for the most successful groups, future analyses exploring the interaction patterns among the least successful groups could reveal more consistency in the behaviors that lead to ineffective collaboration. Other questions for future analyses include: What role do behaviors such as question-asking, responsiveness, evaluating proposals, connecting across representations, and generating or hearing explanations play in group success? How are high-quality approaches being discussed or discovered? What contributions do the high-skill versus the low-skill members make to the discussions? Who is acting as the group leader and how do they lead the group? Other preliminary analyses of the discussion suggest that being in a group with a high-skill leader is critical (Wiley et al. 2013).

Although we have motivated our study by focusing on the contribution of mathematical knowledge by high-skill members, there are other mechanisms by which they may have influenced the groups. For example, invention may be a novel type of exercise for many students. High-skill students may be more familiar with these tasks, or they may be more willing to engage in novel tasks, or they may possess a greater sense of self-efficacy in math which enables them to have a more positive approach to these tasks. Alternatively, the high-skill students may possess superior metacognitive abilities, and with those they may help the groups to monitor and reflect on their progress or regulate their learning and studying activities. Either of these alternative explanations suggests that high-skill members may not be necessarily contributing specific knowledge to the mixed groups, but may be helping the groups via other attributes that are generally correlated with expertise in a domain. A complete analysis of the discussion protocols from the Introduction to Psychology sample is currently underway which will help to address these questions.

This analysis of the discussion protocols will also be a great source of insight on what particular behaviors one may wish to support while students engage in learning-by-invention tasks. In the present study, we did not script the interactions among group members, did not assign roles, and did not give students any specific direction on how to engage in the task together. Others have already begun to test (Kapur and Bielaczyc 2011; Roll et al. 2012, 2009; Westermann and Rummel 2012) if students can be supported in order to maximize the benefits of engaging in invention tasks, without nullifying the benefits of invention over direct instruction. Indeed, peer interaction was carefully scaffolded in most of Webb's previous studies, which may have allowed for more stable benefits of mixed groups to emerge. Our goal for the closer analysis of our discussion protocols is to help to determine whether these candidate behaviors seem to facilitate learning by invention or if there are other characteristics of successful interactions that emerge. The present study has demonstrated that students may benefit most from learning-from-invention activities when working in mixed groups. Future research needs to further explore why and how these benefits are afforded and, importantly, whether providing supports for these affordances can ensure benefits in all groups.

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Part VI
Authentic Participation in Real-World Communities

Chapter 15
The Retail Experience for Active Learning (REAL) Experience

Noi-Keng Koh

Abstract The Retail Experience for Active Learning (REAL) was an innovative programme to investigate if students learn better when they are able to make meaningful connections between the school curriculum and their learning experiences at real workplace environment. REAL was implemented with the support of local retailers in Singapore to provide an authentic learning environment for students to experience the authentic customer service environment. Ninety-six Year 9 Elements of Business Skills (EBS) students participated in REAL and completed two phases of workplace attachment where they were given the opportunity to apply business knowledge and skills learnt in school at real workplace environment. It was found that the REAL internship was associated with increased personal relevance towards the business subject, greater self-confidence and better problem-solving skills.

Keywords Experiential learning • Student internship • Cooperative education • Learning environments • Business skills

Introduction

Elements of Business Skills (EBS) was a new GCE N-level subject introduced by the Singapore Ministry of Education in 2008 and the revised syllabus was implemented in 2014. The EBS syllabus is designed to provide foundational knowledge and skills for students who are less academically inclined and to prepare them for the services sector. Learning opportunities for students have been incorporated within the curriculum to reinforce their conceptual understanding of the business environment and application of skills like marketing and customer service in retail, travel, tourism and hospitality industries.

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To investigate the effectiveness of using short-term workplace attachments to extend learning activities in the classroom for EBS students, the project “The Retail Experience for Active Learning (REAL)” was conceptualised and implemented with Grade 9 students in Singapore. The purpose of the learning attachments was to provide a planned exposure and bridge from the classroom to the real workplace. It was hoped that by immersing students in real workplace environments, students will be motivated and engaged in learning on the job and applying what they have learnt in classrooms to work situations and vice versa (Koh 2010).

In solving real problems at the workplace, students also learnt to realise and activate a range of cognitive processes and mental activities. It simulated problem-solving cognition needed to solve real-world challenges.

Literature Review

Experiential Learning in the Workplace

One of the challenges facing education in the information age of the twenty-first century is the changing nature of work (Watkins 2005). The traditional paper qualification on its own is no longer sufficient for success at the workplace. Johnson (2000) reported that students believed that their ability to succeed in the workplace was a “direct function of possessing career-specific knowledge”. Yet students demonstrated a lack of understanding of how their subject knowledge was relevant to their future and showed little awareness of the connections between school and the workplace.

Experiential learning theory has played a large role in the development of educational practices. The experiential learning model by Kolb and Fry (1975) consists of four elements: concrete experience, observation, reflection and formation of abstract concepts. This model posits that learning is a continuous cycle, and that learning process can begin at any of the indicated stages. However, learning will not be complete without going through all the stages. This argument has been acknowledged by many educators. McCarthy and McCarthy (2006) discussed that theory alone “cannot substitute for learning that occurs through experiential learning activities, which provide students with a direct personal encounter” (p. 201). They recommended that experiential learning programmes be made compulsory in the business curriculum. Likewise, Mintzberg (2004) has advocated an approach to management education that is more grounded upon learning from experience.

For many students, the formation of new business concepts and skills cannot be gained from classroom instruction alone. Watkins et al. (2002) argued that when students experience active learning and shared inquiry, they develop prosocial skills and positive emotions towards the subject. While an active learning community “cannot be engineered into existence in a classroom, an engineering approach to schooling can crowd it out” (Watkins et al. 2002).

Workplace learning attachments complement students' academic studies by providing the practical experience for students. Students can test out the abstract concepts taught in the classroom through experimentation in the workplace. This process provides students with concrete learning experiences and the emotions associated which will help them make the relevant connections between work and school. Students' observation and reflection upon these practical experiences and feedback from their workplace mentors will then lend towards the formation of new abstract concepts. These new concepts can then be experimented again in another situation, creating new experiences for students (Kolb 1984). When students are placed in real-world environments with the autonomy to explore in a structured, monitored and accessed manner, students operate within their Zone of Proximal Development (ZPD; Vygotsky 1978). While in their ZPD, they can strive towards the next level of awareness through independent problem-solving of real-world issues with guidance from their supervisors and workplace mentors or in collaboration with more capable peers such as their colleagues (Vygotsky 1978).

Completion of workplace attachments has been positively associated with improved academic performance, career successes and career self-awareness. In Hong Kong, Kwong and Lui (1991) found a positive effect of the internship experience on immediate post-intern academic performance. Business undergraduates in the USA who completed an internship reported less job-seeking time for their first position and were more likely to experience early career successes (Gault et al. 2000). In addition, prior internship experience was related with finding career-oriented employment (Callanan and Benzing 2004), higher pay and greater job satisfaction which attributed to better understanding of self and career choice (Gault et al. 2000).

Internships also provide benefits to organisations. Internships allow organisations to evaluate the performance of their prospective employees beyond that of a selection interview (Coco 2000). During the internship, organisations would have provided invaluable job training for the intern and the experienced intern can then be hired to continue to work within the company, reducing the cost of recruitment and training. In addition, feedback from interns can help organisations improve their programmes and organisational culture in general (Rothman 2007). A good internship experience can also help build the company's reputation and its ability to attract quality future job candidates, as the interns return to their studies and share company stories with their peers and friends (Turban and Cable 2003).

In Singapore, an exploratory study of the learning outcomes perceived by interns during their internship found that interns gained not only in terms of technical skills but also in the development of interpersonal and intrapersonal skills (John and Hendrik 2008). This intrinsic value of the internship supplemented the perceived instrumental value (Reid 1998). Students believed that their internship experience would support their future professional development and aspirations (John and Hendrik 2008). This would have positive effects on students' motivation and engagement towards learning.

Many long-term internship programmes around the world have been successfully implemented. A good and well-developed example would be the school-to-work programmes in the USA. The School-to-Work Opportunities Act of 1994 provides federal grants to the states and to local partnerships of business, government, education and community organisations to establish different models of school-to-work programmes to suit each locality (Hershey et al. 1997; Joyce 2001). In Singapore, internship programmes, usually of a few months in duration, are common among tertiary students as a requirement of their studies. However, there is no such arrangement for experiential learning attachments for secondary school students currently.

A Model of Experiential Learning Attachment

In this research project, we study the use of short-term experiential learning attachments to authentic retail outlets for EBS students to enhance their learning of business knowledge and skills. The context of learning and the community of practice of the real workplace were considered as key elements that influence the process of knowledge and skill acquisition (Lave and Wenger 1991; Cole 1995; Wenger 1998; Guile and Young 1999).

Workplace learning attachments can take many forms. In this project, job shadowing and internships were employed at Stage 1 and Stage 2 respectively. Students learn about a job by observing first-hand how competent workers complete the daily work activities through job shadowing (Lozada 2001; Reese 2005). Job shadowing provides students with a model of work behaviour to emulate. While students observe and reflect how their more competent co-workers complete their daily tasks, they will be able to construct new concepts required for work. The workplace provides an authentic environment for students to test some of the new concepts learnt which could be difficult to learn through classroom teaching alone.

In addition, students can relate how their academic knowledge is applied to work and ask further questions to their workplace mentor, who is an expert to provide guidance. When well implemented, job shadowing can influence students' knowledge and attitudes about work positively. Meanwhile, internships provide students opportunities to put into practice knowledge and skills they have learnt in the class in real-world situations. During their internships, these individuals could then apply the new concepts learnt while experiencing different work tasks.

In addition, the learning that occurs at the workplace is less routine than the traditional didactic classroom instruction. Students are motivated to learn as they become responsible for their own progress. As such, connections between school and work are constantly made as students apply what they have learnt in school to the workplace and what they have learnt from their co-workers at the workplace to learning in school (cf. Watkins et al. 2002). Taken together, job shadowing and internships reflect a strong experiential learning model.

The purpose of the study was to find out if experiential learning in authentic learning environments were effective in (1) enhancing the learning environment of the EBS classroom (quantitative) and (2) enhancing engagement among REAL students vis-à-vis the cross transfer of knowledge and skills between the classroom and the workplace (qualitative).

The Real Project

Participants

Three hundred and forty-five Secondary 3 (Year 9) Elements of Business Skills (EBS) students from 25 secondary schools were involved in the study. Ninety-six of these students voluntarily participated in the Retail Experience for Active Learning (REAL) programme. They went through a selection interview and the interview panel, which comprised retailers and the author, deliberately selected those who are "average or even shy and not very confident". The better ones were deemed able to fend for themselves and hence were not included in the experiment. The remaining students formed two comparison groups – classmates of REAL participants ($n = 145$) and students of EBS classrooms with no REAL participants ($n = 104$); the former group was involved in order to evaluate whether there is any impact on these students who have a classmate in the REAL attachment; and in the case of the latter, none had exposure to the REAL project.

Research Design

As perceptions of the learning environment influence how learners learn (Ramsden 1992), the primary focus of the study is on the perspectives of Secondary 3 EBS students who interpret their EBS learning environment (Bednar et al. 1991; Cunningham 1991; Salomon 1998). Student perceptions of EBS learning environment (actual versus preferred) and attitudes towards EBS were measured, while pedagogical practice was manipulated. Hence, there were three groups: the REAL participants, classmates of REAL student participants and students from EBS classrooms without REAL participants in this empirical design. Quantitative data was collected and then triangulated using a qualitative approach involving focus group discussions with students to identify how students used the knowledge and skills acquired at school and how they perceive the links between what they have learnt at school and what they have developed in the workplace.

Survey Instrument: Modified Constructive Learning Environment Survey

Students' perceptions of their EBS learning environments were assessed using a modified version of the Constructivist Learning Environment Survey (CLES). CLES was selected because of its ability to characterise key elements of the constructivist learning environment, namely, personal relevance, uncertainty, critical voice, shared control and student negotiations (Taylor et al. 1997). In addition,

Table 15.1 Scale description and sample items for modified CLES questionnaire

Scale	Scale description	Sample item
Personal relevance	Extent to which EBS is perceived as relevant to students' out-of-school experiences	I learn about the world outside of school in my EBS class
Uncertainty	Extent to which EBS is perceived as ever changing	I learn that EBS is influenced by people's values and opinions
Critical voice	Extent to which students feel free to express concerns about learning in the EBS classroom	It is OK for me to ask the teacher "why do I have to learn this" in my EBS class
Shared control	Extent to which students share control of their learning with their teacher in the EBS classroom	I can discuss with my teacher on what I am going to learn in my EBS class
Student negotiation	Extent to which students are able to interact with each other to improve their learning in the EBS classroom	I give my opinions during the EBS class discussions

CLES incorporated a critical theory perspective on the sociocultural framework of the classroom learning environment (Grundy 1987; Habermas 1972, 1984; Taylor et al. 1995, 1997).

The modified CLES contains 20 items in total, with four items in each of the five scales. It was reduced from the original 30-item CLES to avoid repetition and for parsimony (Koh 2009). The response alternatives for each item are as follows: almost always, often, seldom and almost never to CLES items in 5 scales (see Table 15.1).

Attitude Towards Subject Questionnaire

Students also responded to a 16-item questionnaire to indicate students' attitudes towards EBS. The development of this questionnaire was guided by the Test of Science-Related Attitudes (TOSRA; Fraser 1981), of which validity and usefulness have been established (cf. Fraser and Fisher 1982; McRobbie and Fraser 1993). Items were modified to make them more relevant for students in Singapore and for the EBS subject. The scale descriptions and sample items are provided in Table 15.2.

Procedure

There were four phases in this whole study before, during and after the work attachment programme. Each phase served its purpose towards contributing to the research process.

In Phase 1 (March), students, teachers and retail industry mentors were briefed on the learning objectives and the selection of relevant activities and tasks under the

Table 15.2 Scale description and sample items for attitude towards subject questionnaire

Scale	Scale description	Items	Sample item
Enjoyment of EBS lessons	Students' enjoyment of EBS lessons	8 items	I look forward to EBS lessons
Self-efficacy	Students' beliefs about performance in EBS class	4 items	I will be able to achieve most of the goals I have set for myself in my EBS class
Motivation	Students' motivations in EBS class	4 items	I enjoy learning new things in my EBS class

REAL programme. This was done to ensure that REAL students and partners were clear about their roles at the outset.

In Phase 2 (May–June), REAL students were briefed on the project and expectations of adapting to workplace ethics and required behaviour. A recapitulation of the EBS key learning points was conducted as an introduction to the briefing so as to remind students to apply and reflect on what they have learnt in EBS when on attachment to the retail outlets. In June, they shadowed their workplace mentors for 2 weeks. After the attachment, students were engaged in focused group discussions to find out more about their work attachment experience.

In Phase 3 (November–December), REAL students completed their 4-week internship at their assigned retail outlets. They performed work tasks as retail assistants. Students were closely monitored by their industry mentors, teachers and the research team. Students were also encouraged to use Facebook as a means for collaborative learning by sharing their experiences. Useful links and videos relating to business skills were also uploaded and shared via Facebook to promote self-directed learning. The research team monitored students' progress by visiting students at their workplaces to obtain formative feedback on students' progress from workplace mentors and shared with students.

In Phase 4 (January–March), the research team administered the survey questionnaires to REAL students and students from the comparison groups. Focus group discussions were conducted with REAL students to seek their views on (1) their overall REAL experience, (2) their attitudes and perceptions towards experiential learning attachments as an extension of their EBS learning activities and (3) the transfer of knowledge and skills between the classroom and workplace.

Results

The effectiveness of REAL was evaluated using 3×2 repeated measures MANOVA to compare three groups of students: REAL participants, classmates of REAL participants and students in EBS classrooms with no REAL participants. The dependent variables comprised the actual form of the five modified CLES scales (personal relevance, uncertainty, critical voice, shared control and student negotiation) and the

Table 15.3 Average item mean and standard deviation and difference between three instructional groups (based on ANOVA results) for learning environment and attitude scales

Scale	Group	*M*	SD	*F*
Learning environment				
Personal relevance	REAL	3.19	0.60	16.94***
	REAL classmates	2.97	0.62	
	Non-REAL	2.63	0.66	
Uncertainty	REAL	3.22	0.52	8.82***
	REAL classmates	3.05	0.63	
	Non-REAL	2.82	0.65	
Critical voice	REAL	3.00	0.59	7.56***
	REAL classmates	2.84	0.64	
	Non-REAL	2.62	0.71	
Shared control	REAL	3.01	0.67	12.21***
	REAL classmates	2.78	0.73	
	Non-REAL	2.46	0.78	
Student negotiation	REAL	2.92	0.70	10.49***
	REAL classmates	2.75	0.71	
	Non-REAL	2.46	0.70	
Attitude to EBS				
Enjoyment of lessons	REAL	3.27	0.49	0.97
	REAL classmates	3.25	0.57	
	Non-REAL	3.17	0.56	

***$p<.001$

student attitude scale (Enjoyment of EBS Lessons). Because MANOVA revealed that there was a significant difference between instructional groups for the set of dependent variables as a whole ($p<.001$), the univariate ANOVA results were interpreted for each individual dependent variable.

Table 15.3 shows the average item mean and standard deviation for each learning environment and attitude scale of each of the three instructional groups (REAL, REAL classmates and non-REAL). The ANOVA results in Table 15.3 indicate that there was a statistically significant difference ($p<.001$) between instructional groups for every learning environment scale, but not for the student attitude scale of Enjoyment. A comparison of students' perception of their actual (A) and preferred (P) learning environments is shown graphically in Fig. 15.1.

In order to interpret the statistically significant between-group differences in learning environment scores identified through the ANOVAs reported in Table 15.3, Tukey's HSD multiple comparison procedure was carried out to ascertain the statistical significance of differences between the three pairs of groups (REAL vs. REAL classmates, REAL vs. non-REAL, REAL classmates vs. non-REAL). Tukey's test revealed a statistically significant difference ($p<.05$) for all three pairwise between-group comparisons for every learning environment scale.

Based on these post hoc tests, the graph in Fig. 15.1 was drawn to portray statistically significant pairwise comparisons between the three instructional groups for

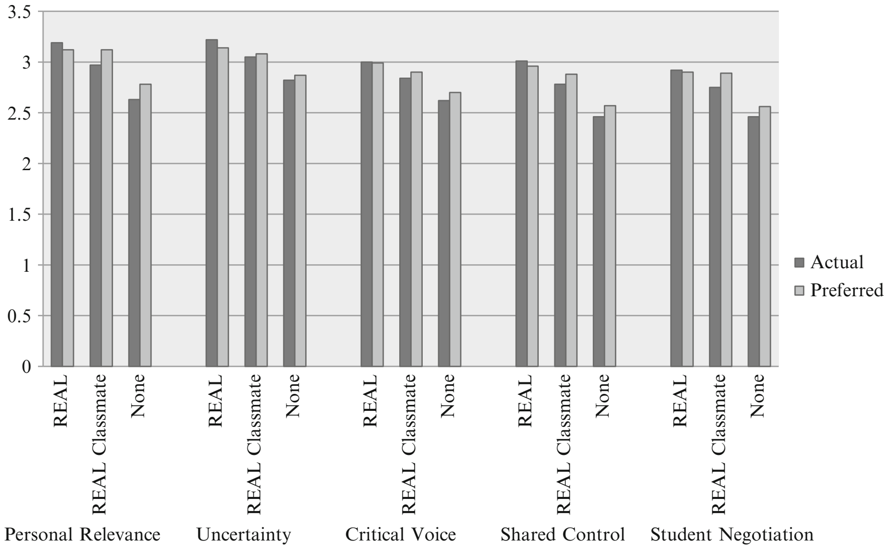

Fig. 15.1 Mean Values of Actual vs Preferred Learning Environment on Each of the Modified CLES Scale

Table 15.4 Average item means, standard deviations and results of one-way ANOVA for each of the three attitude towards EBS scales for (1) REAL participants, (2) classmates of REAL participants and (3) students of EBS classrooms with no REAL participants

Attitude scale	Group	Mean (SD)	*F*	*p*
Enjoyment of EBS lessons	(1)	3.27 (.49)	0.973	.379
	(2)	3.25 (.57)		
	(3)	3.17 (.56)		
Self-efficacy	(1)	3.20 (.48)	2.143	.119
	(2)	3.11 (.54)		
	(3)	3.05 (.54)		
Motivation	(1)	3.35 (.49)	1.946	.144
	(2)	3.31 (.54)		
	(3)	3.21 (.59)		

each learning environment and attitude scale. Because differences in Enjoyment between the three instructional groups were nonsignificant, the same overall scale mean of 3.23 is used in the graph for each instructional group in Fig. 15.1.

Students' Attitudes Towards EBS

For each of the three scales on the Attitude towards EBS questionnaire, a one-way ANOVA was performed. The results indicated that there were no significant group differences on the three attitude scales. The F-values are reported in Table 15.4.

Discussion

The quantitative findings are discussed herein. The qualitative findings from the focus group discussions with REAL students illuminated the quantitative findings interpretation of their REAL experience and how it played out as an extension of their EBS learning activities to bridge the transfer of knowledge and skills between the classroom and workplace.

Impact of Experiential Learning Attachments on Students' Perceptions on EBS Learning Environments

REAL students tended to perceive their EBS learning environments most positively, compared to their peers, across all five scales on the modified CLES. During the focus group discussions, REAL students unanimously preferred the workplace as the ideal learning environment for EBS as compared to just classroom lessons. This was supported by the consistently more positive and more congruent actual and perceived EBS learning environment reported by REAL students. This also suggests that the experiential learning attachments were effective in enhancing the EBS learning environments. The hands-on approach in the workplace meant that students were able to test out the business knowledge and skills learnt in the classroom in an authentic environment, and therefore such concrete experience provided relevance and meaning to what they have learnt in class. A student respondent commented, "in EBS, [the] teacher keep[s] talking in class about merchandising, decorate the store… In my attachment, [everything] in the textbook comes alive".

