15 Problem-Based Learning

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Problem-based learning (PBL) is an active approach to learning in which learners collaborate in understanding and solving complex, ill-structured problems (Barrows, 2000; Savery, 2006). Because of their complex and ill-structured nature, these problems require learners to share their current knowledge, negotiate among alternative ideas, search for information, and construct principled arguments to support their proposed solutions. The goals of PBL address a large range of cognitive and affective dimensions, with studies indicating that PBL students productively engage in deep approaches to learning and problem solving (Walker & Leary, 2009). As students engage with ill-structured problems, they develop skills in reasoning and self-directed learning and construct flexible knowledge (Hmelo-Silver, 2004). Compared to traditional forms of instruction, PBL enhances students' ability to transfer knowledge to new problems and to achieve more coherent understandings (e.g., Hmelo, 1998).

To provide readers with an idea of how PBL looks, we present two examples from clinical disciplines. The first is an example of how a typical diagnostic PBL problem works in a medical context.[1]

Example 1

A group of second-year medical students attended a PBL tutorial that usually consisted of two two-hour sessions. At the start of the first session, they were presented with a *problem scenario* (also known as a "case") written on a piece of paper. The problem scenario occurred in a curriculum unit organized around the musculoskeletal system and was presented as follows:

> Mr. Ho was a 60 year old machine operator in a garment factory who had enjoyed good health previously. He has married and had a son and a 4 year old grandson. The family had lived for 15 years on the 4th floor of a public housing estate with no elevators. Mr. Ho visited his family physician and complained of discomfort in both knees, worse on the right side. Each morning, he had to walk to the bus stop to get to work. In

[1] Case excerpted from the PBL curriculum of the Medical School of The University of Hong Kong.

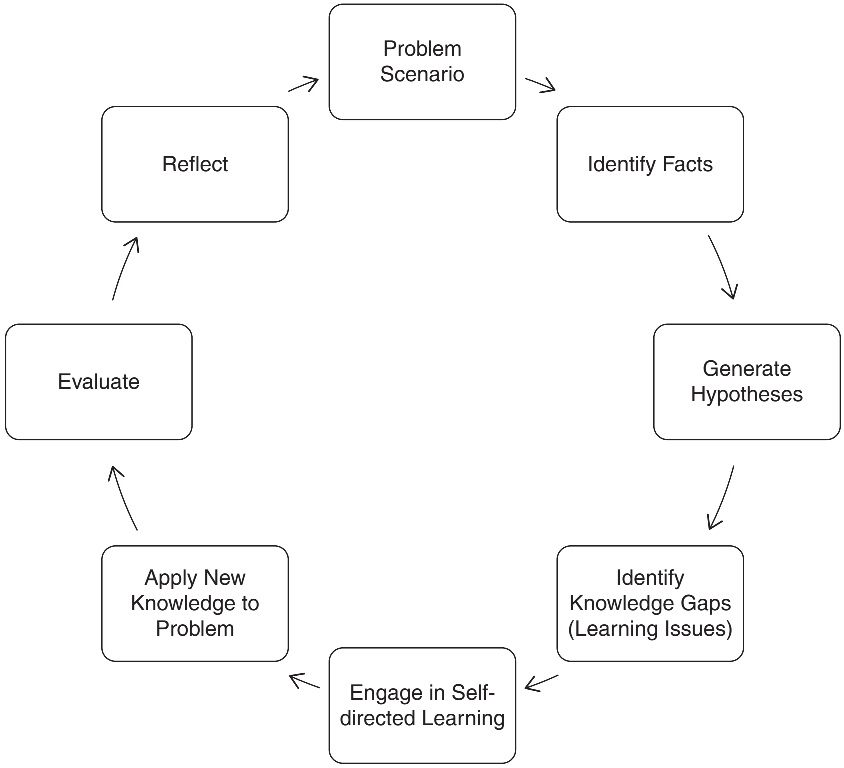

Figure 15.1. *PBL tutorial cycle (adapted from Hmelo-Silver, 2004).*

> the past few months, he had found this increasingly difficult, particularly when he was walking down the stairs. Additionally, he was not spending as much time playing with his grandson as he used to.

We show the PBL cycle for how this problem would be enacted in Figure 15.1. After reading the problem scenario, students were asked to *identify important facts*, such as the patient, Mr. Ho, was 60 years old, he was experiencing discomfort in both knees, and was having escalating difficulty walking.

