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

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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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Y.H. Cho et al. (eds.), *Authentic Problem Solving and Learning in the 21st Century*, Education Innovation Series, DOI 10.1007/978-981-287-521-1_5

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

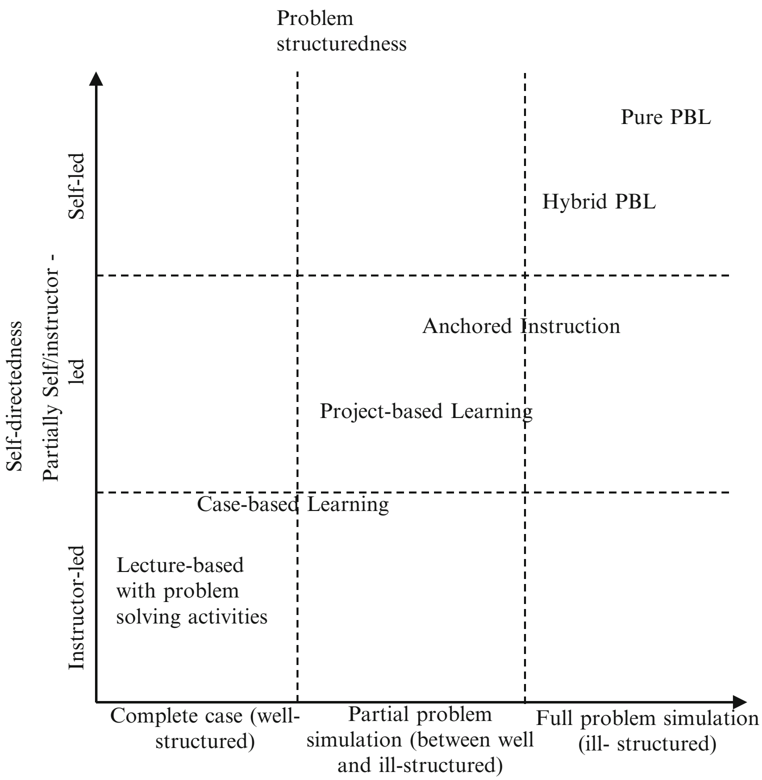

Fig. 5.1 Six representative PBL models in Barrows' PBL taxonomy (Source: Hung 2011)

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.

References

Ak, S., Hung, W., & Holen, J. B. (under review). The effects of authenticity, complexity, and structuredness of problem design on students' motivation in problem-based learning: A case study. *Teaching in Higher Education.*

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine, 68*, 52–81.

Allen, D. E., Duch, B. J., & Groh, S. E. (1996). The power of problem-based learning in teaching introductory science course. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing problem-based learning into higher education: Theory and practice* (pp. 43–52). San Francisco: Jossey-Bass.

Azer, S. A. (2001). Problem based learning: Challenges, barriers and outcome issues. *Saudi Medical Journal, 22*(5), 389–397.

Barak, M., & Dori, Y. J. (2005). Enhancing undergraduate students' chemistry understanding through project-based learning in an IT environment. *Science Education, 89*(1), 117–139.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education, 20*, 481–486.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bring problem-based learning to higher education: Theory and practice* (pp. 3–12). San Francisco: Jossey-Bass.

Barrows, H. S., & Kelson, A. (1993). *Problem-based learning in secondary education and the Problem-Based Learning Institute* (Monograph). Springfield: Southern Illinois University School of Medicine.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York: Springer.

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge: Cambridge University Press.

Bartlett, F. C. (1968). *Remembering*. London: Cambridge University Press.

Bridges, E. M., & Hallinger, P. (1996). Problem-based learning in leadership education. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing problem-based learning into higher education: Theory and practice* (pp. 53–61). San Francisco: Jossey-Bass.

Cermak, L. S., & Craik, F. I. M. (Eds.). (1979). *Levels of processing in human memory*. Hillsdale: Erlbaum.

Cognition and Technology Group at Vanderbilt. (1993). Anchored instruction and situated cognition revisited. *Educational Technology, 33*(3), 52–70.

Cunningham, W. G., & Cordeiro, P. A. (2003). *Educational leadership: A problem-based approach*. Boston: Pearson Education.

de Grave, W. S., Boshuizen, H. P. A., & Schmidt, H. G. (1996). Problem-based learning: Cognitive and metacognitive processes during problem analysis. *Instructional Science, 24*, 321–341.

Derry, S. J. (1989). Strategy and expertise in solving word problems. In C. B. McCormick, G. Miller, & M. Pressley (Eds.), *Cognitive strategy research: From basic research to educational applications* (pp. 269–302). New York: Springer.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In E. Spada & P. Reiman (Eds.), *Learning in humans and machine: Towards an interdisciplinary learning science* (pp. 189–211). Oxford: Elsevier.