Impact of Experiential Learning Attachments on Cross Transfer of Knowledge and Skills

Students in both comparison groups tended to perceive their actual learning environments less favourably than their preferred learning environments. This was contrasted by REAL students' perceptions that their actual learning environment was more constructive than their preferred learning environments on three scales: personal relevance, shared control and student negotiation. This negative preferred-actual gap was statistically significant and suggested that REAL students have been rather successful in transferring business knowledge and skills from the classroom to the workplace and vice versa, such that they were able to make meaningful connections between their everyday workplace tasks and learning experiences.

The real-world practices at workplace concretised the scenarios described in the textbooks and provided suitable contexts for students to review and apply the concepts and skills learnt in the classroom. This helped students to relate better to concepts taught, allowing them to create new experiences with repeated practices at the workplace (Kolb 1984). For example, a student cited how she learnt to place books strategically in a bookstore to help customers shop with ease, while another cited how he used electronic databases to provide more accurate and timely customer service.

The connections made between school and the workplace were not limited to their cognitive domains, but extended to the affective domains. REAL students reflected that they observed an improvement in their levels of self-confidence. While they were shy at the beginning of their learning attachments, they found themselves gaining confidence as they became familiar with approaching customers and communicating with them. Some students were also able to articulate clearly the customer service philosophies of the organisations they were attached to.

Students also gained insights on the way they managed their emotions. They reflected that when they had to handle difficult requests from customers, they had to control their anger, frustrations and impatience. With the guidance and role modelling by their workplace mentors, they learnt how to exercise self-control to better manage their emotions. A finding shows that while students in both comparison groups tended to perceive their actual learning environments less favourably than their preferred environments, REAL students perceived their actual learning environments more favourably on the personal relevance, shared control and student negotiation scales. The significant interaction effects on these three scales indicate that the REAL student participants perceived the actual EBS learning environment as being more relevant to their out-of-school experiences. This has exceeded our expectations as we had expected a narrower preferred-actual gap for REAL students, rather than the actual learning environment being more positive than the preferred. This suggests that the REAL programme has been very successful in enhancing students' perception of their learning environment in the EBS classroom.

The negative preferred-actual gap suggests that REAL students have been successful in transferring business knowledge and skills from their workplace to the classroom and vice versa, such that they make meaningful connections between their everyday and learning experiences. The connections made were not limited to their cognitive domains and extended to the affective domains. A number of student respondents reflected during the focus group discussions that after the REAL experience, they became more aware of their emotions, commonly anger, when they had to handle difficult requests from customers. They mentioned that they have learnt how to exercise self-control to manage their anger and emotions, instead of venting their emotions on others. A student respondent shared that he "learnt to be more patient and not to [show] anger towards the customer, even if the customer is not that patient". Many also expressed that they felt more confident approaching and communicating with strangers after their retail experience.

The workplace also provided dynamic real-world challenges which required REAL students to think on their feet to interact with customers. They have to think of solutions and make decisions, sharing the locus of control for problems that occur in the workplace. In addition, the guidance of their supervisors and interaction with co-workers provided invaluable on-the-job training and just-in-time learning for students, while developing their self-confidence and motivation towards excelling in the workplace.

In solving real problems at the workplace, students also learnt to realise and activate a range of cognitive processes and mental activities. It simulated problem-solving cognition needed to solve real-world challenges. Students also have to learn to think on their feet as the interaction with people in the workplace is often dynamic, hence developing their thinking skills and interpersonal skills. The on-the-job (OJT) training and just-in-time (JIT) learning provided invaluable teachable moments for the REAL participants to learn relevant skills and knowledge. From the in-depth focus group discussions with the students, it is revealed that students made sense of their internship experience in terms of their learning and personal growth.

Feedback from Workplace Mentors and Teachers

The mentors observed that students were very receptive towards constructive feedback and were able to cope with the workload as retail assistants with guidance. However, students were not prepared for the long hours and independent working environment at retail outlets initially. Nonetheless, many mentors noted that there was a marked improvement in students' customer service and retailing skills at the end of the attachment. Mentors have also expressed interest in rehiring student apprentices should they seek employment after graduation. In fact, a few of these interns informed the schools that they eventually secured full-time employment with the retailers that they were attached to.

Teachers gave full support to the REAL project as they could see the change in students' cognitive, affective and behavioural aspects when they are back in the classrooms. The intervention has encouraged them to relate their experience more confidently and they were able to cite real examples in class and articulate what was required and expected of them when performing their role as retail assistants when explaining to their classmates. However, one feedback from some parents through teachers was that the time and effort spent at the retail outlet did not commensurate with the token allowance given to the students. Though teachers and the research team tried to explain that this internship was carried out for the personal growth and also with the intention of contributing towards meaningful learning of the EBS syllabus, these parents felt that they could also get the experiential learning experience by working part-time during the holidays and receive better monetary rewards. While experiential education programmes are not designed to offer attractive compensation packages, organisations can show their appreciation to interns using non-monetary perks such as transportation benefits and care packages (Gold 2002). On the other hand, the parents who turned up at the appreciation-cum-certificate presentation ceremony organised by the author were grateful for the "life-changing experience" they saw in their children and urged the Ministry of Education to continue with this initiative.

Implications

In view of the present model of experiential learning attachment being successfully implemented, other models of work attachments for students to authentic learning environments could also be explored and compared. For instance, EBS students could be allowed to work regularly, perhaps 1 day a week, at a retail outlet to hone their EBS content, skills and values, as well as communication and interpersonal skills. Such recent experience could then be brought into class for further analyses and discussion and the teachers could scaffold and relate the EBS syllabus to these real-life experiences.

EBS students can be also encouraged to take up a learning attachment at an authentic workplace to experience a real workplace setting and to benefit from the business knowledge learnt on their own, as suggested by some parents. The practical experience will help EBS students make relevant connections to help them in their academic pursuits, increasing their self-efficacy towards EBS. The teachers' role, then, is to make connections between workplace learning and classroom learning, without being saddled with the administrative burden of monitoring the students' attendance at the workplace.

Lastly, other than learning attachments in retail industries, students can also be attached to hospitality industries to gain experience and to compare similarities and differences between industries to develop business knowledge and skills. For the twenty-first-century competency skill set, learners are required to be self-directed learner, to be able to communicate and be confident. At the same time, through this 6-week experiential learning attachment, students can develop a better understanding of self and their career preferences.

Conclusion

This study was designed to evaluate the impact of using experiential learning attachments to authentic retail outlets for EBS students to enhance their learning of business knowledge and skills. The findings reported the gaps between the actual and preferred environments and the strong evidence where REAL participants consistently showed up as having highest scores and better congruence in the learning environment than comparison groups. REAL students tended to perceive the EBS classroom more positively as a constructivist learning environment. This suggested that experiential learning attachments to authentic learning environments had been effective in enhancing the learning environment of the EBS classroom. The efficacy of REAL was evidenced in this study as this intervention contributed to the learning of EBS in the classroom where learning environments were perceived by REAL participants and their classmates to be more congruent with students' preferences.

The implications for educators and policymakers include exploring the availability of such authentic learning environments for students so that their quest for knowledge and skills is consistently driven by solving real problems at the workplace. This study has shown that the on-the-job (OJT) training and just-in-time (JIT) learning presented invaluable teachable moments for honing problem-solving skills. The participative and interactive nature of work attachments makes them an ideal pedagogical tool to facilitate experiential learning which in turn provides a rich reference point for the teacher when unpacking the lessons learnt.

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Chapter 16

Authentic Learning Experiences in Informal Science Learning: A Case Study of Singapore's Prospective Teachers

Mi Song Kim and Xiaoxuan Ye

Abstract This one-year study examines the impact of informal learning by Singapore's prospective teachers (PTs) who codeveloped an informal astronomy workshop based on a big idea of "size and distance." Drawing upon design-based research, this qualitative study collected the PTs' lesson plans, audio- or/and video-recordings of learning and teaching activities, modeling artifacts, surveys, interviews, researchers' field notes, and reflection journals. Based on an in-depth analysis of the five PTs engaging in multimodal modeling activities, their teaching practices reflected the influence of their learning experiences mediated by the workshop design principles and their expert mentor's teaching strategies. This result implies the importance of teachers' authentic learning experiences toward building this participatory learning environment.

Keywords Authentic tasks • Informal learning • Multimodal modeling • Digital storytelling

Introduction

This study aims to develop a participatory learning environment where participants are encouraged to participate in and codesign multimodal modeling activities (also known as Embodied Modeling-Mediated Activity, EMMA) that seek to facilitate not only the construction of scientific models but also the engagement of authentic inquiry rather than directed by teachers (Kim et al. 2012). Modeling-mediated learning has been proved to be a successor to constructivism and can account for students' conceptual change (Clement 2000; Lehrer and Schauble 2000; Lesh

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and Doerr 2003). Despite such affordances of multimodal modeling processes, many teachers experience difficulties in modeling-based teaching due to the lack of modeling experiences, meta-modeling knowledge, and pedagogical content knowledge on modeling instruction (Kim et al. 2011, 2012; Schwarz et al. 2009).

Multimodal modeling also implies the important role of observation that could offer opportunities for learners to recognize inconsistencies between observed experiences and their own models and hence promote inquiry, especially in the domain of astronomy. In early times, astronomy only comprised the observation and predictions of the motions of objects visible to the naked eye. From these observations, early ideas about the motions of the planets were formed, and the nature of the Sun, Moon, and the Earth in the universe was explored philosophically, which is known as the geocentric model of the universe. So authentic astronomy learning should not exclude real-world observations.

For example, for the comprehension of the Moon phases, it is essential for learners to observe at least a full cycle of the Moon phases so as to get the data and try to find a pattern as well as generate questions based upon their embodied engagement within specific contexts. Observation, whether it was made in the real-world environment (Sherrod and Wilhelm 2009; Trundle et al. 2010) or designed virtual environment (Bakas and Mikropoulos 2003), provides learners embodied experiences in an authentic learning environment. This does not only facilitate learners' conceptual learning but also enhance their motivation and interests (Kucukozer et al. 2009).

Astronomy is not taught in formal learning contexts for the youth in Singapore despite students displaying high interests in learning astronomy concepts. Hence, through building a community of learners that consists of astronomy experts from universities, science teachers, science education researchers, and astronomy amateurs, we not only hope to codesign authentic and embodied learning experiences for the learning and teaching of astronomy in informal learning settings but also to investigate effective ways to develop multimodal modeling activities in promoting participants' conceptual understanding in astronomy. The participants in our learning community, in this sense, are not merely learners with interests to learn about astronomy concepts, but also potential leaders of a broader Singapore astronomy community. They were offered with opportunities to codesign EMMA activities and perform as facilitators in informal classes organized by both the research team and the Singapore youth clubs. In this vein, we view our participants as "prospective teachers" (PTs hereafter) although they did not take up education courses in formal settings.

PTs voluntarily joined our learning community, generated interest-driven topics to explore multimodal modeling activities, and developed understandings through meaningful participation. This kind of learning echoes sociocultural perspectives that posit the learner as an active participant and not a mere passive receptacle of knowledge (Hay and Barab 2001; Kim 2012, 2013). Following these sociocultural perspectives, our research team aimed to tap benefits of informal science learning in which learning is characterized as self-motivated and voluntary, guided by not only learners' needs and interests (Dierking et al. 2003) but also collaboration and communication among learners and facilitators that are considered as the core skills for twenty-first-century learning.

Most importantly, in this informal learning environment we created, we were able to conceptualize the PTs' facilitation skills for others (e.g., workshop participants) as important evidences of their improved understanding of targeted astronomical concepts that in turn led to a deeper understanding of such phenomena (Boyer and Roth 2006). Hence, as mentioned above, we also provide the PTs with opportunities to teach. In this vein, this study specifically seeks to the influences of this learning-through-teaching approach in EMMA workshops.

Literature Review

Embodied Modeling-Mediated Activity

Drawing upon a sociocultural perspective, we adapt embodied cognition which conceptualizes that learning not only exists in the mind but in the human body as well (e.g., gesture production, manipulation of tools, mobility in a local environment, interactions with others) (Hall and Nemirovsky 2012). Hence, EMMA provides workshop participants with an embodied learning experience by engaging them in authentic observation and related follow-up modeling activities. We particularly promote multimodality in modeling activities, where participants are required to create different types of models such as a graphical model, a 3D physical model using various materials, or/and 3D computer models. Multimodal modeling activity provides abundant opportunities for students' bodily interactions with models that in turn enhance embodied cognition.

For example, students manipulate a model to reason about how different seasons come about, simultaneously using gestures to complement their explanation. By constructing and interacting with the models, students will be required to actively apply their prior knowledge and make sense of the new concept. Furthermore, it also encourages interactions that sometimes exceed the limitation of just verbal communication. For instance, some of our previous workshop participants could not distinguish the meaning of "revolve" and "rotate" scientifically, where they often end up using the words interchangeably. When using their body movement, however, they were able to articulate and distinguish the difference precisely, such as moving their hands to show how the Earth revolves around the Sun and spinning their finger to illustrate the rotation of the Earth on its axis. EMMA was shown to promote learners' understanding of astronomy concepts, such as the solar system (Kim et al. 2011), lunar libration (Kim and Lee 2013), and the Moon phases (Kim et al. 2012).

Previous studies have also shown that different modeling activities were able to provide learners with varied learning experiences and trigger different kinds of skills and sensory modalities (Blown and Bryce 2010). According to Shen and Confrey (2007), when learners try to express their improved understanding, they tend to switch from one model to another in order to better demonstrate their ideas. During this transformative modeling process, learners could progress in conceptual development.

A Big Idea of Size and Distance in Modeling

In the recent review of literature, Lelliott and Rollnick (2009) argued that the concepts of size and distance have been under-researched and under-taught, compared to other astronomy concepts such as the shape of the Earth, gravity (e.g., Vosniadou and Brewer 1992), and the Sun-Earth-Moon system (e.g., Barnett and Morran 2002; Baxter 1989). Not surprisingly, many students experienced difficulty in understanding the concepts of size and distance such as the distance between the Sun and the closest star (Sadler 1998), the scale of the Earth and the Sun, the actual size of the Earth and the Sun, the relative distance of the Earth from the Sun, the relative sizes of planets, and the relative distances between planets (Sharp and Kuerbis 2006). Some studies suggest that students' difficulty in comprehending the vast celestial distance and size lies with, firstly, the lack of life experiences they have relating to vast distances and, secondly, their misinterpretation of their observation (Bakas and Mikropoulos 2003). Lelliott and Rollnick (2009), therefore, conclude that it is important to provide students with a variety of experiences related to size and distance – in order, not only to improve students' knowledge of the spatial scales involved in astronomy but also to develop a deeper understanding of the concepts of size and distance. In that sense, our study adopted Lelliott and Rollnick's (2009) term of "big ideas" with an aim to emphasize coherence across core concepts of size and distance, rather than "themes" or "topics."

Modeling strategies have been adopted in many studies in order to improve students' conceptual change or conception formation. Kuhn et al. (2006) noted that "modeling is therefore more than reproduction: the whole process is a reflected transformation in which students actively organize their own learning. The 'subject' decides which attributes and connections out of the context are accepted, emphasized or neglected and how the results are applied to the real world" (p. 185). With an emphasis on the development of the big idea of size and distance, this study, therefore, draws specific attention to the modeling process, which involves the process of describing, explaining, representing, modifying, and developing the conceptual understanding of learners and demonstrating their learning development (Shen and Confrey 2007).

Learning Through Teaching

Some efforts have been made in previous studies to provide students with teaching experiences in terms of peer teaching, reciprocal teaching, or peer tutoring. Elmendorf (2006) noted that authentic teaching experiences promoted not only her college students' deep conceptual learning of science but also meaningful and personal connections with science. In her study, she provided her college students with an opportunity to use what they have learned in college to design a curriculum for an elementary school. It was noted that her college students learned differently when being casted in the role of teacher. For instance, they became more responsible in their own learning, became aware of their level of knowledge, and wanted to achieve deeper understanding of targeted topics. Her students also consolidated their understanding so that they were able to convey knowledge in multiple ways that in turn allowed their own students to enhance their learning experience. Hence, they eventually gained an appreciation for the learning process and became active learners.

A number of theorists have made efforts to explain how being in the teaching role is beneficial to learning from cognitive, social, emotional, and motivational aspects. The goal-oriented information processing was one possible cognitive aspect to explain the benefits as personal goal setting during learning was recognized as important for learning (Cate and Durning 2007). When preparing to teach, students determine their own goals and priorities rather than try to know what their teacher's priorities are; hence, they apply different cognitive strategies to the study materials. When teaching, students go through the process of verbalization and recitation, making cognitive connections between new concepts and their prior knowledge, which could enhance memory and learning leading to what Slavin (1996) called "cognitive elaboration." Being in a teaching role, students also need to generate questions which lead to high-quality explanation and meaningful interactions with their audience (King et al. 1998; Slavin 1996). Further, taking on students in the role of a teacher also brings social, emotional, and motivational benefits to the students (Puchner 2003). In particular, Cohen's (1986) role theory could explain the motivational benefits of being in the teaching role. When students assume the role of teachers, they also take on teachers' characteristics, self-perceptions, and attitudes that in turn allow them not only to engage in challenging conversations around complex problems but also to develop intrinsic motivation.

However, much research about student teaching experiences seems to have been shaped by the interests of improving the academic performance of students (Roscoe and Chi 2007; Streitwieser and Light 2010; Tessier 2006). Rather than such an outcome-oriented way to examine the effects of the student teaching experiences, Roscoe and Chi (2007) emphasized a process-based approach in which researchers need to examine the process of student teacher's learning and teaching experiences so as to account for their success and failure in teaching and learning. They concluded that peer tutoring could promote not only domain knowledge but also collaboration skills. By drawing on such benefits of learning by teaching, we aim to provide our PTs with an opportunity to teach astronomy through designing and implementing multimodal modeling activities in informal learning settings.

Methods

The Study

This study applies a qualitative methodology to explore learning and teaching experiences of the PTs, which is mediated by multimodal modeling activities in an informal learning setting. Our pilot studies in Singapore revealed that students and

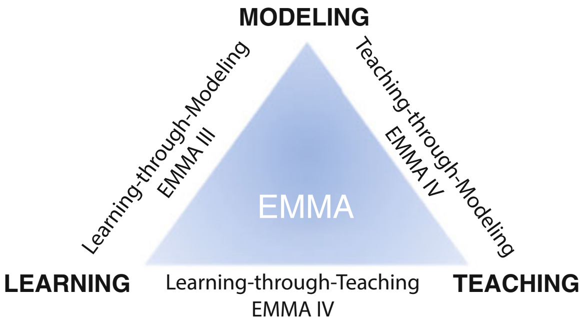

Fig. 16.1 The EMMA triangle

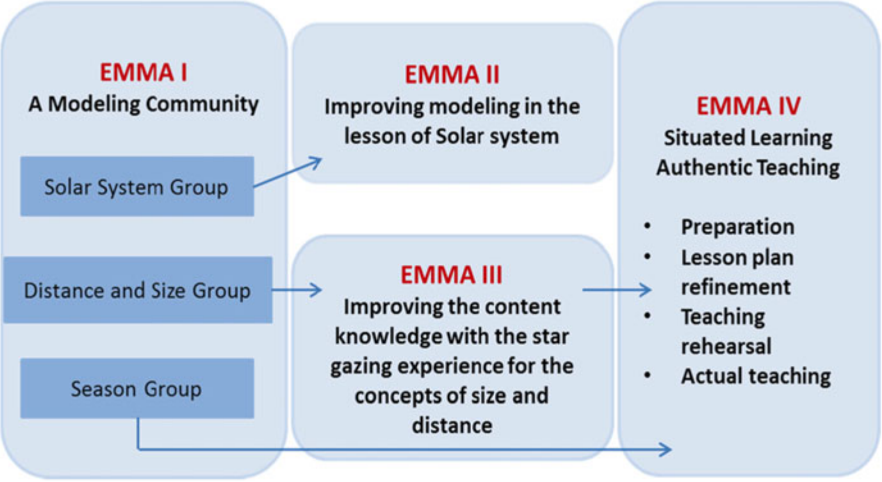

Fig. 16.2 The progress of EMMA workshops

teachers had little experience of real sky observations and modeling activities of various astronomical phenomena (Kim et al. 2011). Thus, for designing EMMA activities, design-based research has been employed to go through iterative cycles of codesigning, implementing, analyzing, and refining the EMMA activities with our research participants including the PTs. Our participants include one expert science teacher and 14 junior college students who are interested in learning and teaching astronomy in informal learning settings. In particular, we attempt to investigate the ways in which learning through teaching is mediated by multimodal modeling activities for the PTs' deep learning in astronomy. In other words, as indicated in Fig. 16.1, our intention is to integrate modeling, teaching, and learning around EMMA activities, which will be described in further details in the discussion section.

As described in Fig. 16.2, there have been four EMMA workshops for three groups of prospective teachers (PTs) before actually getting into real teaching practice involving multimodal modeling activities and lesson design activities with respect to their own chosen topics such as solar system (two male PTs), size and distance (two female PTs), and seasons (two male PTs). In EMMA I, three groups of PTs participated in a 4-day workshop across 5 weeks to explore their topics and to design lessons. For EMMA II, the initial lesson designed for solar system was refined together by the research team, the mentor, and the PTs in order to work with a new group of PTs (one male, three female JC students). In this paper, our discussion will be focused on EMMA III and IV (see Fig. 16.2), which will be introduced in the following sections.

Based upon the PTs' performance in EMMA Workshops I and II, there were four emerging objectives in EMMA Workshop III: (1) improving the accuracy of their models, using proper units of measurement and scaling, (2) understanding that the distances between celestial objects can change due to the motion of the celestial objects, (3) understanding the different methods of measuring distances and sizes of various celestial objects, and (4) using appropriate celestial objects to explain the concepts of distance and size. To achieve these objectives, the research team designed the EMMA Workshop III around authentic, embodied experiences of sky observation, multimodal modeling, and outdoor activities situated in a two-night field trip in Malaysia. The PTs were involved in observing the planetary alignment and constellations; constructing multimodal models using the fact sheet of planet properties, various modeling materials (e.g., Styrofoam balls, marbles in various sizes, play dough), and sky simulation programs (i.e., Stellarium); and measuring the distance to faraway objects in the sea. Table 16.1 describes activities and objectives for EMMA Workshop III.