The students then used their background knowledge and the facts they had just identified to *generate initial hypotheses* about Mr. Ho. Students were then given more information about Mr. Ho's medical history and physical examination, which they used to *generate learning issues* and *identify knowledge gaps*, which in turn led them to engage in *self-directed learning* aimed at confirming their diagnosis and at formulating plans for managing the treatment of Mr. Ho. During the second two-hour session, students used what they had learned during the self-directed learning of the first session and applied it to solving problems arising from the presentation of additional information such as the results of laboratory orders and information on clinical and socioeconomic management. They *evaluated* the information and made final decisions on the diagnosis and management of Mr. Ho's medical problems. Finally, the students revisited the learning issues and *reflected on* what they had learned in the PBL unit. During both two-hour sessions, the tutor asked many questions to *scaffold* students' problem solving (see Reiser & Tabak, Chapter 3, this volume), including the causes of symptoms, diagnosis and differential diagnoses, indicators from the physical exam and laboratory tests, treatment plans, side effects of the surgery, and so forth. The whiteboard is an important tool for representing key case information (often listed in a column labeled "Facts" and hypotheses), sometimes labeled "Ideas," and for recording the "learning issues" that will drive self-directed learning, discussion, evaluation, and reflection.

Example 2

Another style of problem in first-year undergraduate dentistry (also at The University of Hong Kong) follows a similar cycle but illustrates the role of educational technologies in PBL. Using the timed release function of the Learning Management System (Moodle, in this case) in the first tutorial (T1), all six groups simultaneously access a video-based problem accompanied with inquiry materials in the form of 3-D anatomical images. The group process of *problem exploration* (facts and ideas) is stimulated and mediated by large-screen visualization and digital object manipulation using an interactive whiteboard (IWB). Moodle resources such as recordings of thematically linked presentations (in-house and open access) and supporting materials for practical workshops (e.g., anatomy) posted after T1 and online discussion forum postings for self-directed learning provide further *scaffolding of learning*. Second tutorial (T2) discussions *share new information and apply this to the problem*, in some groups through generating a collaborative document. Additional use of tools such as concept mapping software (Bridges, Dyson, & Corbett, 2008) *consolidates learning* as a post-problem assignment posted on Moodle after the final tutorial.

In these examples, PBL was a curriculum-level pedagogical strategy. Full, curriculum-level implementation means that PBL is the pedagogical base of a curriculum, not simply one component of a curriculum that is otherwise didactic and instructionist. As such, the careful mapping of content and organization of problems aligned to learning outcomes across the years of the curriculum becomes both the driver and link across disciplines. Characteristics of successful PBL environments include: content integration across a range of disciplines; collaboration and teamwork; application and synthesis of new knowledge toward greater understanding of the dimensions of the problem at hand; reflection on the learning process with self and peer assessment; engagement with real-world problems and issues; and examination processes measuring progress toward the goals of PBL (Savery, 2006). These goals can be achieved at a macro level-- through full implementation of an overarching, integrated curriculum design-- and at a micro level in the complex interactions that occur in small group, student-led, and educator-facilitated discussions.

History of PBL

PBL had its beginnings in medical education at the Health Sciences Centre at McMaster University in the 1960s. The driving rationale was the observation, on the part of the faculty, that medical students were not learning how to apply their basic science knowledge to clinical care (Barrows & Tamblyn, 1980). After its beginnings in medicine, PBL in higher education blossomed – initially in other health sciences curricula, then in professional programs such as engineering, architecture, and education, and finally in gifted education and other primary and secondary school contexts (Walker & Leary, 2009). This swift spread across disciplines was also evident geographically, with PBL first moving across most Western higher education contexts, then extending to medical programs in the Asia-Pacific region in the late 1990s, mainly in Australia and Hong Kong, with recent expansion in Southeast Asia and Mainland China (e.g., Hmelo-Silver, 2012).

Indeed, globally, we are witnessing a rapid change in the way education perceives itself and how it is perceived by society, in an era characterized by uncertainty, continuous risk, and shifting loyalties and trust. As our views of time and knowledge have shifted with current expectations for instant access to information on demand, the impact of these social changes on higher education reflects fundamental shifts in the way we perceive knowledge and learning. These shifts can be described in terms of movement from inert and fragmented knowledge to a notion of knowledge as a tool for thinking and acting; from an individualistic model of the learner to one of learning communities; and from a teaching dynamic to a learning dynamic (Bridges, Whitehill, & McGrath, 2012). This has seen a drive away from learning experiences that focus on content and presentation to those that focus on student activity through the design of learning tasks and environments and the provision of tools for individual and collaborative work.