Dolmans, D. H. J. M., & Schmidt, H. G. (1994). What drives the student in problem-based learning? *Medical Education, 28*, 372–380.

Dolmans, D. H. J. M., Gijselaers, W. H., Schmidt, H. G., & van der Meer, S. B. (1993). Problem effectiveness in a course using problem-based learning. *Academic Medicine, 68*(3), 207–213.

Duch, B. J. (2001). Writing problems for deeper understanding. In B. J. Duch, S. E. Groh, & D. E. Allen (Eds.), *The power of problem-based learning: A practical "How to" for teaching undergraduate courses in any discipline* (pp. 47–58). Sterling: Stylus.

Duffy, T. M., & Cunningham, D. J. (1996). Constructivism: Implications for the design and delivery of instruction. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 170–198). New York: Macmillan.

Eitel, F., & Steiner, S. (1999). Evidence-based learning. *Medical Teacher, 21*(5), 506–512.

Geary, D. C. (2002). Principles of evolutionary educational psychology. *Learning and Individual Differences, 12*, 317–345.

Geary, D. C. (2005). *The origin of mind: Evolution of brain, cognition, and general intelligence*. Washington, DC: American Psychological Association.

Hallinger, P., & Lu, J. (2012). Overcoming the Walmart syndrome: Adapting problem-based management education in East Asia. *Interdisciplinary Journal of Problem-Based Learning, 6*(1), 16–42.

Harden, R. M., & Davis, M. H. (1998). The continuum of problem-based learning. *Medical Teacher, 20*(4), 317–322.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.

Hsu, L.-L. (2004). Developing concept maps from problem-based learning scenario discussions. *Journal of Advanced Nursing, 48*(5), 510–518.

Hung, W. (2006). The 3C3R model: A conceptual framework for designing problems in PBL. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 55–77.

Hung, W. (2009). The 9-step process for designing PBL problems: Application of the 3C3R model. *Educational Research Review, 4*(2), 118–141.

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research & Development, 59*(4), 529–552.

Hung, W. (2013a). Conceptualizing problems in problem-based learning: Its role and cognitive tools. In J. M. Spector, B. B. Lockee, S. E. Smaldino, & M. Herring (Eds.), *Learning, problem solving, and mind tools: Essays in honor of David H. Jonassen* (pp. 174–194). New York: Routledge.

Hung, W. (2013b). Team-based complex problem solving: A collective cognition perspective. *Educational Technology Research & Development, 61*(3), 365–384.

Hung, W., & Holen, J. B. (2011). Problem-based learning: Preparing pre-service teachers for real world classroom challenges. *ERS Spectrum, 29*(3), 29–48.

Hung, W., & Loyens, S. M. M. (2012). Global development of problem-based learning: Adoption, adaptation, and advancement. *Interdisciplinary Journal of Problem-Based Learning, 6*(1), 4–9.

Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In M. Spector, D. Merrill, J. van Merrienböer, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 485–506). New York: Erlbaum.

Hung, W., Mehl, K., & Holen, J. B. (2013). The relationships between problem design and learning process in problem-based learning environments: Two cases. *The Asia-Pacific Education Researcher, 22*(4), 635–645. doi:10.1007/s40299-013-0066-0.

Jacobs, A. E. J. P., Dolmans, D. H. J. M., Wolfhagen, I. H. A. P., & Scherpbier, A. J. J. A. (2003). Validation of a short questionnaire to assess the degree of complexity and structuredness of PBL problems. *Medical Education, 37*(11), 1001–1007.

Jacobsen, M., & Spiro, R. (1994). A framework for the contextual analysis of technology-based learning environments. *Journal of Computing in Higher Education, 5*(2), 2–32.

Jonassen, D. H. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm. *Educational Technology Research & Development, 39*(3), 5–14.

Jonassen, D. H. (1992). Evaluating constructivist learning. In T. M. Duffy & D. H. Jonassen (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 137–148). Hillsdale: Erlbaum.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research & Development, 45*(1), 65–94.

Jonassen, D. H., & Hung, W. (2008). All problems are not equal: Implications for PBL. *Interdisciplinary Journal of Problem-Based Learning, 2*(2), 6–28.

Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379–424.
Kapur, M. (2010). Productive failure in mathematical problem solving. *Instructional Science, 38*, 523–550.
Karimi, R. (2011). Interface between problem-based learning and a learner-centered paradigm. *Advances in Medical Education and Practice, 2*, 117–125.
Kaufman, D. M. (2000). Problem-based learning: Time to step back? *Medical Education, 34*, 510–511.
Kitchner, K. S. (1983). Cognition, metacognition, and epistemic cognition: The three-level model of cognitive processing. *Human Development, 26*, 222–232.
Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by Design™ into practice. *The Journal of the Learning Sciences, 12*(4), 495–547.
Larkin, J. H., & Reif, F. (1976). Analysis and teaching of a general skill for studying scientific text. *Journal of Educational Psychology, 68*, 431–440.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
Linn, M., Shear, L., Bell, P., & Slotta, J. D. (1999). Organizing principles for science education partnerships: Case studies of students' learning about 'rats in space' and 'deformed frogs'. *Educational Technology Research and Development, 47*(2), 61–84.
Maxwell, N., Mergendoller, J. R., & Bellisimo, Y. (2005). Problem-based learning and high school macroeconomics: A comparative study of instructional methods. *The Journal of Economic Education, 36*(4), 315–331.
Merchand, J. E. (1995). Problem-based learning in the business curriculum: An alternative to traditional approaches. In W. Gijselaers, D. Tempelaar, P. Keizer, E. Bernard, & H. Kasper (Eds.), *Educational innovation in economics and business administration: The case of problem-based learning* (pp. 261–267). Dordrecht: Kluwer.
Nasr, K. J., & Ramadan, A. H. (2008). Impact assessment of problem-based learning in an engineering science course. *Journal of STEM Education, 9*(3/4), 16–24.
Neville, A. J. (2009). Problem-based learning and medical education forth years on. *Medical Principles and Practice, 18*, 1–9.
Norman, G., & Schmidt, H. G. (1992). The psychological basis of problem-based learning: A review of the evidence. *Academic Medicine, 67*(9), 557–565.
Paris, S. G., Lipson, M. Y., & Wixson, K. K. (1983). Becoming a strategic reader. *Contemporary Educational Psychology, 8*, 293–316.
Pletinckx, J., & Segers, M. (2001). Programme evaluation as an instrument for quality assurance in a student-oriented educational system. *Studies in Educational Evaluation, 27*, 355–372.
Rothman, A. I. (2000). Problem-based learning: Time to move forward? *Medical Education, 34*, 509–510.
Rotgans, J. I., O'Grady, G., & Alwis, W. A. M. (2011). Introduction: Studies on the learning process in the one-day, one-problem approach to problem-based learning. *Advances in Health Science Education, 15*(4), 443–448.
Savery, R. J. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-Based Learning, 1*(1), 9–20.
Savin-Baden, M., & Wilkie, K. (2004). *Challenging research in problem-based learning*. Maidenhead/New York: Open University.
Schmidt, H. G. (1983). Problem-based learning: Rationale and description. *Medical Education, 17*, 11–16.
Stillings, N. A. (1995). Cognitive psychology: The architecture of the mind. In N. A. Stillings & S. E. Weisler (Eds.), *Cognitive science* (pp. 15–86). Cambridge, MA: The MIT Press.
Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*, 295–312.

Sweller, J., Clark, R. E., & Kirschner, P. A. (2011, March). Teaching general problem solving does not lead to mathematical skills or knowledge. *Newsletter of the European Mathematical Society*, pp. 41–42.

Trafton, P. R., & Midgett, C. (2001). Learning through problems: A powerful approach to teaching mathematics. *Teaching Children Mathematics, 7*(9), 532–536.

Tseng, H.-C., Chou, F.-H., Wang, H.-H., Ko, H.-H., Jian, S.-Y., & Weng, W.-C. (2011). The effectiveness of problem-based learning and concept mapping among Taiwanese registered nursing students. *Nurse Education Today, 31*, e41–e46.

Wells, S. H., Warelow, P. J., & Jackson, K. L. (2009). Problem based learning (PBL): A conundrum. *Contemporary Nurse, 33*(2), 191–201.

Wieseman, K. C., & Cadwell, D. (2005). Local history and problem-based learning. *Social Studies and the Young Learner, 18*(1), 11–14.

Wilkerson, L., & Gijselaers, W. H. (1996). Concluding comments. *New Directions for Teaching and Learning, 68*, 101–104.

Woods, D. R. (1996). Problem-based learning for large classes in chemical engineering. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bring problem-based learning to higher education: Theory and practice* (pp. 91–99). San Francisco: Jossey-Bass.

Zwaal, W., & Otting, H. (2012). The impact of concept mapping on the process of problem-based learning. *Interdisciplinary Journal of Problem-Based Learning, 6*(1), 104–128.