Based upon such multimodal modeling experiences in EMMA III, the PTs spent 3 months to rethink the previous lesson plan they designed in EMMA I so as to revise it for implementing the lesson in EMMA IV in which they were supposed to facilitate 30 secondary school students in an astronomy camp organized by a nonprofit community center. In addition to face-to-face meetings, online communication through Facebook, phone, and e-mail allowed the PTs to revise their lesson plan in and out of the EMMA workshops.

This study examines the following questions: (1) How do the prospective teachers (PTs) develop their understandings of astronomical concepts of size and distance in EMMA workshops? (2) What affordances or benefits do learning-through-teaching opportunities bring to the PTs' engagement in EMMA workshops?

Participants

The EMMA workshops started with seven young adults (aged 17–18), and later, seven more joined. Having high interests in astronomy, they invited their friends to join our community and volunteered themselves to be facilitators (so-called prospective teachers) to conduct astronomy workshops. Participants hence came with diverse backgrounds in terms of astronomy knowledge, academic backgrounds,

Table 16.1 Activities and objective in EMMA Workshop III

Main activity	Sub-activities	Objective
Modeling of the solar system	1. Pre-workshop online discussion: PTs were asked to give comments and ask questions about the simulation-generation picture of the planetary alignment	1. Identify different planets in the sky
	2. Observation of the sky in the morning on 28 and 29 May 2011	2. Construct more accurate model to generate argument and explain phenomena
	3. Explore the sky through simulation software (Stellarium)	3. Understand relative size and distance of different planets in the solar system
	4. Modeling of the solar system on that day to explain why the geocentric argument brought by the mentor is incorrect and the planetary alignment phenomenon	
Modeling of Scorpio constellation	1. Observe the sky	1. Appreciate vast distance of celestial objects in the sky
	2. Sketch the constellations observed	2. Appreciate cultural differences in constellation in different regions
	3. Sharing talk by the mentor on cultural differences in constellation	3. Understand that the distance and size of the stars that consist constellations are varied
	4. Modeling of Scorpio constellation considering distance and size of the stars	
Measure the distance of a distant object in the field	1. Problem-solving task on how to measure the distance of a distant object without going there with compass and measuring tapes	1. Understand and appreciate the parallax methods in measuring the distance of distant objects
	2. Field practice: measuring the distance of an object in the sea	2. Improve problem-solving skills using interdisciplinary approaches
	3. Discussion with the mentor on how the method can be applied in measuring distant celestial objects	

and sky observation and modeling experiences. Their commitment to facilitating workshop participants motivated them to equip themselves with astronomy content knowledge and pedagogical knowledge, which had been facilitated by the research team members and Hong Jian (hereafter "HJ") who is an expert physics teacher with strong interests and rich content knowledge in astronomy. All names used in this paper are pseudonyms (see Table 16.2). As mentioned earlier, this paper focuses on the group of five PTs working on the concepts of "size and distance," Mei Fong (MF), Vivian, Emma, Faith, and Santhi. MF and Vivian participated in EMMA I, III, and IV, and the rest three participated in EMMA III and IV. Table 16.2 describes a brief profile of five PTs.

All the PTs grew up and have been educated in Singapore, and our survey conducted before EMMA IV revealed that there were a variety of their perceptions of learning

Table 16.2 Profile of five prospective teachers

Name	Race	Age[a]	Favorite subjects	Current status[b]
Mei Fong (MF)	Chinese	19	Chemistry	University, Material Engineering
Vivian	Chinese	19	English, Art, PE	University, Sociology
Santhi	Indian	19	Mathematics	University, Biological Engineering
Ellen	Chinese	17	Chemistry, Physics, Chinese	Junior college, grade two (equivalent to grade 11 in the USA)
Faith	Chinese	17	–	Junior college, grade two

Note: [a]when they participated in EMMA III; [b]in the year 2012

Table 16.3 Data sources and purposes in EMMA III and EMMA IV

Workshop	Data sources	Purposes
EMMA III	Video-taping of the entire process of EMMA III	Learning difficulties of PTs during solar system modeling
	Multimodal modeling artifacts (2D drawings and 3D concrete models)	PT's learning process guided by the mentor
	Pre-event survey and post-event survey on content	
EMMA IV	Versions of lesson plans since EMMA I	PTs' development on their lesson design and the development process
	Researchers' field notes on the rehearsal day	
	Pre-survey on the perception of learning and teaching, teaching through modeling, and modeling experiences	
	Video-taping of EMMA IV lesson implementation	PTs' performances including instruction to the whole class and interactions with each group
	Researchers' field notes on the actual teaching day	PTs' views on modeling-mediated teaching and their learning-through-teaching experiences
	Post-interview with PTs	

and teaching. All of them felt that EMMA workshops were beneficial to their understanding of astronomy knowledge. They often mention that EMMA workshops were different from their previous learning experiences in their schools such as "something that is beyond conventional ones," "more hands-on activities," and "a lot of modeling and have to find answers by ourselves" (from EMMA IV pre-surveys).

Data Collection and Analysis

This qualitative study collected multiple interconnected data sources as described in Table 16.3. In particular, with regard to the EMMA III video data, we have selected modeling activities such as planetary alignment since they are similar to those designed and implemented in EMMA IV by the PTs. Through the examination of the process data of both learning and teaching events, we seek to explore how the PTs will be able to connect their learning with teaching experiences.

Data collected were analyzed using a constant comparison method (Boeije 2002; Strauss and Corbin 1990). Comparisons were iteratively conducted separately within EMMA III and EMMA IV and between these two workshops for developing emerging themes. Interestingly, there were similar themes in both workshops such as “PTs’ modeling process of solar system,” “guidance and questioning from HJ,” and “argument put forward by HJ” in EMMA III and “PTs’ modeling teaching process,” “guidance to their students,” “argument put forward by PTs” in EMMA IV. These themes from open coding were then compared to that of EMMA III and EMMA IV, in order to find a relationship between the PTs’ learning and teaching experiences. Once the relationship was identified, a detailed discourse analysis was conducted. Other data sources such as researchers’ field notes, artifacts (i.e., models), and survey data were also constantly analyzed to triangulate themes generated mainly in the form of video data.

Data analysis involves three major steps. Firstly, each segment of the workshop was identified according to the modeling processes such as constructing, revising, and using models. Secondly, episodes were defined based on astronomy-related topics so as to identify not only the PTs’ learning moments but the facilitators’ facilitation as well. Whenever a new discussion topic occurred, it was defined as a new episode, and there were 20 episodes in EMMA III and seven episodes in EMMA IV. Thirdly, detailed discourse analysis was conducted on selected episodes to understand the PTs’ learning and teaching experiences. For EMMA III, we focused on the PTs’ learning difficulties and how HJ facilitated them to solve the problems; for EMMA IV, we focused on the PTs’ instructions and their interactions with the students. A total of nine episodes were selected for detailed coding.

Drawing upon Chin’s (2006) study that took place in Singapore, the unit of analysis in this paper was a move of communication (i.e., initiation, response, follow-up), as well as the types and purposes of the utterance were also considered. Compared to Chin’s research context where students mainly replied to their teacher’s questions, participants in our study took active roles and became more flexible in informal multimodal modeling activities. Hence, we emphasized the dimensions of the learning process by including not only the participants’ cognitive learning process (Anderson and Krathwohl 2001) but also the ways of how their learning was mediated.

Findings

Transforming Learning Difficulties to Teaching Moments

Although EMMA IV was the PTs’ very first teaching practice, with learning experiences facilitated by their mentor’s (HJ) expertise in EMMA III, they were able to engage the workshop participants in learning through the design of a modeling task and the generation of an argument based on real, authentic observation. They were also able to evaluate the participants' achievements by setting out certain criteria. Specifically, the PTs have effectively integrated modeling approaches into the lesson plan in three ways, with regard to the concepts of size and distance. Firstly, *they changed from lecture-oriented to a modeling-based student-centered lesson design*. In their first lesson design, they made efforts to engage students to participate in a band-making activity. However, most of the learning objectives such as the relation between distance and size were designed to be achieved by the lecture format that emphasized on content delivery. Then, after having multimodal modeling experiences in EMMA III, they had much clearer learning objectives and modeling-based activities. Secondly, their revised lesson plan demonstrated that *learning could be enhanced by the workshop participants through exploration rather than "pass-over."* In their first lesson plan, they intended to include as many YouTube videos as they could. Similarly, hands-on tasks were mainly designed for fun. Their revised lesson plan, however, aimed to address means to promote the active engagement of the workshop participants. For instance, instead of showing videos about size and distance to the workshop participants, the PTs endeavored to design multimodal modeling activities in order to engage them to construct a scaled-down model of the solar system. This allows them to calculate with varying scales of distance and size and helps them to make sense of the vast distance and understand the concepts of relative distance and size. Thirdly, *their learning activities became more situated in real-world, authentic contexts with more embedding questions*. In the final version of their lesson plan, the PTs incorporate factual knowledge of "size and distance" under authentic contexts of making the solar system and sky observation experiences in order to facilitate easier understanding for the workshop's participants.

Drawing upon these changes, in order to understand the influences of EMMA workshops in supporting a learning-through-teaching approach, we identify one claim: Learning through teaching in EMMA workshops resulted in a transformation of the PTs' learning difficulties to teaching moments that in turn led to deep learning for PTs. EMMA III provided the PTs with a sky-gazing experience which enabled them to leverage their observational experience with their learning-through-modeling experience (see Fig. 16.1). Prior to the field trip of EMMA III, HJ posted a planetary alignment picture (see Fig. 16.3) from a sky simulation software on Facebook in order not only to support the PTs' inquiry but also to promote authentic learning for them. This alignment was expected on the actual days of the field trip.

During the field trip of EMMA III, HJ intentionally created an argument that was *observationally possible*, but *scientifically unsupportable* – it was based on a geocentric model of the solar system. He used observations of stars moving across the sky (as seen from naked eyes, the telescope, and the simulation software) and planetary alignment (Fig. 16.3) in support of his argument. HJ asked the PTs to construct models to disprove his argument. Based on PTs' planetary modeling activity in EMMA III and their teaching practice in EMMA IV, we identified the PTs' two specific learning difficulties that were later transformed into effective teaching moments: (1) making both distance and size on the same scale and (2) using models to examine astronomical phenomena from different perspectives.

Fig. 16.3 Planetary alignment photo in EMMA III

Making Both Distance and Size on the Same Scale

With respect to their own model of the solar system during the EMMA Workshop III and the relation to their sky observation experiences in which all planets in the solar system were aligned, the PTs' initial model (see Fig. 16.4a) was not scientifically scaled in terms of both distance and size. For instance, Jupiter was not represented as 11 times bigger than the Earth. The PTs did not pay attention to the scale of models even though they were given a fact sheet of the planets regarding distance and size.

Hence, HJ's feedback was focused on asking questions for the PTs to think about the scales they have used for their models. The PTs' explanations about their current model were questioned by HJ, and their responses were followed by HJ's comments, feedback, or follow-up questions. HJ always referred to their models in this process, which in turn led to the PTs' modification of the models. Such an iterative process of constructing, evaluating, and modifying their own models mediated by HJ facilitated the PTs' engagement in cognitive processing such as recognizing and identifying objects, retrieving relevant information from previous experiences, inferring from known facts, and comparing different ideas and resources.

Specifically, HJ purposefully challenged the PTs to use the same scale for both the distance and size of the planets since they were struggling to appreciate the vast celestial scale. He also suggested that they should make full use of the open space to represent the appropriate distances among the planets, rather than restricting their models within a given space. After receiving such feedback from HJ, as indicated in Fig. 16.4b, the PTs revised their initial model so as to improve the accuracy of scaling.

The PTs spent a total of 3 h to calculate the scales, select the appropriate scale for size and distance, and find the appropriate objects. Eventually, they applied an

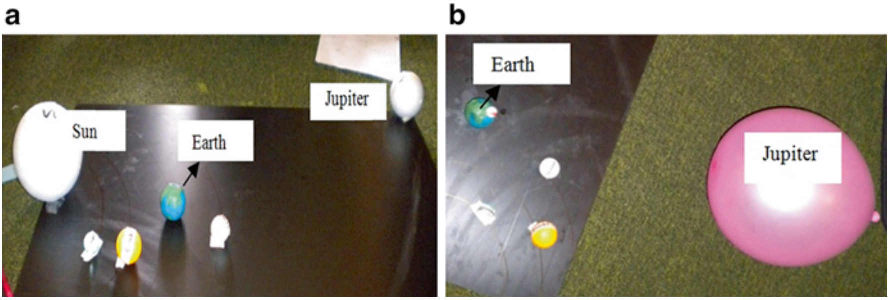

Fig. 16.4 PTs' initial and revised models in EMMA III: (**a**) PTs' initial model. (**b**) PTs' revised model

elimination strategy to take out any relatively oversized or distant objects (e.g., the Sun) in their models for constructing their own scaled-down solar system model. Regarding such learning experiences in EMMA III, Faith felt that the planetary alignment modeling activity was much more challenging than other activities because "it's very hard to find the suitable objects to represent the size… and the scale of distance and the scale of size is difficult to be combined" (30 May 2011, Interview with Faith regarding EMMA Workshop III).

Drawing upon their own learning experiences involving models in EMMA III, the PTs changed their lesson design for their actual teaching in EMMA IV. Changes include guiding of the workshop participants to construct their own 3D physical models by scaling the sizes and distances of the planets separately. In other words, by reflecting on their learning difficulties in EMMA III of using the same scale for both distance and size of the planets, the PTs aimed to avoid confusion or difficulties for the workshop participants. Furthermore, compared to the PTs' initial lesson plan designed before EMMA III, their revised lesson plan and instruction in EMMA IV were able to address the accuracy of distance and size more explicitly. For instance, they eliminated their initial idea of a band-making activity in which the workshop participants were supposed to roughly select beads in different sizes in order to represent the relative sizes of the planets, where little attention was paid to the accurate scale. Due to their own learning experiences in EMMA III, they realized the importance of scaling accuracy in constructing models and explaining phenomena such as planetary alignment.

In addition to such changes in their lesson design, the PTs actively adopted what they learned in EMMA III in order to cater for needs and difficulties of the workshop participants in EMMA IV. For instance, in the following excerpt, Santhi provided suggestions for the solar system modeling activity, such as excluding the Sun or using Plasticine to effectively make the smaller size of planets. She said:

> [To the whole class] so by watching this video, you will know that getting a scaled-down size of the Sun is impossible now, Uranus will probably be outside the classroom, so I suggest that you exclude the Sun, so maybe leave that nine planets, oh, eight planets.
>
> [To a group] Try to make good use of your materials … Make use of the Plasticine to make it of a really small size. (13 Aug 2011 in EMMA IV)

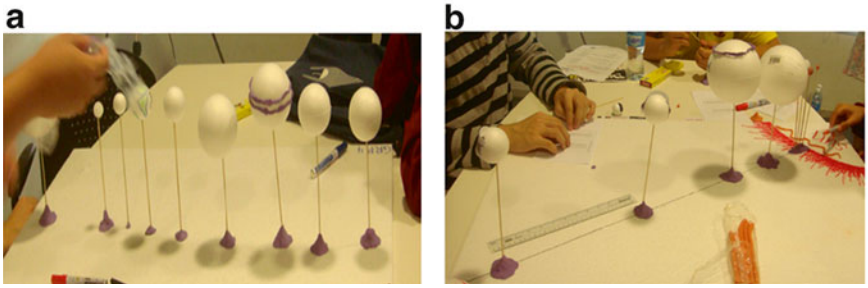

Fig. 16.5 Workshop students' initial and revised models: (**a**) Workshop students' initial model. (**b**) Workshop students' revised model

The PTs also used questioning strategies to attract the workshop participants' attention toward the accuracy of their models. For example, Faith posed a question about the accuracy of the scaled model of the solar system rather than correcting wrong scales right away, "Is this the Earth? This is the Mars? … Do you think it [the Earth] is two times of this [Mars]?" This question drew their attention to selecting proper sizes of Styrofoam balls to represent the planets. The PTs' guidance allowed the workshop participants to improve the accuracy of scaling. Compared with their initial model (see Fig. 16.5a) of arranging the planets with little attention paid to accurate scale in distance, in the revised model, they carefully calculated the relative distances between the planets. As shown in Fig. 16.5b, planets closer to the Sun were positioned closer to each other while Jupiter and Saturn were arranged further away from each other. During their presentation, the workshop participants explicitly articulated such a limitation of their model as using different scales for size and distance.

Using Models to Examine Astronomical Phenomena from Different Perspectives

In EMMA III, the PTs were given an opportunity to develop an understanding of the complex relationships and dynamics among celestial objects in 3D space in terms of examining celestial objects and events from different perspectives beyond that of the Earth (Parker and Heywood 1998). In that sense, HJ requested the PTs to construct a model to disprove his geocentric view of the solar system that explained the phenomenon of planetary alignment (see Fig. 16.3). He generated an argument by saying "you say my model is nonsense right? But my model allows me to see this (referring to the photo of all the five planets aligned in the sky) in the sky." In other words, he purposely challenged the PTs by putting forward an argument that was not only against the PTs' prior knowledge but also corresponded to their sky observation experience.

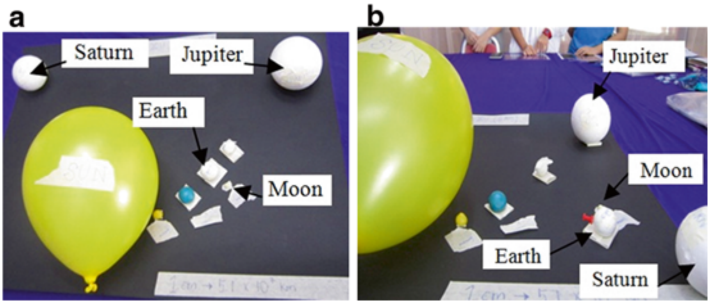

Fig. 16.6 Planetary alignment model before and after revision: (**a**) Model before revision. (**b**) Model after revision

One group of PTs (Faith, Ellen, and Vivian) initially constructed and presented their model in which Mercury, Venus, Mars, Earth, and Jupiter were arranged in a straight line (see Fig. 16.6a). They also put the Saturn randomly on the board without considering the right scale since there was not enough space on the board. Hence, the PTs mainly used their model to simply *illustrate* Fig. 16.3, rather than to argue against HJ's geocentric claims. With respect to such difficulties PTs faced, HJ used a queuing metaphor as shown in the following excerpt:

> HJ: In the morning you saw Jupiter and Venus, right? And the Moon, right? It means that you are like outside the queue, right?
> Ellen: Outside the queue?
> HJ: You get what I mean? You have a row of people queuing for food, ok? And you see all your friends there queuing for food; then are you in the queue?
> Faith: No.
> HJ: No, right? You are not in the queue, right? But you look at your diagram [HJ pointed to the model]. Your Earth is in the queue, right? You get what I mean? Because you can see the queue. So my question is, are you in the queue? If you can see the queue, imagine you are buying food from the canteen and then you can see all your friends queuing up for food. My question is, are you queuing with your friends?
> Faith: Not really.
> Faith: No.
> Vivian: No.
> HJ: No, but you are telling me that you ARE in the queue!
> Ellen: That [pointing to the ball representing the Earth], got to pop out. It's a bit wrong.
> Ellen: Position of the Earth should be moved somewhere.
> (29 May 2011 in EMMA III)

His queuing metaphor allowed the PTs to use their daily experiences to make sense of their sky observation experiences.

With respect to their sky observation experiences (see Fig. 16.3), HJ generated another argument, the so-called caveman argument, arguing that the Moon must be much bigger in size and further away from the Earth than Jupiter. Again, the PTs needed to use the model to prove HJ's argument wrong. While it was not difficult for the PTs to explain why the Moon appeared bigger than Jupiter (i.e., the Moon is closer to the Earth than Jupiter), they encountered difficulty in understanding and explaining why the Moon appeared higher than Jupiter. HJ continuously asked probing questions and guided them to use their model for explaining the observed planetary alignment as described in the following excerpt:

> HJ: Firstly, you look at your pin. During sunrise, where should you be? Put your pin in the more correct position. During sunrise. Because right now I feel that you are like in the middle of the nights. [Ellen and Vivian point at different positions on the Earth. Faith changes the position of the red pin.]
> Faith: Here?
> HJ: Ok. So are you at sunrise now? Ok. So you can see the closest to the Sun will be Mercury followed by Venus, followed by Mars, followed by Jupiter. Then you just put your Moon in the right position. So the question is, again, are you in the queue or are you outside the queue?
> Ellen and Faith: Outside.
> HJ: Outside the queue. If you are outside the queue, are you able to see all the people in the queue clearly this morning? This morning.
> Faith: I can see.
> HJ: Yeah, you can see everybody clearly, right? So if you are able to see everybody in the queue clearly, are you very close to the queue or are you very far away from the queue?
> Ellen and Faith: Far.
> HJ: You should be far away from the queue right to see everybody, right? So where is Earth's position?
> Faith: Further [Faith points at a spot which is further away. Ellen removes the Earth and pastes it on that spot] (see Fig. 16.6b).
> …
> HJ: Ah. Ok. Actually you look at this ah, and you pretend you are the pin. So you see the Sun, you see Mercury, you see Venus, you see Mars, you see Jupiter, right? Then you see the Moon, right? Ah, so all you need to do is shift the Moon a little bit.
> (29 May 2011 in EMMA III)

HJ advised them to use a red pin to represent the observer's position on the Earth in the early morning when they were observing the alignment in the sky so that the PTs could imagine their perspective from the Earth in the model. This indicator helped them to examine the planets from multiple perspectives. The PTs eventually revised and modified their model and were thus able to use their model to explain why the Moon appeared higher and bigger than Jupiter. In addition, they started to become aware of positions and motions of the planets from different perspectives. The PTs also revised the position of Saturn from the Sun (see Fig. 16.6a) to the other side of the Sun (see Fig. 16.6b) so as to explain why they could observe Saturn the night before.