Theory of PBL

PBL is grounded in the constructivist and sociocultural theories that underlie much learning sciences research (see Nathan & Sawyer, Chapter 2, this volume). For example, PBL problems are designed to situate learning in real-world contexts (Greeno & Engeström, Chapter 7, this volume). In a PBL group, identification of the problem, integration of knowledge, and internalization of knowledge occur as a socially negotiated and constructed process (Downing, 2009; Hmelo-Silver & Barrows, 2006). PBL adopts a process-based approach to knowledge construction, seeking to provide students with ways of knowing – not only in developing the skills to access information and gain knowledge, but also in analyzing and synthesizing the multiple and often conflicting sources so as to manage information. PBL is also grounded in adult learning principles of self-directed learning, with the goal of promoting student-centered education (Barrows & Tamblyn, 1980) in an environment of partnership, honesty, openness, respect, and trust.

In PBL groups, students activate prior knowledge in initial discussions, which helps prepare them to integrate new understanding (Schmidt, Dauphinee, & Patel, 1987). Dolmans and Schmidt's synthesis of studies on cognitive and motivational effects of small group learning in PBL found that engagement in the following aspects of the PBL process was consequential to stimulating students' "intrinsic interest in the subject matter":

- activation of prior knowledge;
- recall of information;
- cumulative reasoning;
- theory building;
- cognitive conflicts leading to conceptual change; and
- collaborative learning construction (Dolmans & Schmidt, 2006, p. 333).

Drawing on constructivist theory, Schmidt, Rotgans, and Yew have recently proposed two related explanations for why PBL is effective. The first is an "activation-elaboration hypothesis" to describe the PBL process whereby students activate prior knowledge to initiate and then refine mental models as they discuss the problem and identify knowledge gaps with peers (Schmidt et al., 2011, p. 792). This is supported by studies into understanding knowledge building across the problem cycle whereby learning in one phase of the PBL process is seen as academically consequential to the next phase (Bridges, McGrath, & Whitehill, 2012). In other words, later parts of the tutorial process build on the earlier tutorial discussions and self-directed learning. The second is a "situational interest hypothesis" that explains how the real-world and applied nature of the presented problem arouses students' interest. This interest then leads to an ongoing engagement and a desire to seek out new information until "hunger for new information related to the problem is satisfied" (Schmidt et al., 2011, p. 793).

Because PBL asks learners to work in teams, PBL results in the social construction of knowledge, as learners engage in collaborative inquiry to solve complex real-world problems. For example, medical students learn by solving real patient problems using the inquiry skills of medical practice. From a cognitive perspective, organized learning experiences foster students' understanding of concepts through problem-solving activities, but from a situative perspective, social interactions are part and parcel of knowledge construction. A situative perspective argues that social practices support the development of students as capable learners, competent in both disciplinary knowledge and problem solving (Greeno & Engeström, Chapter 7, this volume).

These perspectives are integrated in the notion of cognitive apprenticeship (Collins & Kapur, Chapter 6, this volume). A cognitive apprenticeship makes key aspects of expertise visible through modeling and coaching as learners engage in meaningful tasks (Hmelo-Silver, 2004). Facilitators make their expertise visible through questions that scaffold student learning through modeling, coaching, and eventually fading back some of their support. In PBL, the facilitator models learning strategies rather than teaching content knowledge (Hmelo-Silver & Barrows, 2006, 2008). In PBL, the facilitator must continually monitor the discussion, selecting and implementing appropriate strategies as needed. In many cases, these strategies involve posing questions to guide the student team's inquiry process. In other cases, the facilitator may push students to justify their thinking or explain their ideas. This may help group members to realize the limits of their understanding and identify learning issues. As students become more experienced with PBL, facilitators can fade their scaffolding as the learners gradually adopt much of the facilitator's questioning role. A sociocultural perspective provides further theoretical grounds if one is to take the view of PBL as a social system embedded in larger cultural contexts. Additionally, for small group learning, sociocultural perspectives reflect the influence of the Vygotskian notion that the act of speaking transforms thought (John-Steiner & Mahn, 1996). Bridges, McGrath, and Whitehill (2012) traced how semiotic mediation and intervisual links between real and virtual inquiry materials are consequential for learning in a PBL. As, such, the building of academic discourse through negotiation in the PBL process can be seen as highly contingent to learning.

Others have proposed that the knowledge building perspective (Scardamalia & Bereiter, Chapter 20, this volume) can explain learning in PBL. Hmelo-Silver and Barrows (2008) documented the interaction of social and cognitive activity that supported collaborative knowledge building as the PBL groups engaged in joint activity to support the collective improvement of ideas. This aligns with a Vygotskian perspective that knowledge begins in the external world (e.g., the group knowledge building) and is later internalized by the individual.

PBL Pedagogical Design

The heart of PBL is the PBL tutorial process (Figure 15.1) during which students are first presented with information about a problem and then engage in collaborative inquiry to better understand the problem and identify learning issues. Thus, the quality of the problem is the basis for the success of PBL.

The Role of Problems in PBL

PBL presents students in different subject domains with various kinds of problems to solve, such as diagnostic problems, design problems, strategic performance problems, and decision-making problems.

- *Diagnostic problems* are those in which learners have to determine the cause of a problem. The classic example is the medical patient diagnosis problem in which learners need to construct a pathophysiological explanation (e.g., Hmelo-Silver & Barrows, 2008).
- *Design problems* involve creating an artifact, generally based on a set of functional specifications.
- *Strategic performance problems* ask for "applying tactics to meet strategy in real-time complex performance maintaining situational awareness" (Jonassen, 2000, p. 75). Examples include managing an investment portfolio or playing an interactive computer game.
- *Decision-making problems* means a choice/decision needs to be made from a number of competing alternatives. This type of problem is often used in business administration (Stinson & Milter, 1996), leadership education (Bridges & Hallinger, 1996, 1997), or emergency medical care scenarios where personnel are asked to make high-stake decisions in high-risk settings (Lu & Lajoie, 2008).

Although they have important differences, these problems have a number of features in common that are key to the design and success of PBL activities. For instance, problems are often categorized as well structured and ill structured (Newell & Simon, 1972). However, structuredness is a continuum along which problems vary from highly structured problems such as algorithmic problems, to very ill-structured problems such as design problems and dilemmas (Jonassen, 2000). A well-structured problem is a problem for which the goal, problem space, path to solution, and information needed to solve it can be clearly and explicitly specified. An ill-structured problem is a problem for which the goal, problem space, path to solution, and information needed to solve it cannot be clearly and explicitly specified. In PBL, problems are often moderately ill structured, with the degree of structure tailored to the age and expertise of the learners and their learning goals.

PBL problems can also be characterized in terms of their complexity, which refers to the breadth of knowledge needed to solve them, the level of difficulty involved in understanding and applying the relevant concepts, the level of skill and knowledge needed to explore the problem, and the degree of linearity involved in relations among the variables in the problem space (Jonassen & Hung, 2008). Structure and complexity determine how difficult a PBL problem will be for students to solve and how willing they will be to try to solve it. However, in problem design, theory-driven considerations of structure and complexity fail to target student perspectives such as promoting self-directed and significant learning, stimulating critical thinking, and triggering interest. Given that the quality of problems is a major factor in determining learning outcomes (Van Berkel & Schmidt, 2000), features that are valued by researchers and by students should be taken into consideration in the problem design though they might be different. Classically ill-structured problems are multidimensional and may not afford a direct or easy solution. By engaging in a structured reasoning process, however, students gain understanding of the problem complexities and apply appropriate reasoning processes and disciplinary discourse practices.

In a recent meta-analysis, Walker and Leary (2009) found that certain kinds of problems may more effectively promote learning than others. Although in studies of PBL diagnostic problems were most commonly used, other types of problems have been successfully employed in PBL. The meta-analysis showed the greatest achievement effects were for design problems and strategic performance problems. The ill-structured problems used in PBL can serve as the basis for high levels of problem-relevant collaborative interaction; however, groups may need higher-quality facilitation as the problems become less structured to make this interaction productive (Van Berkel & Schmidt, 2000).

Scaffolding

Students would not be successful in PBL without scaffolding for their problem solving and inquiry (Hmelo-Silver & Barrows, 2006). Scaffolding in PBL helps learners manage the complexity of the ill-structured problem space and group dynamics while gently guiding learners toward achieving content and reasoning goals. Scaffolding is temporary support that allows learners to accomplish their goal. It is support that (a) enables a student to accomplish tasks they could not otherwise do and (b) facilitates learning to succeed even without the support. Well-designed scaffolds help ensure that learners succeed at new tasks and can extend their competencies (Reiser & Tabak, Chapter 3, this volume). In general, scaffolding is meant to fade, disappearing over time so that the learner can succeed without the support. In PBL, scaffolding tends to take three forms.

1. *Communicating process* involves presenting the process involved in solving the problem to students, structuring and sometimes simplifying the process. Presenting the process to students can occur through modeling or demonstration. This structure constrains and guides student inquiry. The PBL tutorial process is a good example of this. The whiteboard also helps communicate the process by reminding learners what they need to attend to.

2. *Coaching* refers to providing guidance to learners while they are performing a task. This can be accomplished by highlighting critical steps of the process as the student is working on a problem. Coaching can include statements that help frame the problem and articulate inquiry goals. In PBL, the facilitator helps accomplish this through questions that model the kinds of thinking that students should be learning. For example, asking them why they need particular pieces of information helps students focus asking questions on particular goals rather than just trying to gather all possible information.
3. *Eliciting articulation* is asking the student to explain (to themselves or others). This can enhance constructive processing and make thinking visible and therefore an object for discussion and revision. Questions that ask learners to articulate their thinking can lead to significant reflection and subsequent learning. Encouraging reflection helps prepare learners to transfer the knowledge and skills they are learning (Salomon & Perkins, 1989).