Based on their learning experiences in EMMA III, the PTs further employed simulating observations (see Fig. 16.7) using software in order to create an observationally possible yet scientifically unsupportable argument. The PTs requested the workshop participants to argue against it using their model as indicated in the following excerpt:

> Ellen: Look at the picture, you can see that the Moon is further away from Earth because like this picture, the Moon is higher up compared to Jupiter. So I can infer that the Moon is actually further away from the Earth than Jupiter, is that true? Is that really true? (13 Aug 2011 in EMMA IV)

However, this initial introduction did not work as effectively as HJ's argumentation in EMMA III as described earlier. Many workshop participants in EMMA IV questioned why they were supposed to argue against something that was clearly

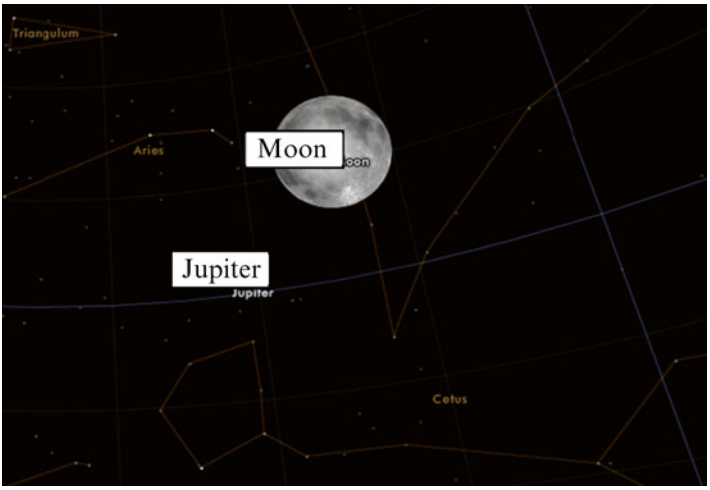

Fig. 16.7 Simulated observation picture used in EMMA IV

nonsense. One participant even asked: "If we already know the distance from Jupiter and Moon to the Earth, then what's the point of this argument?"

Facing this challenge from the participants, Santhi emphasized the use of the model in the explanation of the phenomenon. She said:

> We have a hypothesis that the Moon is further from the horizon, as you can see from the picture (Fig. 16.7), we say that the Moon is further than Jupiter, so you have to prove us wrong with the correct explanation in addition to the use of your model. (13 Aug 2011 in EMMA IV)

The workshop participants manipulated and revised their models, such as adjusting the positions of the planets so as to disprove the PTs' hypothesis. One group relied on their daily experiences in their explanation, for instance, when a big stone is thrown further away, it will appear smaller and smaller. Another group used a theory of trigonometry not only to explain how the distance of the Moon from the Earth could be calculated but also to prove that the Moon is closer to the Earth. These approaches indicate that although the PTs guided them to use their model to explain the reasoning behind the observed astronomical phenomena, the workshop participants tended to pay more attention on displaying factual information without making connections with their models explicitly.

Discussion

As shown in Fig. 16.1, in order to explore the impact of "learning through teaching" via the EMMA workshops, we have also considered both "learning through modeling" (occurring mainly in EMMA III) and "teaching through modeling" (occurring mainly in EMMA IV) with an aim to facilitate five prospective teachers (PTs) to develop a deeper understanding of the big idea of size and distance in two ways: (1) providing an authentic sky observation experience to improve the PTs' spatial knowledge and (2) offering teaching opportunities using multimodal modeling experience for reflecting on their teaching and learning experiences.

Although comparatively little research attention has been focused on the concepts of size and distance (Lelliott and Rollnick 2009), it was suggested that students who lacked observation experience posed a challenge in trying to understand it. Hence, our design-based research designed EMMA III activities (e.g., see Table 16.1) to provide our PTs with embodied experiences in outdoor environments that aimed at promoting "learning through modeling" as indicated in Fig. 16.1. For instance, the stargazing outdoor activity offered them a real-world, authentic learning setting that in turn encouraged the PTs to experience and appreciate how vast the universe is. The sizes of the planets and their distances from the Earth are not just numbers for the PTs to memorize using a fact sheet, but tools to make sense of their authentic sky observations and related astronomical phenomena. Specifically, our intention of "learning through modeling" allowed them to reflect on their sky observation experience through the construction of their own models that in turn led to improved explanatory power.

The PTs were also motivated by arguments that their mentor, HJ, intentionally created to challenge their prior knowledge (i.e., the heliocentric model of the solar system) that could not be easily explained by their authentic sky observation experiences in EMMA III. To argue against his observationally possible yet scientifically unsupportable nonsense arguments, the PTs needed to construct and use their models to prove HJ's ideas wrong through the understanding of the complex interrelationships among distances, sizes, and positions of celestial objects. This provides implications on the curriculum designs, especially in an informal learning environment where integrating observations in embodied modeling activities is considered for the PTs to visualize different perspectives and to improve spatial perception for understanding the size and distance of the 3D celestial objects.

Based on such "learning-through-modeling" experiences, the PTs effectively transformed their learning difficulties or challenges faced in EMMA III to valuable teaching moments for their workshop participants in EMMA IV. This can be referred to as "teaching through modeling" shown in Fig. 16.1. Through reflecting on their own "learning-through-modeling" experiences, the PTs endeavored to design and revise the workshop activities so that the workshop participants would face the similar learning difficulties that they had in EMMA III. The PTs also encouraged the workshop participants to construct, use, and revise their models not only by reflecting on their prior knowledge and experiences (e.g., mathematical knowledge) but also by collaborating with others.

Through such a teaching-through-modeling process, the PTs also highlighted the importance of making sense of the size and distance of the celestial objects, rather than focusing on just memorizing factual information. Hence, although EMMA IV was the PTs' very first teaching practice, the PTs had effectively integrated modeling approaches into their lesson design based on the concepts of size and distance in three ways. Firstly, they changed from lecture-oriented to a modeling-based inquiry-oriented lesson design. Secondly, their revised lesson plan implied that learning could be enhanced by the workshop participants through exploration rather than pass-over. Thirdly, the learning activities were situated in more concrete contexts. These changes showed that the PTs attempted to actively adopt what their mentors had done, especially in multimodal modeling tasks, but it is important to note that the PTs explicitly elaborated the explanatory power of modeling in their teachings as described earlier in findings. The progression in PTs' pedagogical designs of lessons implies the potential of teaching through modeling in transforming novice teachers' pedagogical orientation from traditional ways to more constructive and inquiry-based ones. In this sense, this study contributes to the professional development of science education, and future research can work on incorporation of modeling-centered teaching into science teacher education, especially for astronomy education.

Consequently, during EMMA IV, the PTs transformed their learning experiences based on the concept of size and distance into their teaching practice with an emphasis on making both size and distance on the same scale and using models to examine astronomical phenomena from different perspectives. They engaged the workshop participants through multimodal modeling activities so as to ensure learning using multiple models and to generate questions and hypotheses for explanation. Similar to our claims, some other studies (Elmendorf 2006) have also argued that students' teaching experience could facilitate their own learning process by rethinking their knowledge, reflecting on their mistakes, and maximizing their potentials. Boyer and Roth (2006) also postulated that learning is a change in the form of participation, where the participants are constitutive of the setting and they respond to and transform the resources available. In that sense, through "learning-through-teaching" experiences, the PTs transformed social and material resources not only for mediating the workshop participants' learning activities toward a deeper understanding of size and distance of the planets but also for improving their own meta-modeling, pedagogical, and content knowledge. Hence, learning through teaching is also proved to be an effective way of learning in informal contexts.

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Chapter 17

Exploring the Process of Problem Finding in Professional Learning Communities Through a Learning Study Approach

Yuen Sze Michelle Tan and Imelda S. Caleon

Abstract Professional learning communities (PLCs) have established their niche as a key driver of teacher professional learning for about two decades. Collaborative problem solving, usually in the form of reflective inquiry, has been identified as one of the key features of successful PLCs. One approach that PLCs use in carrying out collaborative problem solving (CPS) is the learning study. In using the learning study approach for CPS, two key processes are involved – problem finding and determination of the solution procedure. Noting the imbalance in the extant literature in favor of the latter, this article seeks to explore how the process of problem finding takes place, as a PLC formed by biology teachers follows the learning study model. We focused on how members of this PLC negotiate to determine the object of student learning and, in the process, find the problem that would be addressed by the team. The findings and insights that were presented in this article were drawn from multiple data sources (e.g., minutes of meetings, field notes, teacher journal entries, and teacher interviews) that detail teacher interactions in four consecutive meetings of a PLC located within a Singapore school. On the basis of our findings and the relevant literature, we formulated recommendations to facilitate problem finding of a PLC via learning study.

Keywords Professional learning communities • Collaborative problem solving • Learning study • Problem finding

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Introduction

Contemporary educational landscape that is responsive to teachers' evolving professional development (PD) needs, such as those arising from meeting the challenge of developing competencies among learners and working in education system suited for the twenty-first century, usually features collaborative social structures, such as professional learning communities (PLCs). The term "PLC" usually connotes a practice-situated PD initiative that helps build teachers', as well as schools', capacity and effectiveness to improve students' learning (Sigurðardóttir 2010). A PLC comprises a group of professionals who engage in collaborative learning activities that are guided by a common vision of implementing student-focused teaching (Stoll et al. 2006; Wood 2007). Serving as a social sphere wherein teachers can co-construct and share new knowledge (McLaughlin and Talbert 2001, Wood 2007), effective PLCs also encourage teachers to negotiate and take control of the content and path of their own PD, while they engage in a collaborative inquiry into their practice (Nelson et al. 2008; Scribner et al. 2007). Through these activities, PLCs can support not only teacher growth but transformation of knowledge, beliefs, and praxis (Nelson et al. 2008; Pella 2011; Sigurðardóttir 2010).

The effectiveness of PLCs is largely underpinned by several supportive conditions that favor the emergence of sustainable collaborative activities, which are focused on student learning. It is important for researchers, educators, and policy-makers to gain a sound understanding of the nature of these collaborative activities, including the environments in which these activities take root and flourish, so as to develop ways and means that can scaffold and enhance the likelihood of PLCs to reap their intended outcomes. In Singapore, PLCs have been increasingly gaining popularity as a means to address classroom- and school-based problems and for improving instructional practice. An investigation of the processes that take place during PLC activities would be valuable as it can help identify areas of strengths and areas that need improvement. Through a Singapore case of learning study, this research endeavor aims to contribute to the existing knowledge base on PLCs by focusing on a team of four Singapore teachers participating in collaborative problem solving (CPS). We are particularly interested in the problem finding process, which is a key aspect of CPS that has been given scant attention in the literature, especially at the group level. Noting the strong influence that the problem finding process exerts on the outcome of the problem-solving process (Lee and Cho 2007) and how this influence increases as the degree of structure of the problem decreases (Mumford et al. 1994), understanding the problem finding process within the context of ill-structured and real-world tasks, such as those experienced by teachers working together as a community to solve day-to-day classroom problems, would yield distinctive insights that may enhance the efficiency of CPS in authentic contexts.

In the context of learning study, this study aims to answer the following research questions:

1. How does a PLC, formed by Singapore biology teachers, collaboratively identify problems as experienced through the crafting of a learning object (i.e., students' capability to be developed)?
2. What are the aspects of the teachers' experiences that facilitated the problem finding process?

CPS in PLCs

CPS, which we equate with *collaborative inquiry*, has been considered as a distinctive component of successful PLCs (Hipp et al. 2008; Nelson et al. 2008). Drawing upon Jonassen's (1997) conceptualization, a problem involved in CPS can be defined as an unknown that arises from any situation in which a group has a "felt need" to fulfill in order to achieve a particular goal (p. 66). The CPS process which is carried out in school PLCs involves an ill-structured problem situation (see Slavit and Nelson 2010). In these situations, the problems are usually emergent, with unclear goals, constraints, concepts, rules, and principles; have multiple solutions (Jonassen 1997; Voss 2005); are context dependent; possess parameters that are less manipulable; and require construction of multiple problem spaces (Jonassen 1997). A problem space refers to the gap between an initial state and a goal state, along with the set of possible actions needed to move from the initial state to the goal state (Newell and Simon 1972).

Consistent with Jonassen's (1997) description of the different stages involved in solving ill-structured problems, the CPS process commences when the problem or question –"the focus of inquiry"– is explored and identified (Nelson et al. 2008, p. 3). In ill-structured problem situations, the initiation or formulation of problems, or *problem finding*, is necessary because the problem is entrenched in the information on hand (Lee and Cho 2007). As CPS participants engage in selecting the problems existing in their contexts (Nelson et al. 2008; Slavit and Nelson 2010), they also negotiate about and challenge their individual and collective assumptions (Slavit and Nelson 2010). It also needs to be emphasized that the problem finding or focusing phase usually takes place at, but not confined to, the initial stage of the process.

The succeeding phases of the CPS process comprise the planning, implementation, and evaluation of the solution procedure (Slavit and Nelson 2010), which is meant to reduce or close the chasm between the initial and goal states within the problem space (Newell and Simon 1972). The evaluation phase can take place in all parts of the CPS process and may lead to the modification of the problem being addressed. The dissemination phase is carried out after the evaluation results are found satisfactory (Slavit and Nelson 2010). As participants take part in CPS within the context of PLCs, they are likely to develop a shared understanding of pedagogical goals and issues (Roschelle and Teasley 1995), adopt an inquiry stance (Nelson et al. 2008), and forge an inclusive working culture. To enhance the likelihood of positive outcomes through CPS, it is important to have a "common ground" which serves as an anchor for participants to reconcile their multiple perspectives (Schwartz 1995).

Although the extant literature on problem solving involves a number of studies that focused on the latter phases of CPS, there is paucity of published articles that dwell on the process of problem finding (Lee and Cho 2007). The dearth of information available in relation to problem finding is more pronounced when the units of analysis are groups, rather than individuals (Reiter-Palmon and Robinson 2009), such as in relation to PLCs. We have found a few studies of this kind, but they merely involved cursory description of the problem finding stage. A pertinent example would be the research report of Slavit and Nelson (2010), which presented a thorough discussion on the implementation and assessment of CPS but included only a brief description of how participants engaged in multiple rounds of identifying the research problem. In another study, Padwad and Dixit (2008) explored how teachers perceived classroom problems and how their participation in PLCs improved these perceptions. Focusing on the problem finding process, Bray (2002) underscored some criteria for selecting problems to be focused on during CPS. Bray emphasized that the problem has to be interesting to participants, should not have a readily available solution, and has the richness to open up opportunities for participants to learn. Nokes-Malach et al. (2012) added that the problem should neither be too easy nor too difficult. Although focused on the emergence of distributed leadership during PLC meetings, Scribner et al. (2007) were able to collect empirical evidence indicating that effective problem finding, as well as problem solving, can be facilitated when the PLC group develops a collective understanding of its objectives and its members are given the level of autonomy that is appropriate for these objectives.

In enacting CPS via PLC efforts, participants usually adopt the lesson study and learning study approach. With particular focus on the planning, implementation, and evaluation of research lessons (Chong and Kong 2012), these approaches provide a common space where teachers are given the chance to collectively deal with classroom difficulties (Pang and Marton 2003, 2005) and learn through their engagement in the process.

Learning Study and CPS

The learning study is a teacher PD approach that is gaining attention worldwide (Holmqvist 2011; Runesson et al. 2011). Similar to the lesson study approach (Lewis et al. 2009; Stigler and Hiebert 1999), both approaches utilize the teachers' own classroom contexts as sites for teacher research (Borko and Putnam 1996), where pedagogical arrangements that were collaboratively determined can be tried out (Pang and Marton 2003, 2005). In promoting teacher collaboration (Runesson et al. 2011), teachers are encouraged to pool resources and knowledge to jointly tackle curricular and pedagogical challenges; in this view, learning studies provide opportunities for teachers to solve authentic problems related to their own teaching and learning.

A key feature of learning study that differentiates it from lesson study is the application of a theoretical framework to shape teachers' learning study experiences (Holmqvist 2011; Pang and Lo 2012) and to concurrently enhance student learning (Lo et al. 2006). According to Pang and Marton (2003), learning study has compensated for the lack of theoretical frame in lesson study, by adapting design experiment's (Collins 1992, 1999) idea of combining the instrumental and theory-oriented aspects of (teacher classroom) research. In a learning study, researchers or in-school consultants usually serve as resources to help teachers understand and use relevant theories of learning to frame their lessons (Holmqvist et al. 2007).

A cycle of learning study can be deemed to have five key phases that mirror the general CPS stages described above:

Problem Finding Phase (Focusing Phase)

In this phase of the learning study, the teachers formulate specific goals, consider curriculum and standards, and identify a topic of interest (Lo et al. 2006). The process of problem finding primarily includes the step of determining the *learning object*, which directs teachers to discuss and decide on what is worth tackling and what is worth for students to learn. Moving beyond helping students to master content knowledge, focusing on a learning object encourages teachers to determine the capability students are to develop through the research lessons (Marton and Booth 1997); this is premised on how learning study privileges students' development of capabilities (which may promote more "enduring" understandings) over mere content mastery, where the former promotes learning of a more meaningful and transferable nature as opposed to the latter (Erickson 2008). In the context of learning study, the object of student learning may often be derived from the teachers' anticipated difficulties in teaching various topics or from the learning difficulties students faced.

The learning object can be further understood through the identification of its critical features (Lim et al. 2011) – commonly known as critical aspects. For example, in Pang and Marton's study (2005), in order to determine the change in market price of a commodity (i.e., learning object), 16–18-year-old students can deepen their understanding of how price is determined by demand and supply and relative magnitudes of changes between the two, all of which form the critical aspects.

Planning the Solution Procedure

In this planning phase, teachers collaborate to plan the research lessons using a theory as a framework. Pretests may also be administered to students and the results may be used to guide the lesson planning. In this phase, the learning study approach assumes a certain degree of structure and partly deviates from the usual approach in solving ill-structured problems.

Implementing the Solution Procedure

This phase in CPS typically coincides with the research phase in learning study. The research lessons are implemented, with one teacher teaching the lesson while the rest of the team collects data. The lesson observations may focus on what students learned in relation to the teacher's pedagogy.

Assessing the Solution Procedure

During this phase, posttests may be administered to students. Post-lesson discussions are also conducted to discuss the research lessons and the solution procedure. Feedback to improve the delivery of subsequent lessons is also discussed.

Dissemination Phase

The last phase involves the dissemination of the research findings, along with the problem finding and formulation of solution procedure.

Worthy of mention is how previous learning studies have paid little attention to detailing the process of determining the learning object. An exception may be Holmqvist's (2011) study, where she investigated how teachers in Sweden developed an increased ability to analyze the critical features of the learning object through reiterative cycles of the learning study. Nevertheless, the process of determining the learning object, as part of a problem finding process, still presents a gap in learning study literature. As such, we deem that the process of collaborative problem finding warrants greater attention. Furthermore, previous studies have underscored clear goals – such as the learning object – as being crucial to teachers' positive competence development (Seidel et al. 2005).

Methods

Singapore Case of Learning Study

The Singapore case of learning study is situated in the context of four Grade 9–10 biology teachers collaborating to plan and teach new genetics content in the curriculum; the learning study was supported by a researcher-facilitator (first author). The teachers taught in an independent school comprising high ability students. The school and teachers were chosen due to their availability. The school had an ongoing teacher PD program where an hour a week was allocated for teachers to collaboratively plan, teach, and evaluate the lessons as a way to improve teaching practice. Thus, the teachers welcomed the learning study as a potential PD approach they could participate in during the allocated hour, as supported by the school leaders. The teachers had varying teaching experiences: both Amy and Pam taught biology for 3 years (total years in teaching), while Chris taught biology for 5.5 years (out of a total of 14 years) (names are pseudonyms). Kate taught biology for 7 years (out of a total of 15 years). The four teachers belonged to the same PD group as organized by the school leaders; this was based on the subject and grade levels taught. Although this was the first time the teachers participated in a learning study, the teachers often worked together as a team as they functioned as the biology department. Nevertheless, the opportunities to deliberately collaborate to promote teacher PD were mostly confined to the allocated PD hour.

The teachers wanted to address the challenges in working with a new genetics curriculum; the new content constituted a 6-year cycle by central authority to develop, implement, and evaluate new biology curriculum. In view of the importance of genetics to everyday life and to scientific literacy, this new curriculum included new aspects of genetics that may be unfamiliar to teachers.

In the context of a learning study, the teachers participated in the process of problem solving as detailed in the previous section, namely, the problem finding (determination of learning object) and the planning, implementation, evaluation, and dissemination of the solution procedure. This paper focuses only on the problem finding phase.

Consistent with previous learning studies (e.g., Pang and Marton 2003, 2005), we implemented a learning study model that included the introduction to the theory of variation. The theory was introduced as offering a perspective to learning during the problem finding phase and in the latter stages of the learning study process. Through this theory, learning can be appreciated as increasing one's capability to experience a learning object in more advanced or complex ways than before (Marton and Booth 1997), the demonstration to identify critical aspects about the learning object. Simultaneously, how the theory served as a pedagogical theory and tool (Elliott 2012; Pang and Lo 2012) was underscored, where the theory underpins the design of *patterns of variation and invariance* (see e.g., Pang and Marton 2005). In designing these patterns, aspects that are varied can be brought to the attention of the students, while the rest of the aspects are kept invariant and thus relegated to the background.

Data Collection and Analysis

Employing *interpretative case study* (Merriam 1998) as the method of inquiry, the analysis of the study entailed the construction of a narrative description of the meetings and a thematic approach to data analysis (Creswell 1998; Miles and Huberman 1994). With the intent to explore and theorize about the phenomenon

(Fernández 2010) of how teachers experienced the process of problem finding in a learning study, a range of data were collected and simultaneously analyzed (Merriam 1998; Miles and Huberman 1994). The multiple sources of data served as a source of triangulation (Lincoln and Guba 1985) to establish credibility of the findings. Our attempts to guard against bias and ensure reliability of the findings included our regular engagements in in-depth discussions of the analysis and constructed themes: this approach allowed for a collective and consensual interpretation of the data set to be developed (Corbin and Strauss 1990; Stake 1995). In drawing from the researcher-facilitator's own notes, the interpretations made were also often questioned by the second author of the paper, who also served as a critical friend (Lincoln and Guba 1985).

The findings presented in this chapter were drawn from a larger study that examined the personal learning experiences of teachers who participated in a learning study (Tan 2014a, b; Tan and Nashon 2013). The learning study lasted 22 weeks and comprised 11 meeting sessions (total of 12 h), four post-lesson discussions (total of 4 h), and eight lesson observations (total of 10.5 h). In this chapter, we analyzed a portion of this data collected. We included 4 h of audio-video recordings of four meetings, during which the problem finding process took place; 12 transcripts of semi-structured interviews with individual teachers (approximately an hour each) that detail their experiences before and after the learning study; teachers' reflective journal entries; and minutes of meetings, field notes, and the researcher-facilitator's own notes.