Teacher as Scaffold

In PBL, the facilitator's role is to guide active learning on the part of the student team, rather than to provide information through lecture or instruction. PBL facilitators accomplish most of their scaffolding through open-ended questioning and by deploying an array of strategies (Hmelo-Silver & Barrows, 2006, 2008). Hmelo-Silver and Barrows (2006) identified these strategies through an interaction analysis of video of an expert facilitator (see Table 15.1).

Representations as Scaffolds

In PBL, students externalize their developing ideas by inscribing them on a whiteboard for display and discussion. Externalized representations contribute to collective knowledge construction in several ways (Roth, 1998). First, representations serve as shared referential objects for group members and provide common ground for discussion. Second, the structure of the representation can guide the students' discussion (Suthers & Hundhausen, 2003). In PBL, several representational artifacts are constructed by student teams under the guidance of a facilitator. One representation is a formally structured PBL whiteboard with facts, ideas or hypotheses, learning issues, and an action plan (Lu, Lajoie, & Wiseman, 2010). This helps guide the students to consider certain issues that the facilitator believes will lead to a more effective learning discussion. The whiteboard serves as an external memory for the students – it reminds them of their ideas, both solidified and tentative, as well as hypotheses that students need to test. One ritualized aspect of the PBL tutorial is "cleaning up the boards" (Hmelo-Silver & Barrows, 2006). The whiteboard provides a constant reference point within the learning space, allowing the facilitator (or the students themselves) to

Table 15.1. *Facilitation strategies (adapted from Hmelo-Silver & Barrows, 2006)*

Strategy	How accomplished
Use of open-ended and metacognitive questioning	General strategy to encourage explanations and recognition of knowledge limitations
Pushing for explanation	Construct causal models Students realize limits of their knowledge
Revoicing	Clarify ideas Legitimate ideas of low-status students Mark ideas as important and subtly influence direction of discussion
Summarizing	Ensure joint representation of problem Involve less vocal students Help students synthesize data Move group along in process Reveal facts that students think are important
Generate/evaluate hypotheses	Help students focus their inquiry Examine fit between hypotheses and accumulating evidence
Map between symptoms and hypotheses	Elaborate causal mechanism
Check consensus that whiteboard reflects discussion	Ensure all ideas get recorded and important ideas are not lost
Cleaning up the board	Evaluate ideas Maintain focus Keep process moving
Creating learning issues	Knowledge gaps as opportunities to learn
Encourage construction of visual representation	Construct integrated knowledge structure that ties mechanisms to observable effects

take advantage of this external representation of the students' unfolding ideas about the problem. This occurs at several times but, in particular, after students have discussed the resources they used for their self-directed learning. This is important because it provides an occasion for students to evaluate each of their hypotheses, look at the fit to data, and reflect on what they have gleaned from their self-directed learning. Discussions of which hypotheses are more or less likely often center around what needs to be filled in on the whiteboard (see examples in Figure 15.2).

Students often discuss how hypotheses should be ranked or when they should be added or deleted. These structured whiteboards serve as a focus for students to negotiate their ideas and identify those that can be postponed for later consideration. When students mark something for entry on the whiteboard, it also signifies agreement by the group that the item is worth attending to. The use of the whiteboard supports reasoning, knowledge

Facts	Ideas	Learning Issues
Ann George	Diabetic neuropathy	Guidelines for hypertension
72 y/o F	Multiple sclerosis	Diabetic neuropathy
CC: Numbness on Bottoms of Feet	~~Alcoholic neuropathy~~ ~~Malnutrition~~	Multiple Sclerosis
HPI Numbness in feet 4-5 weeks	Afferent Neuropathy Peripheral neuritis	Peripheral neuritis
Weak tingling in fingers	~~Guillain Barré syndrome~~ Spinal cord lesion	Innervations of foot and Blood supply
EXAM HR 72 T 98.6 RESP 16 Broad-based gait	Herniated Disc ~~Hypothyroidism~~ Toxicity Arsenic Lead ~~Anemia~~ ~~Pernicious~~	Pathophysiology of numbness Guillain Barré Paresthesia
ROS 0 HA, Migraines	~~Scleroderma~~ Electrolyte	Paralysis Afferent Tracts

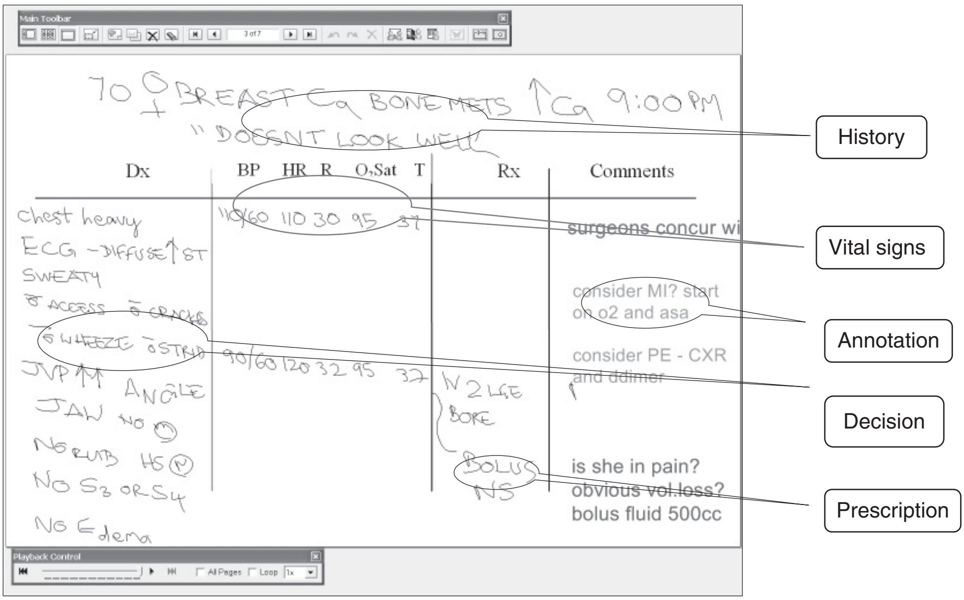

Figure 15.2. *(a) Transcribed PBL whiteboard in medical education (adapted from Hmelo-Silver & Barrows, 2008), (b) Example of PBL electronic whiteboard used in solving medical emergency problems (adapted from Lu et al., 2010).*

construction, and self-directed learning, as students use it to remind them of what they are considering, what they know, and what they still need to learn. Other representational tools students may construct are less formal representations such as flow charts, concept maps (Bridges et al., 2009), and diagrams. Hmelo-Silver and Barrows (2008) provided an example of how the activity of drawing one of these representations led to rich discussion.

Self-Directed Learning

A key feature of PBL is the self-directed learning (SDL) that is initiated through the identification and discussion of learning issues. Students discuss problems initially based on their prior knowledge. The learning issues are concepts that students have identified that are important for the PBL task and that they cannot address with their existing knowledge (Hmelo-Silver, 2004). The student-centered nature of PBL supports SDL as students have to identify knowledge gaps, plan their research to address the learning issues, critically evaluate the information sources they unearth, and engage in self-assessment to see if what they have learned matches their learning goals (Hmelo & Lin, 2000). This involves the use of self-regulated learning strategies as students are required to be metacognitively aware of their knowledge, to plan their research, to allocate time and effort appropriately, and to be intrinsically motivated.

Collaboration

Collaboration requires students to make their thinking visible, as they discuss their developing understandings and hypotheses, thus making their ideas open for negotiation and revisions. One obstacle to implementing PBL is that many medical schools consider small group learning less cost-effective; the financial pressures are toward larger student groups. Conventional practice in PBL has been for groups to be medium-sized, ranging from five to eight students for optimal engagement in the process and academic outcomes (Barrows, 2000; Dolmans & Schmidt, 2006). Lohman and Finkelstein's (2000) design study of the effect of group size in PBL on selected outcome measures found that students' levels of self-directedness increased in small (3 students) and medium (6 students) groups, but decreased in large (9 students) groups. Additionally, they posited that, to promote the development of students' problem-solving skills, PBL needs to be used recurrently over a fairly long period of time, thereby supporting other research findings suggesting that PBL should be the core foundation of the curriculum, rather than one added element to an otherwise instructionist curriculum, such as a single-semester class. Research in the learning sciences suggests that this is because of the time it takes to develop new cultural norms associated with PBL practices (Kolodner et al., 2003).

Reflection for Learning and Transfer

In PBL, learners are encouraged to constantly reflect on their developing understandings in order to support the construction of extensive, flexible, and usable knowledge (Salomon & Perkins, 1989). Reflection helps students: (1) relate their new knowledge to their prior understanding, (2) mindfully abstract knowledge, and (3) understand how the strategies might be reapplied. PBL incorporates reflection throughout the tutorial process, and also when completing a problem. Students take opportunities to reflect on their hypothesis list and their own knowledge relative to the problem. After a problem, students reflect on what they have learned, how well they collaborated with the group, and how effective they were as self-directed learners. As students make inferences that tie general concepts and skills to the specifics of the problem that they are working on, they construct more coherent knowledge. This "mindful abstraction" that occurs during reflection is a critical aspect of the PBL process. The reflection process in PBL helps learners make inferences, identify knowledge gaps, and prepare to transfer problem-solving strategies, self-directed learning strategies, and knowledge to new situations.