A narrative description was constructed based on the following. First, audio-video recordings were viewed in tandem with the reading of the researcher-facilitator's field notes. This stimulated recall and allowed for a chronological account of the events that took place in the meetings to be constructed. Second, thorough reading of interview transcripts and journal entries (teachers' and the researcher-facilitator's) was carried out; this guided the researcher-facilitator's interpretations of the events that occurred and allowed her to check her own interpretations against that of the participating teachers. In other words, the data set was triangulated to construct the narrative descriptions. Whenever necessary, relevant excerpts from the interview transcripts and journal entries were presented to anchor and enrich our descriptions and interpretations of the significant events during the meetings.

The subsequent thematic analysis (for details, see Miles and Huberman 1994; Tan and Nashon 2013) included the following:

> Selection and reduction of data, with the constructed description and data set read reiteratively and alongside each other, and relevant parts that depicted the teachers' experiences of problem finding were marked.
>
> Construction of themes through a search for recurring regularities in words, phrases, meanings, relationships, and patterns from the marked parts of the data.
>
> Verification of themes by checking them against other data sources, and adjustments were made whenever necessary.

Results and Discussion

A narrative description, organized in terms of four consecutive meetings, is presented to provide details of the problem finding process the teachers have experienced. This includes the challenge teachers faced in finding the problem, exploration of strategies to overcome the challenge (through the application of theory of variation and determination of curricular flow), and the subsequent identification of the problem. The thematic analysis also surfaced two aspects of teachers' experiences that supported the problem finding process, namely, a meaningful engagement with the curriculum and teacher ownership and empowerment. The former underscores the need for teachers to develop collaboratively a more holistic approach to the curriculum in order for shared meanings to emerge. The latter emphasizes the importance for teachers to take ownership of their own problem finding process.

Experiencing Problem Finding Process via Learning Study

Meeting 1: Challenge in Finding the Problem

At the beginning of the session, teachers were introduced to the notion of a learning object and were shown examples of learning objects from different research studies (e.g., Pang and Marton 2003, 2005). In order to help teachers reflect on teaching genetics, they were given a short questionnaire to fill up. The questionnaire was intended to help teachers explore their views on student learning genetics and their teaching of the topic. For example, it probed for what teachers thought were important outcomes of teaching and learning genetics – "are the outcomes of teaching genetics expressed in terms of students learning *more* or different content?" The questions were adapted and modified from studies of Koballa et al. (2005), Samuelowicz and Bain (1992), and Trigwell and Prosser (2004). In order to further engage the teachers, they were also provided short notes of previous research studies that highlighted the challenges of teaching and learning genetics (based on Duncan and Reiser 2007).

Although the teachers were provided the genetics questionnaire and research literature to guide their exploration of the challenges in teaching genetics and thus to facilitate the problem finding process, it appeared that they were having difficulties coming to a decision on what problem they wanted to work on. In the interviews, the teachers described this difficulty as a frustration (Kate's interview transcript), where they felt like they were "going around in circles" (Pam's interview transcript). According to the teachers, as expressed through the interviews and reflective journal entries, they faced two challenges in trying to determine the learning object. Firstly, the teachers highlighted the difficulty in teasing out the pedagogical and curricular problems embedded within the genetics unit: the teachers indicated that “genetics was a huge topic” – “spanning across six chapters” in their textbooks (Pam’s interview transcript). It is also our belief that the teaching and learning of genetics is fraught with other challenges (Duncan and Reiser 2007), such as students’ confusion and the concomitant need to approach genetics at different levels (macro- and microlevels; chromosomal, DNA, and gene levels), and the time gaps in teaching different genetic subtopics. We believe that these exacerbated the lack of clarity in identifying a problem.

The new experiences in the learning study constituted the second challenge. During the interviews, the teachers constantly mentioned about how they were unsure of the scope and depth of the details to include (Amy’s interview), especially since they were teaching the new genetics content for the first or second time. Moreover, the idea of determining a learning object runs counter to how “we often focused on curricular content instead” (Kate’s interview transcript). In other words, the teachers attributed the challenge of finding a problem to their unfamiliarity with what a capability was. As described by Pam in the interview:

> “… I know we were quite stuck initially… at the end of the first session or something like that, I still wasn’t very clear on what we were going to focus on”. Similarly, Kate described the experience as follows: “I thought it was a bit of a stalemate sitting there and don’t know what was going on”, resulting in them feeling “a lot more frustrated” (Kate’s interview transcript).

Meeting 2: Strategies to Overcome the Challenge – Introducing Theory of Variation

With the intent to encourage new ways of thinking about teaching practices and student learning, the *theory of variation* (for details, see Pang and Marton 2003, 2005) was introduced in this meeting. In accordance to the learning perspectives provided by the theory of variation, what was emphasized to the teachers was that learning can be seen as increasing one’s capability to experience a learning object in more advanced or complex ways than before (see also Marton and Booth 1997). The increasing complexity can be appreciated as the learner discerning and simultaneously holding in his/her focal attention more critical aspects of the learning object or phenomenon studied than before; these critical aspects are identified as aspects that are crucial to mastering the learning object or understanding the phenomenon, and may be constituted by what the learner could focus on or the meanings ascribed to a particular way of experiencing the learning object. It was also highlighted to the teachers how the theory serves as a pedagogical theory and tool (Elliott 2012; Pang and Lo 2012) to support the problem-solving process. Patterns of variation and invariance could be designed with the view that critical aspects that are varied will come to the attention of the learner while other aspects are kept invariant. These patterns draw the learner to aspects that he/she is unaware of previously, and the consequent discernment of these aspects may promote learning. Examples of *patterns of variation and invariance* employed in different learning studies were provided, such as those that focused on promoting students learning in economics (Pang and Marton 2003, 2005) and physics (Linder et al. 2006). It is worth noting that a genetics example was not included as it was not available then; thus, the teachers were provided other examples.

The introduction of the theory of variation was intended to help explore possible critical aspects and clarify a learning object the teachers might have in mind, but were not able to fully articulate and describe. In this case, rather than focusing solely on the variation, it was hoped for that teachers could develop an understanding of what critical aspects were in relation to how they constitute the learning object, prior to how these aspects may be varied. The hour-long meeting provided enough time only for the introduction of and discussion about the theory. Thus, an in-depth discussion concerning the learning object did not take place. Rather, the teachers were provided with readings (e.g., Pang and Marton 2003, 2005) that could help them further clarify the relationships between critical aspects and learning object.

Meeting 3: Strategies to Overcome the Challenge – Determination of Curricular Flow

With the intent to provide teachers with additional resources and to facilitate the problem finding process, teachers were provided with examples of how their own teaching experiences and knowledge, coupled with the use of research literature and theory of variation, can be drawn upon to help determine the critical aspects of the learning object. A case illustrating how the exploration of the "parts" of a problem (critical aspects) could be used to construct the "whole" (learning object) was presented to the teachers. Although the time gap between Meetings 2 and 3 is short (a week), this activity in the meeting was designed with the intent of giving teachers more time to explore the theory. However, it was not the expectation of the researcher-facilitator for teachers to fully grasp the theory at this point. Rather, they may begin thinking about the challenges in teaching genetics in terms of critical aspects and object of learning.

The teachers were then encouraged to employ this "new strategy" of using the critical aspects to help determine the learning object. Contrary to the intention of the researcher-facilitator, it appears that trying to get the teachers to explore possible critical aspects could have confused them further, rather than to help clarify the problem; it was observed through the audio-video recordings and documented in the researcher's notes that the teachers seemed to have problems discussing in terms of "critical aspects." Recognizing that this could be attributed in part to the "newness of thinking in terms of critical aspects" (Kate's interview transcript), the teachers' interview transcripts also suggest that the difficulty lies in how they were facing difficulties navigating through the "parts" because they have not grasped a sense of the "whole." In other words, the teachers faced the challenge of making sense of the whole-part relationships embedded within a problem they could work on. This suggestion also draws its support from the event that followed.

Emerging from the sense of “frustration” (Kate’s interview transcript) was another strategy the teachers proposed to try. In abandoning the intent to determine the learning object then, the teachers suggested exploring the whole genetics unit instead. The teachers started to write on Post-it® notes the different key topics spanning across the six genetics chapters and proceeded to stick them onto a large piece of paper. The teachers began to link different subtopics in the textbooks, e.g., linking the topic of hereditary with mutation, genetic engineering as a “stand-alone” chapter, and linking mitosis and meiosis with cell division. The links were articulated verbally (captured in the audio-video recording). Moving the pieces around, the teachers started to situate new genetics content onto their maps and proposed linking structure of genetic entities (chromosomes, DNA, and genes) with the processes of transcription and translation (new genetics content). The mapping process (Åhlberg et al. 2005), as a way to determine the sequence of the subtopics, thus seems to have directed the teachers’ conversations to the relationships between the different subtopics. As described by Chris in the interviews, he felt that the activity prompted the determination of the flow of subtopics based on these relationships rather than the order presented in the textbook.

The teachers anticipated pedagogical and learning challenges associated with the different subtopics through the mapping process. They also discussed different curricular problems even as they explored different possibilities to sequencing the subtopics, such as potential gaps in understandings or difficulties in rearranging the predetermined scheme of work. In rearranging and re-sequencing genetic subtopics differently from the prescribed curricular materials, the mapping process also granted teachers opportunities to discuss and defend their suggestions. What emerged appears to be a new way in which the teachers could approach the problem finding process, which they termed the “determination of curricular flow.” The teachers pooled their resources and teaching experiences (manifested in how they drew from these experiences to anticipate challenges and establish links between the subtopics) and quickly established consensus without much tension as to what they would tentatively like to focus on in terms of the object of learning. As observed in the video, all the teachers contributed to the discussion without clear directions from any one member of the team. In fact, when prompted to share about their experiences of determining the curricular flow, the teachers expressed appreciation that the process constituted a good and “new” experience (Kate’s interview transcript) to help organize student learning experiences – “the mapping was good” in helping to explore “other possibilities” (Chris’ interview transcript). Similarly, the teachers all expressed appreciation for the opportunities to collaborate in this way and to “see another person’s point of view” (Pam’s interview transcript).

Meeting 4: Problem Found

The teachers proposed to further their discussion on the curricular flow, rather than proceeding to define the learning object; in differing from the researcher-facilitator’s suggestion, this was documented as a “critical incident” where the researcher-facilitator felt that the teachers were beginning to take greater ownership as to what they wanted to do in the allocated time. Jointly, the teachers identified students' potential difficulties in understanding the structural relationships between genetic entities (e.g., genes, DNA, and chromosomes), as well as the relationships between the structural and functional aspects of these entities; these were subsequently documented in the meeting notes. How these difficulties may be further amplified in their students' struggle to link the structure of genes to genetic processes of transcription and translation and to real-life genetic phenomenon (e.g., mutation) was also discussed.

After the prolonged discussion that comprised active contribution of perspectives from all members of the team, the teachers decided to work on what they felt was a fundamental aspect of learning genetics, in other words, the development of a "fundamental capability" that would eventually help the student better understand the different genetic subtopics (Kate's interview transcript). The teachers identified the process of gene expression (including the processes of transcription and translation) as the topic of interest and began crafting the learning object around it. They decided that the learning object would be the development of students' capability to understand and apply the principles of the genetic processes of transcription and translation (new curricular content) to real-life contexts, such as mutation. What is worth mentioning is that the newly identified link between the genetic processes and mutation was established through the application of the theory of variation. As highlighted by the teachers when they were prompted to share about the usefulness of the theory of variation, the teachers made mention of how the theory helped them link the genetic processes of transcription and translation to mutation, a "missing link" (Kate's interview transcript) they would otherwise have failed to pay attention to especially since the two subtopics were taught at different grade levels. According to the theory of variation, varying the genetic processes results in cascading changes (varying gene structure and thus the products of these processes) that may eventually lead to mutation. With this pattern of variation crafted, the teachers (preliminarily) identified the critical aspects of the learning object as the structural and functional relationships between genes, DNA, and chromosomes.

In this context, the teachers applied the variation theory to help organize curricular content, rather than as a learning theory or a pedagogical tool (as reviewed earlier). In addition, the identification of this "missing link" that the teachers focused on subsequently led to the determination of the learning object: in wanting to help students develop the link between the genetic processes and mutation, they articulated the importance of students applying the principles of the genetic processes to help understand genetic phenomenon such as mutation. What is also noteworthy is that the collective identification of this missing link, which the teachers also termed as a "fundamental capability," allowed them to reach an agreement on what the learning object would be. This was observed in the audio-video recording and has been supported by the interview transcripts, where all the teachers mentioned about the importance of this capability to help students learn genetics. The teachers expressed this idea in terms of "stones" and "foundation" necessary for students to "fill in the gaps" in genetics (Kate's interview transcript). During the meeting, the teachers also expressed their readiness to proceed with the next phase of the learning study when they began discussing how the lessons could possibly be structured. As a result, other possible problems teachers could have worked on were not further explored, thus differing from typical problem finding processes.

Using CPS terminologies, the aspects of the problem that were identified by the teachers when they participated in the learning study can be described as follows. The initial state corresponds to the condition when students experience conceptual difficulties in relation to the genetic processes of transcription and translation, with a particular focus on their nature and real-life applications. The goal state (i.e., the learning object) refers to the development of students' capability to understand the genetic processes described, along with their practical applications. The elements of the problem space that were highlighted include the linkage among and sequencing of curriculum topics, knowledge of students' difficulties, gaps in students' understanding, literature on genetics, and theory of variation.

Facilitating Problem Finding

Drawing from the narrative descriptions above, two themes that emerged from the authors' analysis further explicate the problem finding process and underscore possible modes of action to facilitate teachers' problem finding process: meaningful engagement with the curriculum as a strategy to attain clarity of the problem and teachers taking ownership of their own problem finding process.

Meaningful engagement with the curriculum during the problem finding process. What was evident in the teachers' experiences of the problem finding process was that the opportunity to determine the curricular flow was pertinent in enabling the teachers to clarify the problem they wanted to work on. As demonstrated in the teacher interviews and reflective journal entries, the teachers identified three ways whereby the curricular flow contributed to the determination of the learning object:

1. The discussions enabled the teachers to gain a "more holistic picture" (Amy's reflective journal entry) of the genetics curriculum and the associated challenges.
2. The teachers valued the opportunities to identify the key topics and the links between them and thus articulate often tacit links – "looking at big picture and looking for links between sub-topics was important" (Kate's reflective journal entry). In addition, the teachers appreciated how the discussion allowed for the identification of links that they themselves did not make.
3. The teachers appreciated the opportunities to discuss student learning difficulties and the difficulties in teaching various aspects of genetics, such as helping students link the structural and functional aspects of genes.

As seen from the above, it appears that the opportunity for meaningful engagement with the curriculum (Clandinin and Connelly 1992) supported the problem finding process by allowing teachers to gain a better understanding of the problem. For one, the determination of curricular flow encouraged teachers to carefully study the genetics curriculum. Moreover, pedagogical challenges, such as students' difficulties in learning genetics and the difficulties in teaching aspects of it, were situated within the larger frame of the entire genetics unit that was mapped. In other words, the teachers identified possible gaps in students' existing knowledge and competencies in relation to specific genetic concepts and capabilities that teachers intended to develop among students; the cause of this gap, or the "cause of imbalance in functional operations" (Ramirez 2002, p. 19), was students' difficulties in dealing with structural and functional aspects of genetic concepts.

Furthermore, mapping of the curriculum could have served as a "common ground" (see Schwartz 1995) for the teachers to situate their subsequent discussion of the problem. The construction of the links between the subtopics embodies what Schwartz described as "shared representation" (1995, p. 349), which acted as a catapult that allowed the problem finding process to take off. By focusing on the links between the subtopics and by engaging in a discourse that require them to explore, suggest, and defend their suggestions of how to sequence the topics, the teachers also began situating difficulties in students' learning in the prescribed arrangement of topics in the curriculum. For example, the teachers highlighted that teaching mutation together with the topic of inheritance may result in students lacking the ability to understand the phenomenon of mutation in terms of its processes. Reordering the prescribed sequence in the textbook, they decided to link mutation with gene expression instead. Examining the interconnection among topics was also emphasized by Ramirez (2002) as an important step in the problem finding process of teacher teams. What has been observed in this study, but was not detailed by Ramirez's, is the importance of going beyond commonly known links which may be found in textbooks to identifying "nonexistent" and yet essential links.

Thus, the "more holistic picture" that the teachers frequently mentioned may be understood as the opportunity to situate pedagogical and curricular challenges into (1) the context of teaching particular topics, (2) the larger context of the genetics curriculum, and (3) the context of their own classrooms, where their prior experiences and knowledge of their students serve to further clarify the challenges in teaching. Seen in this light, the teachers' experiences are a manifestation of how they have meaningfully engaged with the genetics curriculum. Phrased differently, what is suggested is that the process of problem finding is not merely the identification of a problem, but that it requires a process of meaning-making, to be able to tease out the pedagogical and curricular problems embedded within and to situate it in multiple contexts that affect the complex process of learning (see Clarke and Hollingsworth 2002). Consequently, this process of collaborative meaning-making promotes building of a common knowledge base that could potentially enhance the "synergistic benefits" (Nemeth and Chiles 1988, p. 53) from the collaborative problem finding process, a knowledge base situated within the teachers' own classroom contexts.

Although the narrative descriptions are presented in a linear fashion, the teachers' need to revisit the curricular flow in two sessions – including the need to revisit various discussions reiteratively in order to gain a "more holistic picture" – suggests the *complexity* of the problem finding process. Furthermore, as demonstrated above, teachers are required to simultaneously hold multiple aspects of an approach to curriculum in their focal attention when engaging in problem finding: these include establishing links of explicit (as suggested in prescribed curriculum materials) and implicit (new and often unarticulated links) nature, situating different subtopics within the larger curricular unit, identifying student learning challenges within the topics, as well as negotiating a discourse where varied views can be examined. Following up on the latter, the learning study discourse has allowed for the diverse views of the teachers to be discussed and negotiated – as was noted by Reiter-Palmon and Robinson (2009) – which promoted further sharing of the views among the team (as was also noted by Nemeth and Chiles 1988) and the development of a deeper understanding of the possible problem to address (see also review of Chiu 2008). For example, the participating teachers had varied opinions on what was a problem worth tackling. Some of the teachers wanted to work on gene expression, while others on the newly introduced topic of cell division (including the processes of mitosis and meiosis); the teachers had different assumptions as to what students struggled with in learning genetics. As the teachers mapped the curricular flow and continued to engage in discourse, the integration of varied conceptualizations of the possible problems "provided us [them] with a holistic view of the problem" (Kate's reflective journal entry). As illustrated, the teachers' efforts to create a point of convergence in their diverse ideas about the problem to be tackled by the team widened the common ground among the team members, an aspect crucial in the success of a collaborative process (Nokes-Malach et al. 2012; Roschelle and Teasley 1995). The foregoing points also resonate with Jonassen's (1997) view that identifying problems in ill-defined real-world situations requires consideration of alternative views and analysis of the broad range of knowledge situating the problem.

Teacher Ownership and Empowerment

It is interesting to note how the teachers overcame the challenges of defining the learning object and took charge of the problem finding process, that is, by suggesting the alternative strategy of approaching the genetics curriculum as a whole. The demonstration of teacher ownership and empowerment in the problem finding process situated in the present study resonated with Kincheloe and Steinberg's (1998) assertion of the importance for teachers to engage in the development of their own knowledge. We have seen how the teachers developed their own knowledge through a meaningful approach to the curriculum (discussed above). Similarly, teacher empowerment is also manifested in how a meaningful approach to curriculum also frees the teachers from being "disempowered in their role as information delivers, servants of knowledge and curricula produced elsewhere" (Kincheloe and Steinberg 1998, p. 13). In developing their own knowledge, it appears that the collective interpretations of the curriculum and its associated challenges that emerged allowed for an internalization of the curriculum. This manifested in how the teachers were able to subsequently explain the rationale for choosing the learning object and for the final sequence of the genetic topics. In other words, the teachers were better able to defend their decisions rather than basing it on decisions made by someone else.

Conclusions and Implications

The findings of this study serve as an exemplar of how teachers engage in collaborative problem finding (which is a key part of CPS process) in an authentic setting. We have found that problem finding implemented within PLC initiatives and via the learning study approach is a challenging process that can be streamlined by meaningful engagement with the curriculum and by developing conditions that favor teachers' sense of empowerment.

Teachers' meaningful engagement with the curriculum may be a pertinent aspect of a productive problem finding process within PLCs. In teasing out the pedagogical and curricular challenges associated with teaching a particular unit and then resituating these key barriers in developing targeted capabilities back into the contexts of the larger curriculum, as well as into the contexts of the teachers' own classrooms, teachers can develop their abilities to negotiate meanings and commit to a learning object. The mapping of the curricular flow also afforded the construction of a common knowledge base through a negotiation and amalgamation of the differences in varied assumptions. This common knowledge base was augmented by the researcher-facilitator's presentation of the theory of variation. Noting that the employment of a theoretical framework is a hallmark of learning study, it can be surmised from the results of this study that elements of learning study can be blended with CPS structures in order to promote efficient problem finding and, perhaps, the entire CPS process. This assertion is in consonance with Laughlin et al. (2003) that underscores the importance of having common knowledge resource to enhance the probability of good team performance in carrying out CPS.

In promoting greater teacher autonomy and empowerment (Carr and Kemmis 1996; Kincheloe and Steinberg 1998) in the context of problem finding, a meaningful discourse around the curriculum may well be an effective platform for teachers to explore their beliefs pertaining to the problem to be addressed. In concurring with the view that teachers must be convinced of the importance of new aspects of teaching (e.g., a problem-solving strategy) to their daily teaching practices in order for them to take an interest in acquiring a knowledge or skill (Abd-El-Khalick and Akerson 2004; Martín-Díaz 2006; Schwartz and Lederman 2002), we make our proposition: the opportunities for teachers to make sense of the problem through mapping (1) *their* own assumptions, (2) *their* collective understandings, (3) *their* own knowledge derived from research literature, (4) *their* situated knowledge about their own students and classroom contexts, and (5) *their* understandings of the pedagogical and curricular challenges onto a learning object may well serve as the necessary motivation for teachers to be engaged in CPS in more empowering ways.