Assessment

Given the aspirations of PBL (and other learning sciences-based approaches to 21st-century skill learning) to promote deeper conceptual understanding, integrated and situated knowledge, and adaptive expertise and transfer, we need a better understanding of how to develop appropriate formative and summative assessments. Assessment of PBL may focus on the mastery of knowledge and skills or on the mastery of problem-solving processes. After all, in many practice-oriented professions, knowledge is neither inert nor limited to classroom settings; rather it has the goal of enhancing professional practice. For example, in medicine, students learn basic medical science such as physiology and biochemistry to prepare them for clinical practice. Because the purpose of PBL is to help students apply basic medical knowledge, it would be more meaningful to assess students with respect to their ability to integrate their physiological or biochemistry knowledge into clinical practice rather than ask them to write down the facts about their knowledge. Thus, PBL assessment seeks to emphasize elements involved in clinical practice.

Effects of PBL

A number of meta-analyses have focused on the effectiveness of PBL (Albanese & Mitchell, 1993; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Strobel & Van Barneveld, 2009; Vernon & Blake, 1993). For instance, its effectiveness has been assessed with respect to academic achievement, cognition, metacognition, attitude, and behavior under different teaching methods. Most assessment has focused on knowledge structure and metacognitive skills (Gijbels et al., 2005). For instance, compared to students receiving lecture-based instruction (Albanese & Mitchell, 1993; Vernon & Blake, 1993), PBL students had stronger procedural knowledge and were better at linking and applying declarative and procedural knowledge to situations, but non-PBL students had more solid basic science knowledge (Gijbels et al., 2005). PBL is predicted to promote metacognitive skills, particularly planning and monitoring skills (see Winne & Azevedo, Chapter 4, this volume). Several studies have confirmed this prediction; for instance, the metacognitive skills of first-year undergraduates in a year-long PBL program were significantly higher than those of students in a non-PBL program on all dimensions (Downing, 2009).

Students tend to have positive attitudes toward PBL. For instance, medical students find PBL programs more engaging and useful, but also more difficult than non-PBL programs (Albanese & Mitchell, 1993). PBL students are more confident in coping with uncertainty and in recognizing the importance of social and emotional factors in illness (Silverstone, 1998). Students find PBL environments more interesting and relevant (de Vries et al., 1989; Schmidt et al., 1987), more conducive to teamwork, and more supportive of doctor-patient relationships (Bernstein, Tipping, Bercovitz, & Skinner, 1995).

PBL is also found to facilitate self-directed learning. Comparing PBL and non-PBL trained medical students, Hmelo and Lin (2000) found that the former were more likely to use hypothesis-driven strategies in planning learning and to integrate new information into revised explanations. PBL students tended to use self-chosen learning resources and non-PBL students tended to use lecture notes (Blumberg & Michael, 1992), and PBL students tended to use more diverse and meaningful study techniques than non-PBL students (Coles, 1985).

With PBL's roots in medical education, outcome assessment tends to focus on the effectiveness of PBL in this field. However, more research is focusing on other fields (Abrandt Dahlgren & Dahlgren, 2002) and on learners at different levels. Further research should examine why, how, and in what contexts PBL might lead to attitude changes, and to what degree.

Most assessment research has focused on measuring types of knowledge and knowledge applications, whereas PBL also supports the development of reasoning (Wood, Cunnington, & Norman, 2000), problem solving (Hmelo, Gotterer, & Bransford, 1997), and decision making (Lu & Lajoie, 2008), all of which should be emphasized in future research on PBL.

PBL in Transition/and Transforming PBL

PBL: Future Practice

Almost four decades have passed since PBL was first introduced, and it has undergone a number of transformations or revisions. For instance, the original McMaster undergraduate MD program has gone through two major curriculum revisions since adopting PBL in 1969 (Neville & Norman, 2007). While the first PBL curriculum emphasized small group tutorials, self-directed learning, and tutorial performance-based assessment, the second curriculum focused on building a foundation based on common medical problems so as to equip students with the knowledge and skills they needed to understand and manage common medical conditions. The third curriculum focused on structuring and arranging concepts and body systems into logical sequences. These revisions reflect changes in the requirements and demands of medical education as well as possible tensions regarding curriculum coherence at the program level.