The results presented in this article offer microlevel insights into the process of collaborative problem finding in authentic contexts. We acknowledge, however, that these results, which are based on a single case study, have limited generalizability and applicability. Noting the complexity and challenges faced by a team of teachers during problem finding as part of a learning study and in view of the lack of extant literature explicating this aspect, more studies detailing how teachers craft the learning object and the challenges faced are certainly worthy of pursuit. In the same vein, more empirical studies need to be carried out to further understand how the formidable process of problem finding in collaborative teams can be facilitated and how different aspects of this process influence the quality of solutions generated during CPS. Another potentially fruitful research direction that would serve as a good follow-up to this study is the determination of ways and creation of environments that foster teacher empowerment, in such a way that teachers become more equipped and prepared to take control of the trajectories of their own PD and make it responsive and relevant to the needs of twenty-first-century learners.

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Chapter 18
Problem-Solving of Teacher-Generated Classroom Management Cases in Wiki-Based Environment: An Analysis of Peers' Influences

Choon Lang Quek and Qiyun Wang

Abstract This study reports a case of findings from a group of 24 learners also beginning teachers (BTs), engaged in discussion with peers to solve classroom management cases in a wiki-based environment supported by Learning Activity Management System (LAMS®). Specifically, it investigates how peers contribute to these learners' problem-solving of classroom management cases. Using the question prompts designed in the wiki, these learners who came from 10 secondary schools were scaffolded in their case discussions related to problem identification, strategy proposition, and making decision for their own case solutions. These learners' online scripts were analyzed qualitatively and quantitatively to explore peers' influences on the learners' case-based learning. A summary of the learners' and peers' problem-solving behaviors was presented. To confirm the peers' influences on learners' case-based learning, the frequency of problems identified, strategies proposed, and strategies accepted by learners and their peers were further analyzed using *t*-test and hierarchical regression analysis. Based on the results, implications and recommendations for future research in designing collaborative wiki-based learning environments were proposed.

Keywords Beginning teachers (BTs) • Cases • Classroom management • Peers' influences • Problem-solving • Wiki-based environments

Introduction

The fast changing global landscape in the twenty first century has brought about the exigent need to build learners' critical thinking and problem-solving skills in dealing with growingly ambiguous and complex real-world problems. In response, educational systems across the world have put more and more emphasis on the

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development of the twenty first century competencies among learners. In Singapore schools, the twenty first century competencies were defined to encompass three domains (Ministry of Education [MOE] 2010), namely, cognitive competency (critical and inventive thinking), intrapersonal competency (civic literacy, global awareness, and cross-cultural skills), and interpersonal competency (information and communication skills). In order to nurture learners' twenty first century competencies, a redesigning of existing didactic classroom practices that often lack authentic learning contexts and learner-centered pedagogy to solve real-life ill-structured problems is needed so as to give more emphasis on learners' self-regulated learning processes and co-construction of knowledge with peers (Hogan and Gopinathan 2008). In this respect, case-based learning, being one variation of authentic learning approach, was growingly recommended as effective in promoting learners' twenty first century competencies. Authentic learning refers to the type of learning that is seamlessly embedded in the real-life context (Jonassen et al. 2008). By solving authentic real-life cases with peers, learners were more likely to engage in critical and reflective thinking, collaborative knowledge building, and self-regulation and thereby develop transferrable twenty first century competencies (Brown et al. 1989; Hmelo-Silver and Barrows 2008).

Designing authentic learning activities such as engaging in peer learning to solve real-life problems in the technology-enhanced learning environments is found to be one of the effective approaches used in teacher education. Through peer learning, learners can receive peer feedback, restructure ideas through mutual discussion, promote higher levels of thinking, and co-construct knowledge with peers (Black 2005; Brown and Duguid 1993; Vygotsky 1978). This study thus sets out to investigate how peer learning influences the learners' problem-solving of classroom management cases in a wiki-based environment in Singapore teacher learning context.

One of the challenges confronting beginning teachers (BTs) with less than three years of teaching experience is solving daily encountered classroom management problems (Doyle 1986; Evans and Tribble 1986; Evertson and Weinstein 2006; Jones and Jones 1998; LePage et al. 2005). Classroom management problems cover a wide variety that may no longer be best perceived as disciplinary problems only but also include problems such as how to best support instruction and handle teacher-student relationship (Piwowar et al. 2013). Previous research consistently highlighted that BTs are generally unprepared in dealing with the unpredictable nature of classroom management. To successfully solve classroom management problems, BTs should be at least equipped with problem-solving skills and situated knowledge of classroom management (Choi and Lee 2008; Harrington et al. 1996). Simply teaching decontextualized strategies listed from textbooks to BTs was found to be ineffective because BTs become confused and encounter difficulties in applying their learning to real classroom setting (Choi and Lee 2008, 2009; Lee and Choi 2008). To support BTs' growth in this respect, case-based pedagogy, as one variation of authentic learning, is deemed effective in that it can bridge the gap between the theory and practice (Flynn and Klein 2001), facilitate BTs' application of knowledge to real-life classroom settings (Choi and Lee 2009), and build advanced tacit knowledge and expertise that is difficult to achieve using didactic instruction (Wang 2002).

Learning classroom management through solving teacher-generated classroom management cases provides even more authentic and efficient learning pathways for BTs (Choi and Lee 2008; Silverman et al. 1994). Teacher-generated classroom management cases often emerge from real classroom incidents that are encountered and reported by teachers. Those cases allow BTs to gain an insight into their peers' problem-interpreting, solution-brainstorming, and decision-making processes. Such situated and inquiry-oriented learning experience will expedite BTs' transition to teaching and professional development in a short term that may otherwise need several years' teaching experience to evolve (Harrington et al. 1996; Kim and Hannafin 2009).

The development of technology-enhanced case-based learning environment design creates new potential for the case-based pedagogy in that it supports interactive peer learning process (Heitzmann 2007). Peer learning refers to the use of instructional strategies in which students can learn with and from peers without the teacher's direct intervention (Boud et al. 1999). Although several studies have reported the benefits of researcher-developed online case-based learning environments in assisting teachers' learning (Choi and Lee 2008, 2009; Kim and Hannafin 2008, 2009; Lee and Choi 2008), very few, if any, studies have specifically examined the influences of peer learning in shaping learners' case-based learning quality in the wiki-based environment. Furthermore, most of the existing technology-enhanced, case-based authentic learning design research has been conducted in the Western context; few similar studies have been conducted in the Asian context such as Singapore. Since technology-enhanced case-based learning activities may be designed, implemented, and accepted differently in different cultures (Barab et al. 2000; Chen et al. 1999), therefore in this study, we intend to investigate how peer learning in a wiki-based environment influences Singapore BT learners' problem-solving of classroom management cases.

Literature Review

Classroom Management and Technology-Enhanced Case-Based Learning

Classroom management is a multifaceted construct. It refers to teachers' actions that aim at managing students' behaviors to foster students' academic, social, and emotional learning inside classrooms (Evertson and Weinstein 2006). Specifically, it encompasses the actions such as establishing and maintaining orderliness, offering effective instruction, handling misbehaviors, attending to students' emotional and cognitive needs, and managing group processes (Emmer 2001). Classroom management is a major domain of teachers' expertise that contributed to effective teaching and student learning (Brophy and Good 1986). Many studies indicated that successful classroom management can enhance students' learning by positively influencing their attention, engagement, and motivation (Wang et al. 1993). Despite its importance, in reality, classroom management is continuously being rated as the most difficult aspect for BTs. Classroom management skill is not a gift that bestowed on some teachers. Conversely, it is adaptive expertise that needs long-term reflection and practices on the part of the teachers to develop.

Classroom management problems are ill-structured in nature (Doyle 1990; Lee and Choi 2008), and they are complex and heterogeneous that no direct solution can be found from books (Choi and Lee 2008). To improve BTs' competence in this aspect, technology-enhanced case-based pedagogy is suggested as an effective instruction method in that it can help BTs see the meaningfulness and relevance of what they learn and facilitate knowledge transfer by contextualizing knowledge in authentic situations and contribute to the development of real-life problem-solving skills that is difficult to convey using traditional didactic instruction (Choi and Lee 2009; Flynn and Klein 2001; Wang 2002). In addition, technology-enhanced case-based learning environments can provide rich and meaningful learning platforms where BTs could vicariously experience real-life dilemmas that other teachers have faced when managing classrooms. BTs are prompted to articulate justification for improvement in their cases by linking relevant educational theories with practices. They are provided with the opportunities to envision and articulate their thinking, seek for peers' feedback, and plan for real-world teaching. By engaging BTs in such active inquiry, they can construct active knowledge and develop into critical thinkers and problem-solvers.

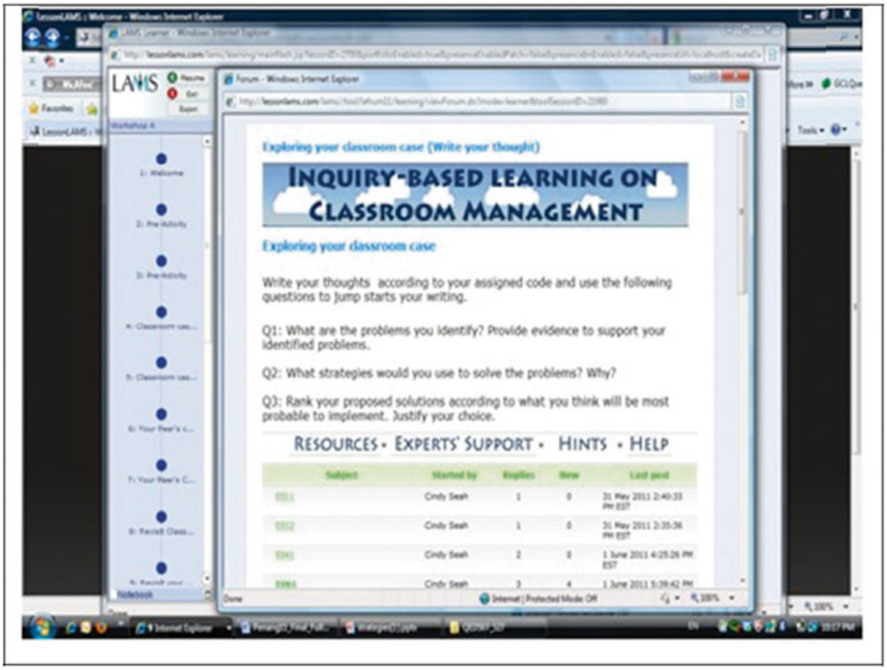
Peers' Influences and Wiki-Based Learning

The topic of peers' influences in online learning is well discussed in the literature (Allen 1973; Black 2005; Greene and Land 2000; Harasim 1990). Peers' influences in this study are conceptualized as the learning that takes place between two individual students when they go through the peer learning that is designed in our technology-enhanced case-based learning environment. Peer learning refers to the use of instructional strategies such as student-to-student learning partnership and peer feedback in our case-based learning activity design where students can learn with and from peers without the teacher's direct intervention (Boud et al. 1999).

Peer learning is suggested to be more effective than traditional instructional approaches in fostering some transferable and lifelong learning skills such as teamwork, critical enquiry, reflection skills, and interpersonal skills (Johnson et al. 1991; Slavin 1990). It can help learners construct knowledge more actively (Harasim 1990). It can enable learners to have access with multiple perspectives, restructure their ideas through discussion, and acquire new skills from peers (Black 2005). It can facilitate the development of learners' problem-solving and higher-level thinking skills by allowing learners and peers to offer suggestions, negotiate ideas, and share experiences (Greene and Land 2000).

Although the influences of peer learning to the learners' achievements have been documented in computer-supported collaborative learning (CSCL) literature, little is known about its role in the online case-based learning environments. Most existing studies are concerned with reporting how case-based online learning environments as a whole helped develop their students' skills in specific areas, and little is known about the peers' contribution to such learning process. Very few, if any, studies have specifically examined the influences of peer learning in shaping learners' online case learning capability. The purpose of this exploratory study was to fill this gap by examining how peer learning during the problem-solving of classroom management cases in a wiki-based environment contributes to the learners' learning.

Wiki is a web technology that allows a web site or document to be constructed and edited collaboratively. The potential of wiki as a knowledge construction tool through collaboration with peers is well supported by the literature (Brown 2012; Coutinho and Bottentuit 2007; Hew and Cheung 2010; Voorn and Kommers 2013). Given to wiki's various affordances, it is seen by many researchers and educators as an ideal tool for supporting learners' online collaborative learning (e.g., Wheeler et al. 2008). In this study, we explored using wiki to design a structured peer learning approach to support learners' learning of classroom management through three stages of problem-solving (stage one, problem identification; stage 2, strategies proposed; stage three, decision-making) their own classroom management cases (see Fig. 18.1 for the wiki's interface). In particular, it aims to address the following three research questions:



Exploring your classroom case (Write your thought)

Exploring your classroom case

Write your thoughts according to your assigned code and use the following questions to jump starts your writing.

Q1: What are the problems you identify? Provide evidence to support your identified problems.

Q2: What strategies would you use to solve the problems? Why?

Q3: Rank your proposed solutions according to what you think will be most probable to implement. Justify your choice.

Subject	Started by	Replies	New	Last post
[illegible]	Cindy Seah	1	0	31 May 2011 2:40:33 PM EST
[illegible]	Cindy Seah	1	0	31 May 2011 2:35:36 PM EST
[illegible]	Cindy Seah	2	0	1 June 2011 4:25:26 PM EST
[illegible]	Cindy Seah	3	4	1 June 2011 5:39:42 PM

Fig. 18.1 Screen capture of the wiki-based environment supported by LAMS®

1. What are the learners' and their peers' responses to the two learning stages of case discussion in the wiki-based environment?
2. How consistent are the problems identified by the learners and their peers?
3. How is learners' final decision-making on own case solutions influenced by their peers' contributed responses (problem identification and strategy proposition)?

Methodology

Research Design

This chapter reports a part of a mixed methods study on BT learners' case-based learning of classroom management. The learning mode and time duration for each learning sequence were illustrated in Table 18.1. The timing was suggested for the learners to participate in the respective online tasks. The learners also set online clock for their activities. They would post their comments for their online communication with peers. All these activities were carried out in three stages in wiki-supported case-based environment. At stage one, participants read their own case, identify problems, and then post their analysis under comments in wiki. At stage 2, they propose strategies to solve the problems identified from their cases. Next, they exchange their analysis with their peers who were assigned by the researchers using a numerical code (without revealing the identity) prior to the commencement of the workshop. At stage 3, they make decisions of their case solutions.

Table 18.1 Learning sequences designed in the LAMS®-supported wiki-based environment

Learning tasks	Learning mode	Learning stage	Duration (mins)
1. Problems identification	Individual	1	20
A. Read and identify problems from own classroom case			
2. Propose strategies followed by evaluation	Individual	1	40
B. Propose strategies from own case then post response in wiki			
C. Exchange with peer's case analysis and strategies and evaluate and post their responses	Pair	2	80
D. Revisit own case, revise case analysis if necessary	Individual	2	20
3. Decision-making of case solutions	Group	3	20
E. Discuss case analysis and proposed strategies with peers (from 2)			
F. Reflect and make decisions of the proposed solutions to their own case	Individual	3	40

Note: mins = minutes

Sample and Setting

The sample consists of 24 learners (12 learners were assigned to be in one computer lab) who were beginning teachers (BTs) randomly selected from 10 Singapore secondary schools. They were all less than 35 years old and had completed preservice education in Singapore. To prepare for teachers' authentic case-based learning, a researcher visited these teachers and invited them to document their critical classroom encounters and reflections. Based on these teachers' own critical classroom encounters, the researcher cowrote the cases with the teachers. These text-based cases were posted in wiki. As research participants, they were also invited to attend a 2-day workshop "inquiry-based learning on classroom management" for problem-solving teacher-generated classroom management cases at National Institute of Education (NIE), Singapore. These learners had prior learning experience in ICT and classroom management during their preservice teacher education. At the start of the workshop, they were briefed about the wiki-based learning environments and the case-based peer learning sequences. For example, in order to solve the case, each case was assigned randomly to two learners to read, analyze, propose strategies, and reflect subsequently. The entire synchronous online learning took about 12 h that span across 2 days in NIE's two separate computer labs. After the workshop, the teachers also spent their school vacation time to revise their online proposed solutions and reflection.

Data Collection and Analysis

The data consists of 24 learners' online learning scripts. Specifically, the learners' responses for online learning stages one, two, and three were compiled for each of the 24 classroom management cases. By the way, each learner posted one classroom case in wiki before the commencement of workshop. At learning stage one, the learners were expected to identify the problems after reading their own case. At learning stage two, the learners proposed their strategies then exchanged their cases with their peers. Guided by the prescribed process of grounded theory approach (Strauss and Corbin 1998, see Fig. 18.2 for specific coding workflow), using meaning as a unit of analysis, learners' responses to the learning activities one to three were sorted and summarized by a coder. The coding includes classroom management problems identified by the learners and their peers, classroom management strategies proposed by learners and their peers, and proposed classroom management strategies accepted by learners and their peers (see Tables 18.2 and 18.3). To ensure the reliability of coding results, learners' responses to learning activities were resorted and recoded by the same coder after 5 days' break. These two coding results were then compared, which resulted in 100 % intracoder agreement that lends support to the reliability of analysis results.

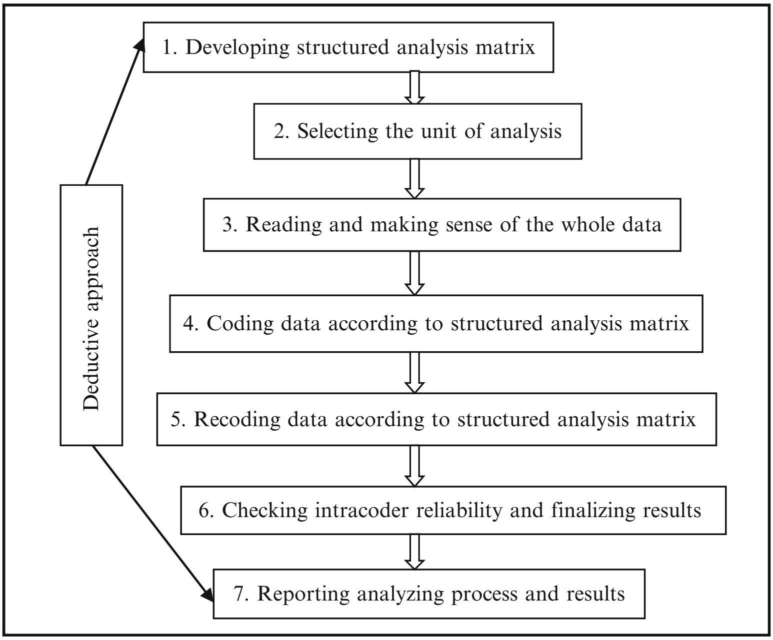


Fig. 18.2 Coding workflow

Following this, quantitative content analysis was conducted to finalize the frequencies of problems identified, strategies proposed, and the proposed strategies accepted by learners and their peers respectively. Two researchers collaboratively coded the data, negotiating differences until 100 % agreement was achieved. The results were summarized in Table 18.4. Considering learners and their peers may identify different problems even though the frequencies of problem identified are the same, the frequency of consistently identified problems by peers was calculated in Table 18.5. To explore further if peers have contributed to the learners' final decision-making on own case solutions, the frequency of the learners' and their peers' problems identified, strategies proposed, and strategies accepted were compared using paired-sample *t*-test and hierarchical regression analysis (IBM SPSS Statistics 20). Paired-sample *t*-test was run between the frequency of problem identified by learners and the frequency of problem identified by peers. Another paired-sample *t*-test was run between the frequency of strategies proposed by learners and the frequency of strategies proposed by peers. Hierarchical regression analysis was conducted to investigate to what extent the peers' problem identification and strategy proposition influence learners' acceptance to strategies.

Table 18.2 Example of content analysis results for one case (self)

Case no.	Content analysis results
Learning stage one: self-problems	
C4	1. Varying academic ability among students
	2. The students are rowdy and inattentive and need a long time to settle down
	3. Another student who frequently misses lesson faces relationship problems and her parents support her absence with medical certificates (MMs) and parents' letters. She also sometimes found crying in the toilet. As a result, her grades suffered
Learning stage two: self-strategies	
C4	1. Clear classroom expectations, enforce strict rules, and provide consequences
	2. Positive reinforcement to reward the better behaved students
	3. Find time to speak to the students who are causing problems and missed a lot of lessons and is currently facing relationship issue
	4. Speak to the parents to show concern and develop plans with them to best help the child and refer the child for counseling if required
	5. For students who submit their work late/do not submit after 3rd times, contact parents
	6. Bargain for small continuous improvements with time
	7. For students who are noisy and are not ready for lessons, talk privately to the students and make use of logical consequences to make them responsible for their own actions 8. Refer the particular girl with high absenteeism and relationship problems to counselor and parents
Learning stage three: self-strategies accepted	
C4	1. Set clear classroom expectations and enforce the rules very strictly
	2. Contact parents if students do not submit their work after 3rd time
	3. Positive reinforcement to reward the better behaved students
	4. Speak to "problematic" students and request for small improvements
	5. For noisy students who not ready for lessons. Either use sarcastic comments, talk privately, or make use of logical consequences
	6. Rope in the help of parents
	7. Refer students beyond you to school level

Results and Discussion

RQ1. What are the learners' and their peers' responses to the two learning stages of case discussion in the wiki-based environment?

To answer this first research question, the frequencies of problems identified and the frequencies of strategies proposed respectively by learners and peers were calculated (refer to columns of Table 18.4 with headings Self-problems, Peer-problems, Self-strategies, and Peer-strategies). In addition, the frequencies of strategies proposed by learners-accepted and the frequencies of strategies proposed by peers-accepted were computed (refer to columns of Table 18.4 with headings Self-strategies Accepted and Peer-strategies Accepted).

Table 18.3 Example of content analysis results for one case (peer)

Case no.	Content analysis results
Peer-problems	
C4	1. Difficult to teach students of different abilities
	2. Particular boy who likes to chat a lot
	3. Girl who is absent professionally
	4. Disruptive behavior of some students (walk around in class and talk to classmates) which affect the pace of lesson
	5. Late submissions in work
	6. A student or two may commit defiant behavior against the teacher
Peer-strategies	
C4	1. Encouraging students
	2. Relating Math to daily life
	3. Stay back strategy for late/no homework submission. Monitor students' homework submission if it's beyond three times, and let the parents know their involvement will be reinforcement
	4. Send the girl for counseling
	5. Pass sarcastic comments to those whom you think can "accept" them. Or get him to present his solutions on the board or use humor to turn the situation
	6. Engage students by giving varied assignment and interesting hands-on activities
	7. Having more discussion and sharing among students. Talk to defiant students or their parents to understand the student more
	8. Setting clear classrooms rules and expectations
	9. Warn the boy first and then explain to him. Use logical consequence
Peer-strategies accepted	
C4	1. I agree that the particular girl should be counseled
	2. I also feel that I should abide strictly to the classroom rules
	3. I also agree to get the students to come up front to present themselves as a form of embarrassment
	4. Motivating them through encouragement and talking
	5. Enforcing staying-back rule for incomplete homework submission. Monitoring the submission for 3 times before notifying the parents
	6. Passing sarcastic comments might be workable for most of the students. Peer pressure seems workable

At learning stage one, the learners identified 87 problems from the 24 cases, while their peers identified 83 problems during their pairwork. To explore the extent of peers' contribution to the learners' problem-solving at this stage, the coded content of learners' and peers' responses for each case was checked and contrasted. To help the comparison of coded content, learners' and peers' coded responses for each case were tabulated side by side in terms of self-problems and peer problems by two coders collaboratively (refer to Table 18.2 for an example for the data handling format). At first, the two coders read the coded responses of learners and their peers repetitively for at least three times independently before they came together to rate whether the peers understand the learners' classroom problems by

Table 18.4 Frequencies of learners' and peers' problem identification, strategies proposition, and acceptance of strategies

	Learning stage one		Learning stage two		Learning stage three	
Case code	Self-problems	Peer-problems	Self-strategies	Peer-strategies	Self-strategies accepted	Peer-strategies accepted
C1	3	3	3	7	0	3
C2	7	4	4	3	1	3
C3	3	6	3	8	3	4
C4	3	6	8	9	7	6
C5	4	6	3	7	1	3
C6	3	4	1	10	1	4
C7	3	3	2	6	2	4
C8	2	3	3	5	1	1
C9	8	1	9	4	1	3
C10	8	2	10	4	3	4
C11	2	3	2	2	0	2
C12	4	5	6	8	3	1
C13	3	3	3	4	1	4
C14	2	3	4	9	3	7
C15	3	4	2	4	1	4
C16	6	3	5	5	4	5
C17	3	4	3	6	2	1
C18	3	2	5	3	4	2
C19	3	3	3	2	3	3
C20	3	5	6	10	5	5
C21	2	2	4	3	0	2
C22	3	3	1	6	1	1
C23	3	2	3	2	3	3
C24	3	3	5	3	3	1
Total	87	83	98	130	53	76

Note: learning stage one: problem identification, where learners identified their problems prior to case discussion with peers. Learning stage two: strategies proposition, where learners exchanged their cases with peers and suggested solving strategies. Learning stage three: making decision of strategies to adopt for their cases, where learners revisited own case, reflected, and made decisions of their case solutions based on peers' input

using four predetermined rating bands (hardly understand, moderately understand, mostly understand, and fully understand). It was found that in most cases except four cases (C9, C10, C11 and C19), peers seemed to understand the problems faced by the learners. For example, in C4 (refer to Table 18.2), while the learner had only identified three problems in his own case, his peer, however, had identified six problems in the learner's case. Clearly, the peer had outnumbered the learner in the quantity of problems identified. From the coded content, it was also observed that the peer not only fully understand the problems faced by the learner (the problems

1, 2, 3, and 4 identified by the peer are consistent with the learners' problem identification) but also identify new problems that might have been overlooked by the learner (the problems 5, 6 identified by the peer). This was also observed for the rest of the cases except four (C9, C10, C11, and C19). Thus, it seems reasonable to conclude that peers contributed to the learners' problem identification in stage one. This shows that peers offer a wider perspective on the learners' classroom problems.

At learning stage two, the learners proposed 98 strategies for own case solutions. In comparison, their peers suggested 130 strategies for learners' case solutions. Thus, peers have proposed larger quantity of strategies than that of learners. To explore further the extent of peers' contribution to learners' problem-solving at this stage, the coded content of strategies proposed by learners and peers is checked and contrasted. The same content comparison procedure is followed except that a slight modification was made on the four rating bands (hardly similar, moderately similar, mostly similar, and totally similar). It was observed that learners' and peers' strategy proposition shows two aspects. The first is solving their previously identified problems. The second is addressing the root causes of their identified problems. Despite some consistently proposed strategies observed between learners and peers, peers seemed to propose more diversified strategies than learners themselves for the 24 cases. For example, in C4 (refer to Table 18.2), the peer offered specific strategies (3rd, 4th, and 9th strategies) to solve the identified problems (5th, 3rd, and 2nd problems) respectively. The peer also generated other strategies (2nd and 6th strategies) for learners to consider. In sum, peers contributed to learners' problem-solving at learning stage two by offering a wider repertoire of strategies to adopt.

RQ2: How consistent are the problems identified by the learners and their peers?

To answer this research question, the learners' problem identification was used as a reference point; the frequency of problems identified by peers is checked against the problem identification list provided by the learners, coded, and summarized in Table 18.5. For example, in C1, the frequency (3) means that three problems were consistently identified by peers and learners, whereas in C8, the frequency (0) means that none of the problems identified by peers and learners was found to be consistent with each other. Out of 87 problems (identified by learners), 50 problems were also identified by peers. This gave rise to 57 % (50/87), indicating that both learners and their peers had consistently identified these problems. This finding implied that peers and their learners did share some common understanding on the learners' problems.

To calculate the consistency rate, consistency frequencies of learners' problem identification (y) and peers' problem identification (x) were also computed (formula: consistency rate $= x/y \times 100$ %). To elaborate, if a learner identified 4 problems ($y_1 = 4$), none of which was consistent with her peer's identified problems ($x_1 = 0$), then their consistency rate would be 0 % (that is 0 divided by 4). However, if the learner identified 4 problems ($y_2 = 4$), and her peer identified 4 similar problems ($x_2 = 4$), then the consistency rate would be 100 % (that is 4 divided by 4). Among the 24 cases, 6 instances of 100 % consistency rates and 12 instances of above 50 % consistency rates were identified. In comparison, only 6 instances of below 50 %

Table 18.5 Frequencies of consistently identified problems by peers

Case code	Problems identified by learners	Consistently identified problems by peers
C1	3	3
C2	7	4
C3	3	3
C4	3	3
C5	4	1
C6	3	1
C7	3	2
C8	2	0
C9	8	1
C10	8	2
C11	2	0
C12	4	3
C13	3	2
C14	2	1
C15	3	3
C16	6	4
C17	3	2
C18	3	2
C19	3	1
C20	3	3
C21	2	2
C22	3	3
C23	3	2
C24	3	2
Total	87	50

consistency rates were found. This result further confirmed that the learners' and peers' problems identification is generally consistent. Put differently, most of the peers understand the learners' problems.

To test further the consistency between learners' and peers' problem identification, the frequency of problems identified by learners ($M = 3.6$; SD = 1.8) and frequency of problems that are consistently identified by peers ($M = 2.1$; SD = 1.0) across 24 cases were compared using paired-sample *t*-test. The results showed that the difference is significant, $t(23) = 4.4$, $p < .001$. In other words, peers may understand the learners' problems; however, they may underestimate the quantity of problems identified.

RQ3. How is learners' final decision-making on the own case solutions influenced by their peers' contributed responses (problem identification and strategy proposition)?

To address this research question, the frequency of accepted peer-proposed strategies at learning stage three was coded and calculated (refer to Table 18.4). Overall, learners proposed 98 strategies, among which they only accepted 53 strategies for their own case solutions. When we compare the frequency of accepted self-proposed strategies to the frequency of self-proposed strategies (53/98), it was found that 54 % of the self-proposed strategies were accepted by learners in the learning stage three. On the other hand, the peers proposed 130 strategies, among which learners accepted 76 strategies for own case solutions. When we compare the frequency of accepted peer-proposed strategies with the frequency of peer-proposed strategies (76/130), it was noted that 58 % of the peer-proposed strategies were accepted by learners in the learning three. Thus, the results showed that peers' strategy proposition (58 %) exerts larger influences on learners' final case solutions than that of learners (54 %). In other words, peers contributed slightly more to learners' final decision-making than learners themselves in learning stage three.

The coded content of learners' and peers' responses at learning stage three was checked and contrasted to examine further the peers' contribution to learners' problem-solving at learning stage three. The same content comparison procedure is followed except that a slight modification was made on the four rating bands (hardly accepted, moderately accepted, mostly accepted, and fully accepted). It was observed that learners tend to moderately accept peer-proposed strategies. Taking C4 as an example (refer to Table 18.2), among the nine peer-proposed strategies, the learner accepted four. Thus, peer-proposed strategies were moderately accepted by learners in C4. It was also observed that the more strategies peers proposed, the more peer-proposed strategies learners would accept in the learning stage three. The peers, by identifying learners' potential problems and suggesting multiple strategies, precipitated learners into active evaluation of the applicability of peer-proposed and self-proposed strategies to their own teaching contexts. Such interactive process in turn facilitated learners' final decision-making. Taken together, peers exerted substantial influences to learners' final decision-making in learning stage three.

Hierarchical regression analysis was conducted to investigate the extent the peers' problem identification and strategy proposition influence learners' acceptance of strategies. Given there were three stages of learning, we reckon that the role of peers provide the initial input could be treated as the independent variables that may affect the outcomes of learners' decision-making at stage 3. In particular, in step 1, the learning stage one peer factor 1 (frequency of problems identified by peers) was entered, $\beta = .46$, $p < .05$. In step 2, the learning stage two peer factor 2 (frequency of strategies proposed by peers) was entered, $\beta = .53$, $p < .01$. The result is summarized in Table 18.6.

To investigate further the extent of peers' contribution to learners' final decision-making on own case solutions, a hierarchical regression analysis was conducted. Results were shown in Table 18.6. First, the collinearity statistics indicated that peer factors in learning stages one and two were not highly correlated (*tolerance* = .98; VIF = 1.02). Thus, the model did not suffer from collinearity issues. Second, the learning stage one predicator explained 20.8 % of the variance ($\Delta R^2 = .21$, $F(1, 22) = 5.77$, $p < .05$), while the learning stage two predicator explained 27.4 % of the variance ($\Delta R^2 = .27$, $F(1, 21) = 11.13$, $p < .01$). These results suggested that the frequency of peer-identified problems and peer-proposed strategies collectively influence learners' final acceptance of peer-proposed strategies.

Table 18.6 Hierarchical regression analysis results on the frequency of accepted strategies proposed by peers

Model	β	t	p	ΔR^2	F for ΔR^2	Collinearity Statistics	
						Tolerance	VIF
Step 1: stage one peer factor						.98	1.02
No. of problems identified by peers	.46*	2.4	.025	.21*	5.77		
Step 2: stage two peer factor							
No. of problems identified by peers	.38*	2.4	.025				
No. of strategies proposed by peers	.53**	3.3	.003	.27**	11.13		

Note: $N=24$. *$p<.05$; ** $p<.01$

Moreover, the predicting effect of learning stage two peer factor (27.4 %) is larger than that of learning stage one peer factor (20.8 %). In other words, the more problems that peers identified, and the more strategies peers proposed, the more strategies learners would accept. It is thus concluded that peers' problem identification and strategy proposition are critical to learners' decision-making on what strategies to adopt in learning stage three.

In sum, learners' decision-making on own case solutions was significantly influenced by peers both in terms of problem identification and strategy proposition. The results implied that peers learning (problem identification and strategy proposition) in this wiki-based learning environment facilitated learners' three-stage problem-solving process. It also enhanced the learners' final learning outcomes.

Conclusion

This study aims to explore the peers' influences on the learners' problem-solving of own classroom management cases in a wiki-based environment supported by LAMS®. The findings showed that the peers' contribution is apparent at each learning stage of learners' problem-solving process (problem identification, strategy proposition, and decision-making on own case solutions). Peers not only confirmed the learners' problems faced, but they also identified other problems that learners might have overlooked. They also offered the learners strategies to adopt. Furthermore, by precipitating learners to evaluate the effectiveness of own and peers' problem identification and strategy proposition through peer learning, peers made substantial contribution to the learners' final case solutions. Little existing literature has specifically explored the influences of peer learning in the learners' learning of classroom management skills in wiki-based environments. The findings of this study will shed more light on the understanding on how to optimize the web-based collaborative activity design to best facilitate teacher learning. One implication could be drawn is that ensuring effective discussion and interaction among learners and their peers are critical in online case-based learning as it may positively influence learners' learning outcomes. Given the small sample size of this study, the results of this study need to be interpreted with caution and cannot be generalized beyond its sample and setting. More studies with larger sample sizes conducted at different settings and countries are needed to ascertain our findings.

Moreover, although technology-enhanced case-based models of authentic learning environments have been documented and evaluated in a number of studies in the Western context, few studies have been conducted in Asian context. For example, mainly Korean researchers designed instructional strategy and developed models and online systems to promote learners' learning and reflection (Choi 2009; Choi and Lee 2009; Choi et al. 2009; Han and Kinzer 2007; Kim and Hannafin 2008). There was little research efforts observed in Singapore and Turkey. In this regard, this study contributed to the existing technology-enhanced authentic learning research by examining an innovative design of technology-enhanced case-based learning in Singapore higher education context. It will also provide future researchers, teachers, and school leaders' useful information that may be applied to their own research, schools, classrooms and offer new insights on how to improve online collaborative instructional practices and make school curriculum innovations.

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Part VII
Conclusion and Future Direction

Chapter 19
Authentic Problem Solving and Learning: Lessons Learned and Moving Forward

Michael J. Jacobson

> *Education is a social process. Education is growth. Education is not a preparation for life; education is life itself.*
>
> —John Dewey (1938)

Abstract This chapter provides reflections on the range of PBL research and practices reported in this volume. Empirical assessments of a variety of PBL approaches are discussed, as well as issues related to effectively teaching PBL in schools. There are also important considerations in this volume related to the relationship of pedagogies such as PBL in cultural and social contexts, with an emphasis on Asia. Still, there is an important question to be asked: How might PBL as a field of research and educational practice advance and move forward? I suggest that researchers should consider three main areas to advance the field: theoretically informed PBL, pedagogical sequences to informed PBL, and technology-enabled PBL.

Keywords PBL • Theoretical issues • Pedagogical issues • Technology-enabled PBL

Although the three broad themes articulated in Chap. 1 for this ambitious, rigorous, and also practical volume are *authentic problems*, *authentic practice*, and *authentic participation*, to this reader, Dewey's vision that *education is life itself* is perhaps overarching. The various chapter contributors each take seriously the difficult educational challenges of bringing authentic issues, practices, and knowledge of relevance to real-life learning and provide insights based on theory, historical and cultural contexts, empirical research, and practical classroom experiences.

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Chapter 1 provides an excellent summary overview of each of the chapters, so in my comments here I focus on selected lessons learned and some suggestions for moving forward.

In terms of lessons learned, PBL represents a family of educational practices that for over a half century[1] have been applied to support learning in a range subject areas and grade levels. PBL might be best viewed as an educational community of practices that have pedagogically evolved over time. Empirical assessments of PBL approaches generally find positive learning outcomes and affective experiences as well, such as discussed in several chapters in this volume. Given PBL can be effective for learning in a range of areas and educational levels, then pedagogical considerations have emerged for teachers and instructors who might be interested in using PBL. Again, excellent chapters in this volume describe research into various issues about effectively teaching PBL in schools, such as the selection of problems, role of the teacher, duration of the learning activities, assessments, and so on. Also considered in this volume are issues related to the relationship of pedagogies such as PBL in cultural and social contexts, with an emphasis on Asia.

Still, given these generally positive and compelling perspectives about the value and practicality of PBL (although there have been criticisms discussed below), there is an important question to be asked: How might PBL as a field of research and educational practice be advanced in order to move forward? I believe researchers should consider three main areas to advance PBL: theoretically informed PBL, pedagogical sequences to inform PBL, and technology-enabled PBL. I consider these areas in turn.

Theoretically Informed PBL Advances

In Chap. 5, Hung provides an excellent overview of several major theoretical perspectives—such as information processing and cognitive theories, schema theory, situated cognition, metacognition, and constructivism—that have been informing various categories of PBL. There is another recent cognitive theoretical approach, *analogical encoding (AE) theory* (Gentner et al. 2003), which has potential relevance to perhaps all PBL approaches both for understanding *why* PBL works as a powerful learning design and *how* the efficacy of PBL might be further enhanced.

Briefly, AE posits that contrasting and comparing cases sharing an underlying principle or concept may help a learner focus on the conceptual similarities rather than on idiosyncratic surface features, which in turn may lead to the abstraction of schema associated with the targeted concept and to enhanced performance on measures of transfer, such as applying knowledge to new problems and situations. This approach differs from the more common use of analogies (i.e., analogical

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[1] Learning approaches similar to PBL, such as the case method in legal education, have actually been used since the late 1890s; see Williams (1992).

reasoning) in which new knowledge is acquired by the use of an analogy that the learner is familiar, such as using water as an analogy of how electrons flow in a circuit.

Considerable research has demonstrated that analogies can be effective educational tools (Bulgren et al. 2000); however, an analogy is *not* effective if the student does not understand an appropriate base example. In contrast, with AE, a learner may initially only have a partial understanding of a principle or idea, but through comparing two cases, the learner can construct a better understanding of the shared principle or idea. The comparison can help the learner focus on structural commonalities rather than surface features of the cases that are idiosyncratic. Thus, with AE, the learning is “two way” in that what a learner understands in one example can map to the understanding of the second example (and vice versa), whereas with analogical reasoning, the knowledge is mapped one way from the known base analog to the targeted area.

A further potential advantage of AE is that compared to studying cases individually, the comparison of two cases will help the learner construct abstracted schema without idiosyncratic surface features associated with a specific case, which can contribute to the “inert knowledge” problem. A learner should be able to recall and apply such an abstracted schema much better than contextualized schema learned through individual examples. Put another way, AE should help a learner understand knowledge by comparing cases in a way that would foster better application (i.e., transfer) of knowledge to new case and problem situations. Consistent with these expectations, a series of studies involving analogical encoding using contrasting cases to learn advanced mental models of negotiation strategies compared to using single cases has demonstrated significant learning and transfer findings (Gentner et al. 2003).

Given comparisons of different PBL cases and problems seem a reasonable learning activity that also has a strong cognitive justification, one would expect research into PBL and AE would be found in the literature. Surprisingly not: a quick Google Scholar search of “analogical encoding and PBL” found some references to PBL, analogical *reasoning* (not *encoding*), and structure mapping but no explicit studies of research involving AE and PBL, with the exception of some of my hypermedia learning environments research (Jacobson 2008; Jacobson et al. 2011). In this volume, there is also no mention of PBL involving AE or the use of comparisons of problems and cases, with the exception of the chapters discussing productive failure where there were comparisons of the student-generated ideas and explorations to canonical solutions provided by the instructor. Anecdotally, in my experience as a university faculty member for over 20 years, conversations with colleagues in medicine and business about how they use PBL in their teaching suggest there is little if any direct comparison of different cases and problems as a formal aspect of these curricula.

Why might AE theory be of interest to PBL researchers and educators? Based on the discussion of theory above, one would expect the use of AE-based comparison activities would lead to enhanced learning of concepts and principles that are common across different cases compared to learning with the problems and cases individually. Perhaps more important, if the comparison of problems and cases leads learners to construct more abstracted schema as posited by AE theory, then there should also be enhanced performance on assessments of knowledge transfer and the ability of learners to apply their knowledge to new real-life problems and situations.

From a practical teaching perspective, asking learners to compare cases and problems is easily implemented as either individual written assignments or as part of collaborative group learning activities. Research that explores hypotheses such as enhanced learning and transfer from problem and case comparisons would be relatively easy to conduct, with these empirical findings being both theoretical interest as well as practical interest to instructors who are currently using PBL. Given the challenges faced by teachers and instructors at all educational levels and in all subject areas, research into a relatively minor pedagogical adjustment to PBL that has the potential to demonstrate more "learning bang for the instructional time buck" would be of real value in the real world of teaching and learning.

Pedagogical Sequences to Inform PBL Advances[2]

As pointed out in Chap. 5, PBL is not a monolithic approach to teaching and learning, but rather a range of different approaches from *pure PBL* to *lectures with problem-solving activities*. Hung proposes a framework for conceptualizing different categories of PBL along two dimensions, problem structuredness and self-directedness (see p. 82).

However, while researchers involved with PBL see many nuances and differences between various PBL approaches, there have been recent criticisms of PBL as a general approach for teaching and learning. Kirschner et al. (2006) provide a critical review of a number of studies of learning, which they broadly categorize as (a) *direct instructional guidance* and (b) *minimal instructional guidance*. They discuss direct instruction approaches such as research involving worked examples (Miller et al. 1999; Quilici and Mayer 1996; Sweller and Cooper 1885) and process work sheets (Nadolski et al. 2005), with research involving minimally guided instructional approaches such as constructivism (Jonassen 1991), PBL (Hmelo-Silver 2004), experiential learning (Kolb et al. 2001), discovery learning (Mayer 2004), and inquiry learning (Van Joolingen et al. 2005).[3] In their analysis of the research on learning with these various approaches, Kirschner and associates (2006) conclude there should be "direct, strong instructional guidance rather than constructivist-based minimal guidance during the instruction of novice to intermediate learners" (p. 84). As one would expect, this assertion has been sharply contested by researchers in the PBL community (Hmelo-Silver et al. 2007).

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[2] This section incorporates material from Jacobson et al. (2013).

[3] The references for these various instructional approaches listed in this sentence are drawn from Kirschner and associates (2006).

Table 19.1 Sequences of pedagogical structure framework (SPSF) and approaches for PBL

Pedagogical sequence	PBL category
Low–low (LL)	Pure PBL
High–high (HH)	Pure lecture
High–low (HL)	Lecture with problems, case based, project based
Low–high (LH)	Productive failure PBL (hybrid PBL), anchored instruction

In an attempt to provide a broader framework from which to view this debate, the direct instruction approaches described by Kirschner and colleagues (2006), as well as other didactic teaching approaches, may be regarded as providing *pedagogical high structure*, whereas the minimally guided approaches provide *pedagogical low structure* during learning activities.[4] We also observe that in many of the studies they review, the main independent variables vary the approach of direct (i.e., high structure) versus minimally guided (i.e., low structure) instruction, with the dependent variables being various assessments of learning or problem-solving success. Such examples can be seen in Albanese and Mitchell's (1993) review of medical PBL research and Klahr and Nigam's (2004) study of direct instruction versus discovery learning for students about experimental design.

However, the conclusion of the review by Kirschner et al. (2006) is based only on the studies that primarily control for high structure or low structure. Further, they do not discuss studies that involve *different sequences of structure during learning activities*, such as investigated by researchers including Schwartz and Bransford (1998), VanLehn et al. (2003), Bjork and Linn (2006), and Kapur and associates (2012; Chap. 12 this volume).

To help conceptualize issues such as these, I propose Sequences of Pedagogical Structure Framework (SPSF), which is a 2 by 2 matrix of possible ways to sequence pedagogical structure: (a) Low-to-Low structure (LL), (b) High-to-High structure (HH), (c) High-to-Low structure (HL), and (d) Low-to-High structure (LH) (Jacobson et al. 2013). For convenience of discussion, a learning activity that is completely high structure is regarded as being in the HH sequence and completely low structure as being in sequence category LL. Thus, the majority of the direct instruction studies referenced in Kirschner et al. (2006) would be classified as a HH sequence.

In Table 19.1, I suggest which categories of PBL proposed by Hung in Chap. 5 align with the SPSF matrix. (Note: Some might view the dimension of *pedagogical sequence* as related to Hung's dimension of *self-directedness* in that a high level of self-directedness would correspond to low pedagogical structure, with a low level of self-directedness corresponding to high pedagogical structure. However, the notion of temporality in this proposed framework seems distinctive to the Hung framework.)

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[4] "Structure" may be broadly conceived in a variety of forms such as structuring a problem, scaffolding, instructional facilitation, providing worksheets or scripts, and so on.

I suggest that the vast majority of PBL research has been in either the LL sequence (i.e., pure PBL) or the HL sequence (i.e., lecture with problems, case-based learning), such as engaging students with complex problems with scaffolding (i.e., high structure) that is then faded (i.e., low structure) over time as the learner presumably becomes more knowledgeable or skilled. The use of problems in lectures is reasonably common in practice, if not often directly researched (although see Schwartz and Bransford (1998) for an important study in this regard), which clearly aligns with the HL sequence. The LH pedagogical sequence is less common in PBL research (and educational research more generally; see Jacobson et al. 2013), although Chaps. 12, 13, and 14 in this volume present different research programs that each align with the LH sequence.

Why might considerations of sequences of pedagogical structure be important in future PBL research? First, it appears this factor is not one that has been explicitly considered in PBL studies. Research involving this factor will allow the design of studies to compare different approaches to PBL with each other as well as various approaches to direct instruction such as those Kirschner and associates are fond of (e.g., worked examples). A second line of research related to sequences of pedagogical structure might be called the efficiency/efficacy trade-off. An issue often raised about the use of PBL is that while it may be effective, it is not efficient as there is "so much to cover" in a course. An instructor persuaded by that argument might therefore select HH pure lecture or the HL lecture with problem approaches. However, in the seminal study by Schwartz and Bransford (1998) that directly studied (using the SPSF terminology) HH, LL, and LH, there was no difference in the relatively poor performance of the HH and LL treatment groups, but a significantly higher posttest performance by the LH group (which they called the "time for talking" group). I believe future research that explicitly considers pedagogical sequences in studies of different approaches for PBL and other teaching approaches would help provide an enhanced empirical foundation from which to advance our understanding of principled ways to design effective and efficient PBL approaches.

Technology-Enabled PBL Advances

In this third area, I briefly consider ways in which technology might be used to enable and enhance PBL. Traditional approaches to PBL in medicine have almost exclusively used paper-based cases for students to work from and served as the basis from which instructor provided facilitation.

In this volume, there are interesting considerations of technology-enabled environments for use with PBL. In Chap. 10, a web-based learning environment is discussed that scaffolds argumentation as part of design activities. In Chap. 11, a web-based environment is discussed that scaffolds argumentation and collaboration as part of design activities, and in Chap. 18, students work on classroom management cases using a wiki-based environment. These chapters nicely illustrate ways in which the representational affordances of technological environments can extend information of relevance to cases and problems as well as to provide conceptual, epistemic, and collaborative scaffolding that can enrich the PBL experience for students in ways that might be more realistic and lifelike. Clearly PBL research in the future should be exploring further ways in which newly possible and affordable technologies such as 3D visualizations, virtual worlds, augmented reality, and so on might be incorporated into innovative PBL learning designs that will advance the field.

Conclusion

In closing, this volume focuses on innovative learning designs broadly embracing problem-based and learner-centered approaches, with an emphasis on the Asian context of learning and teaching. The reader will find a wealth of information and research about lessons learned related to PBL broadly construed. It is also hoped that the three areas suggested in this chapter to advance PBL theory and practice—theoretically informed PBL, pedagogical sequences to inform PBL, and technology-enabled PBL—may stimulate new learning design ideas and research that might help further realize Dewey's challenge to all educators: *Education is not a preparation for life; education is life itself.*

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Chapter 20
Authentic Learning Research and Practice: Issues, Challenges, and Future Directions

Young Hoan Cho, Imelda S. Caleon, and Manu Kapur

Abstract Authentic learning research has focused on diverse topics and applied multiple perspectives including cognitive, affective, and sociocultural aspects. The chapters of this book present theoretical and practical issues in the authentic problem, practice, and participation approaches. We suggest that future research efforts focus on developing a robust theoretical framework, examining the effectiveness of authentic learning for the development of twenty-first century competencies, investigating transition from traditional pedagogy to authentic learning practices and exploring the novel research topics of authentic learning that were presented in the earlier chapters. Researchers, practitioners, and other stakeholders need to make collective efforts to improve authentic learning theory and practice and to resolve contradictions between the new practice and other elements of the current school system.

Keywords Authentic problem solving • Authentic learning • Theory and practice • Future research

Introduction

Authentic learning has been investigated in diverse domains for the development of problem-solving and collaboration skills. Recently, authentic learning approaches have been highlighted for school reform and pedagogical innovation in a number of countries where examination-oriented education hinders students from developing noncognitive skills and values. This book includes theoretical discussions, specific cases of authentic learning, empirical studies about authentic learning processes and outcomes, and challenges that students meet while carrying out authentic tasks.

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These studies provide new insights on educational practices and theoretical issues regarding authentic learning and problem solving.

This book presents diverse approaches on authentic learning. Some researchers emphasize complex and ill-structured problem solving, whereas others encourage students to participate in sociocultural practices of a community. In addition, multiple theoretical frameworks and models (e.g., productive failure, cognitive function disk, embodied cognition) were used for investigating authentic learning phenomena in formal and informal contexts. A few chapters also present pedagogical cases in which authentic learning is reinterpreted and modified according to Singapore school contexts. Although the studies featured in this book utilized diverse approaches, they generally share the assumption that learning should not be separated from real-world practices outside of school (Barab et al. 2000; Brown et al. 1989).

Three Authentic Learning Approaches

In this book, studies on authentic learning are categorized into three approaches: *authentic problem, practice*, and *participation*. These approaches are not discrete, but they highlight different aspects of authentic learning. That is, one study may be involved in more than one approach.

Authentic Problem

The authentic problem approach emphasizes learning from solving open-ended, complex, and/or ill-structured problems including real-world contexts. A well-known instructional model of this approach is problem-based learning (PBL) that has been applied to diverse domains including medical, business, and K-12 school education since the 1960s. As discussed by Hung (Chap. 5), there are a variety of PBL models according to the structuredness of problems and the self-directedness of learners. In Chap. 4, for instance, teachers provided primary school students with an open-ended mathematics problem, which was clearly defined, along with sufficient instructional supports for young children. By contrast, in Chap. 6, polytechnic students solved ill-defined real-world problems through student-centered collaborative activities. Teachers need to make decisions on what PBL model is appropriate for their students, contributes to learning objectives, and is feasible in their school contexts.

Concerning the authentic problem approach, it is crucial to design authentic problems that may determine what students learn from problem-solving activities. Dochy et al. (2003) argued that authentic problems in PBL are used “as a tool to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problem” (p. 535). In Chap. 3, Sockalingam suggests that teachers should design the content, context, task, and presentation of PBL problems through considering their relevance, familiarity, difficulty, and clarity. She also argues that problems should be designed to promote self-directed learning, encourage teamwork and elaboration, stimulate interest and critical reasoning, and lead to learning issues. These principles can be applied to developing authentic problems in a variety of domains. However, it should be noted that the characteristics of authentic problems are varied depending on domains. For instance, design problems of engineers require different problem-solving processes, intuitions, and competencies from scientific inquiry that aims to explain causal relationships about natural phenomena. Jonassen (2011) argued that different instructional approaches are required for students to learn how to solve different kinds of problems; he identified 11 kinds of problems (e.g., logic problems, decision making, dilemmas) according to their structuredness, complexity, and dynamicity.

Authentic Practice

The authentic practice approach includes a variety of learning activities that resemble ordinary practices in a community out of school. This book shows how students learn through such authentic practices as play and remix, argumentation, embodied activities, and failure experience. These practices are often ignored in examination-oriented school systems in Asia. For the development of twenty-first century competencies, students should be engaged in authentic practices beyond acquiring knowledge about a subject. Kafai and Burke (2013) argue that computer programming education should shift from individual coding exercises to the development of real and tangible applications, which can be shared and remixed in online communities, so as to encourage K-12 students to think like computer scientists. Consistently, Baek et al. present the model of authentic thinking with argumentation (ATA) in which students generate, share, and evaluate arguments as scientists or engineers do (Chap. 10). Lim and Ismail also provide the framework of Six Learnings (i.e., learning by exploring, collaborating, being, building, championing, and expressing) that facilitate learning geography through embodied experience in an immersive environment (Chap. 11). The 3D virtual world enabled secondary school students to learn from geographical experience as geographers do in the real world.

In authentic learning situations, such as those involving apprenticeship, people learn from their mistakes, which often lead to a new lesson (Lave and Wenger 1991). According to the productive failure model (Chaps. 12, 13, and 14), it is beneficial for students to generate and explore a variety of solutions to a novel problem before getting a canonical answer from a teacher. Through several empirical studies, Kapur and his colleagues showed that the productive failure activity is more effective for conceptual understanding and transfer in mathematics than direct instruction in which lectures are followed by problem-solving activities. Even if students do not express the correct or most acceptable response based on canonical principles, they can learn from generating diverse representations and solution methods and comparing their answers with the preferred one. Loibl and Rummel also found that a mathematical problem-solving activity prior to instruction enabled students to externalize their existing knowledge and focus on the difference between their knowledge and the canonical solution (Chap. 13). These findings imply that students learn mathematics effectively when they explore, generate, refine, explain, compare, and evaluate their representations and solution methods as mathematical community members do.

Authentic Participation

This book includes a few chapters about the authentic participation approach, which focuses on learning that occurs through participation in a community of practice (Barab et al. 2000; Lave and Wenger 1991). It is necessary to encourage students to be engaged in "learning to be" a member of the community even when they have not mastered sufficient knowledge and skills (Brown and Adler 2008). This approach reverses the traditional pattern that students accumulate a lot of knowledge in school before participating in community practices out of school. In Chap. 15, Koh presents a case in which a school's business curriculum was integrated with internship in retail outlets. In the real workplace, secondary school students shadowed their mentors, conducted real-world tasks as retail assistants, and collaboratively reflected on their experience. In addition, Kim and Ye (Chap. 16) show that prospective teachers learned to teach astronomical concepts of size and distance through observing stars in a field trip, constructing multimodal models to examine astronomical phenomena, actively interacting with their mentor, and teaching secondary school students in a workshop. In both studies, learners were engaged in learning to think and act like their mentors through authentic experience in real-world contexts. The participation and role-playing within an authentic community of practitioners helped the students to assume a persona that was in tune with actual work environments. The students acquired knowledge and skills that are perceived to be relevant in the field of practice of practitioners. More efforts are needed to integrate school curriculums with community-based participation in a variety of domains. For this purpose, teachers can encourage students to use mobile devices or Web 2.0 technologies to build online communities and carry out seamless learning within and out of school (Looi et al. 2010).

Moreover, learning communities formed by practitioners serve as the focus of the other participation-oriented studies: Tan and Caleon (Chap. 17) detail teachers' collaborative problem finding and Quek and Wang (Chap. 18) describe teachers' use of case-based and technology-based learning environments in problem finding and solution determination. Both studies contribute to the scarce literature focusing on problem finding. But unlike in Caleon and Tan's study, the teacher participants in Quek and Wang's study seem to have worked individually rather than collaboratively during the problem-finding process. Quek and Wang focus on problems situated in classroom management cases, while Tan and Caleon focus on real problems situated in the participants' teaching practice. Although different group dynamics are presented in these studies, both underscore the need for effective discussion and having a common knowledge base among team members to facilitate the process of problem solving. Beginning teachers can develop their knowledge, skills, values, and identities through discussing pedagogical problems, reflecting on their teaching practice, collaboratively creating a lesson plan, sharing course resources, and communicating with more experienced teachers in the community of teachers, which is recently supported with Web 2.0 technologies (Goos and Bennison 2008; Herrington et al. 2006).

Future Directions of Authentic Learning Research and Practice

The studies featured in this book show that authentic learning is valuable to complement or revise the existing curriculum and pedagogy that focuses on knowledge acquisition for high performance in tests. In the twenty-first century, students should develop such competencies as collaboration, communication, ICT literacy, citizenship, creativity, critical thinking, and problem-solving skills (Voogt and Roblin 2012). The authentic learning approaches can be more beneficial for the development of the twenty-first century competencies when compared to teacher-directed instruction that seldom promote active participation of students. Despite the potential of authentic learning, there are a few challenging issues about authentic learning research and practice: (1) development of a comprehensive theoretical framework, (2) effectiveness of authentic learning for twenty-first century competencies, (3) transition from traditional pedagogy to authentic learning, and (4) the need for research on novel and emerging topics.

Development of a Comprehensive Theoretical Framework

First of all, it is necessary to develop a robust theoretical framework that explains the mechanism of authentic learning and problem solving. To advance the research of authentic learning, we need to understand how people learn to be a practitioner or professional in a community of practice, what students learn from authentic learning and problem solving, and how authentic learning process influences the development of competencies. In this book, from cognitive and sociocultural viewpoints, there are several explanations of what and how students learn from authentic learning or problem-solving activities. For instance, in Chap. 7, cognitive and metacognitive functions are conceptualized in regard to the process of PBL. Based on cognitive theories, researchers also explained and examined the mechanism of learning through productive failure and the conditions that influence learning by invention (Chaps. 12, 13, and 14). In addition, Talaue et al. applied sociocultural perspectives (e.g., participatory appropriation) in order to investigate how students develop and maintain a common ground during a collaborative inquiry activity

(Chap. 8). Tan and Caleon also describe how teachers negotiate to determine their learning objects and identify curricular and pedagogical problems in a professional learning community (Chap. 17). These diverse perspectives toward authentic learning should be compared with each other and examined through empirical studies in a variety of contexts.

Although researchers with sociocultural viewpoints have different assumptions, research interests, terminology, and research methods from those with cognitive viewpoints (Greeno 1997), they need to share their findings and negotiate the meanings of authentic learning and problem solving. Anderson et al. (2000) asserted that "situative and cognitive approaches can cast light on different aspects of the educational process, and both should be pursued vigorously" (p. 12). For the development of a robust theoretical framework about authentic learning, researchers need not only to investigate the authentic learning mechanism within each perspective but also to synthesize findings from both cognitive and sociocultural perspectives. As an example, Kapur and Bielaczyc (2012) articulate the design principles of productive failure for the problem, the participation, and the social surround within which authentic learning can take place. The mechanisms embodied in the productive failure design operate at multiple levels, from the cognitive mechanisms for designing of the task and the social mechanisms embodied in the collaborative participation structure to the sociocultural contexts of setting appropriate norms and expectations within which such authentic leaning takes place (Bielaczyc and Kapur 2010; Bielaczyc, Kapur and Collins 2013).

Effectiveness of Authentic Learning for Twenty-First Century Competencies

More studies are needed to investigate the effectiveness of authentic learning activities for the development of the twenty-first century competencies. Although there is the critique that the minimally guided approach like PBL and inquiry learning is not efficient for knowledge construction (Kirschner et al. 2006), a few chapters in this book show positive influences of the authentic learning approach on academic and affective learning outcomes. For example, Tan and Nie found that authentic tasks significantly influenced secondary school students' dispositional outcomes including individual engagement, mastery and performance goal orientation, and task values (Chap. 2). In addition, Kapur and Toh reviewed previous studies (e.g., Kapur 2013, 2014, 2015) that showed the effectiveness of the productive failure practice in conceptual understanding and transfer without compromising procedural fluency (Chap. 12).

Nevertheless, few studies have been carried out to investigate the influence of authentic learning activities on the development of such competencies as collaborative problem solving, communication, critical thinking, and citizenship. The studies have been seldom conducted because it is hard to assess these competencies in a valid and reliable way. For example, Kapur and colleagues have attempted to analyze the complex dynamics of collaborative problem solving and how these dynamics influence collaborative and individual outcomes (e.g., Kapur et al. 2005, 2006, 2007). As another example, Griffin et al. (2013) developed a technology-based assessment system pertaining to collaborative problem-solving skills as part of the Assessment and Teaching of 21st Century Skills project. The assessment system can be helpful for investigating the effectiveness of authentic learning for collaborative problem-solving skills. More attention needs to be paid on assessing twenty-first century competencies and investigating the relationship between authentic learning activities and the improvement of these competencies.

Transition from Traditional Pedagogy to Authentic Learning

More research is needed to promote the transition from traditional pedagogy to authentic learning practice. Even if a number of studies support the effectiveness of authentic learning, teachers may still ask such questions as how they may design for authentic learning (e.g., Kapur and Bielaczyc 2012; Kapur and Rummel 2009), how they can change instructional practices or beliefs of learning and teaching (e.g., Cho and Huang 2014; Lawrence and Chong 2010), how they encourage students with low motivation and ability to participate in authentic problem solving, and what should be assessed during or after authentic learning. Tan and Nie point out that students and teachers in ability-driven school systems where high-stakes tests determine future educational pathways are likely to hold a belief of fixed abilities (Chap. 2). This belief may hinder teachers from applying authentic learning activities, which require higher-order thinking skills, for low-achieving students although the activities can be helpful for both low and high achievers (Kapur and Bielaczyc 2012; Zohar and Dori 2003). In addition, Cheng and Toh found three challenges that teachers encountered when using real-world problems in mathematics lessons: giving the same problems to different ability groups, completing authentic tasks within curriculum time, and teaching only basic computational skills before giving authentic tasks (Chap. 4). These challenges are closely related to the contradictions within and between education systems (Engeström 2001). The authentic learning practice can generate conflicts or tensions with other elements of the traditional school system, which include beliefs of teachers and students, curriculum and assessment, and school culture. According to activity theory, these contradictions are important sources of development and change (Engeström 2001). To achieve an effective transition from traditional pedagogy to authentic learning practice, it is necessary to identify, analyze, and resolve contradictions between authentic learning and other elements in a school system.

Need for Research on Novel and Emerging Topics

The chapters of this book present new research issues that should be investigated further. In Chap. 5, for instance, Hung shows a variety of PBL models that are more or less modified from the original model developed in the medical education contexts. Jacobson also suggests the Sequences of Pedagogical Structure Framework (SPSF) that categorized PBL models according to the pedagogical structure and sequence (Chap. 19). Although previous studies often assumed a single type of PBL (Kirschner et al. 2006), future research needs to compare various PBL models from each other as well as compare them with direct instruction. In addition, Lim et al. argue that students in East Asian societies should be more engaged in play that would cultivate creative minds (Chap. 9). More research is necessary to explain how people learn or generate creative ideas through play as an authentic practice and to improve the disposition of play in classroom practices. In Chap. 17, Tan and Caleon also present a new research topic about how teachers find and negotiate problems of their community practices (i.e., curricular and pedagogical problems). In school contexts, problems are usually developed and provided by an instructor even in PBL. In a community of practice, however, it is necessary to identify a new problem and define an existing problem from different perspectives in order to seek for a better solution or make an innovation. Future research is recommended to design authentic learning environments that encourage students to find and negotiate problems in real-world contexts. Another potentially useful research endeavor would be the determination of the linkage between the quality of the problem-finding process and the quality of the solutions generated in authentic learning environments. Because authentic learning research has a short history, researchers need to explore new research issues and develop authentic learning principles based on the reflection of authentic learning practices.

Conclusion

Authentic learning research has been actively carried out in regard to diverse topics such as authentic tasks, problem-based learning, embodied experience, productive failure, and communities of practice. We categorized these studies into the authentic problem, practice, and participation approaches according to the kinds of authenticity on which these studies have focused (Barab et al. 2000). The studies were also conducted from multiple perspectives including cognitive, affective, and sociocultural aspects. These diverse approaches and perspectives can be helpful in understanding the mechanism of authentic learning and developing an authentic learning environment that meets the needs of students in the twenty-first century.

The chapters of this book show that authentic learning activities are beneficial for the cognitive and affective achievements of students as well as for the professional development of teachers. At the same time, researchers found several challenges that teachers encountered in implementing authentic learning activities in school. The challenges seem to be caused by the contradictions and tensions between the new practice and other components of the school system in which exam-oriented education and teacher-directed instruction are prevalent. It is necessary to view the contradictions as opportunities to develop the school system, change the culture of education, and improve authentic learning practice. For the development of authentic learning theory and practice, researchers should make collective efforts to develop an in-depth understanding of authentic learning from diverse perspectives.

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