One of the greatest challenges to curriculum development for any PBL program, especially those adopting PBL at the curriculum design level, is faculty commitment. The silo, course-based approach gives much greater autonomy to individual academics and does not require the level of coordination and faculty collaboration that PBL curricula demand, because careful curriculum mapping is required for content knowledge to be systematically integrated horizontally and vertically in spiral curriculum structures. A single problem, for example, usually integrates knowledge from two to three disciplinary domains. Because no single facilitator can be a content expert for all dimensions of the problem, detailed facilitator guides are devised and shared at regular briefings and debriefings. Some programs have avoided this challenge by introducing PBL at the discipline-specific course level (e.g., Anatomy 101). This requires less cross-disciplinary cooperation and supporting infrastructure, and as such is seen by many as more feasible; however, this changes only classroom method and does not address larger issues of curriculum design and integration that PBL researchers have found consequential to learning (Mok, Dodd, & Whitehill, 2009).

Although PBL emphasizes the role of teachers as facilitators in scaffolding problem-solving processes, little is known about the knowledge and skills teachers bring to such processes and the kinds of knowledge and skills that should be promoted in professional development programs and how to foster them. Ongoing development and quality assurance of PBL facilitators remains a challenge for curriculum managers. While much is done to focus on induction programs for the new facilitator/tutor, there is a pressing need to provide advanced academic development for PBL facilitators. Walker and colleagues (2011) have shown that the training that teachers receive with respect to technology skills and PBL pedagogy leads to differences in how they perceive knowledge and experience and in their confidence in technology integration in PBL, as well as the actual quality of PBL design after the training. The results imply that the ways teachers are trained has an impact on how they design PBL activities, particularly while using technology. With regard to professional development for PBL facilitators and curriculum designers, there is potential for further research to investigate both innovations in the delivery of professional development programs and studies exploring facilitator effectiveness, including in situ judgments regarding tutorial performance. In terms of ongoing quality assurance, the issues of reliability of facilitator feedback and consistency in standards are as increasingly relevant for PBL as for any other education program.

PBL and Technology

The most recent wave of undergraduate PBL students are more increasingly engaged in Web 2.0 technologies that are generally synchronous and interactive. The rise of new educational technologies is seeing Net Generation or tech savvy learners and their facilitators moving into the next generation of blended learning in PBL. Modern PBL curriculum designers in clinical education are building on the initial principles of the traditional PBL tutorial process to adapt to changing programs, students, and technologies (Howe & Schnabel, 2012). As the visual becomes more predominant for digitally engaged learners, intervisual relations between texts can be seen to support and enhance collective and individual cognition whereby in "the social learning process that is PBL, the accessing of visual tools and learning objects in the final tutorial becomes socially and academically relevant" (Bridges, Botelho, & Green, 2012, p. 117).

Other roles for technology in PBL include providing rich contexts, communication spaces, and scaffolds. Hmelo-Silver and colleagues (2013) used video cases as PBL triggers to help medical students learn about communicating bad news. In the STELLAR system (Hmelo-Silver, Derry, Bitterman, & Hatrak, 2009), interactive whiteboards were used to guide students in instructional planning as students engaged in a hybrid PBL model. The whiteboard was adapted from the general PBL whiteboard described earlier to be more specific to these instructional planning tasks with tabs for *Enduring Understanding*, *Evidence of Understanding*, and *Activities.* It served as a communication space for students and the facilitator to comment on and question other students' entries. In another example of a PBL tutorial dealing with medical emergencies, an interactive whiteboard was used as a collaborative argumentation tool where participant students could annotate patient information, comment on, and suggest alternatives for decisions (Lu et al., 2010). Thus, technology was used to scaffold collaborative decision making by promoting the discussion of various proposed actions and plans. These are just a few examples of how technology can support PBL.

Future Directions for PBL Research

Recent work has suggested new directions for research in PBL. Bridges, Whitehill, and McGrath (2012) noted potential research in the areas of student learning outcomes, new research methodologies, and professional development. New studies (particularly comparative and longitudinal studies) are needed to understand the long-term effects of PBL in terms of graduate competences (Shuler, 2012) and effects on professional practice (Toulouse, Spaziani, & Rangachari, 2012).

In particular, we see three general areas that we anticipate would be fruitful for learning scientists investigating PBL:

1. Research in other Disciplines and Grades

PBL research needs to extend to disciplines beyond medical education and to learners in K-12 environments, not only with university students. Most research has focused on medical education, and this has resulted in a lack of research on the development, implementation, and evaluation of PBL in other disciplines – such as history and engineering – and with learners at other levels. This research would be important for the learning sciences to understand under what circumstances PBL might result in enhanced learning outcomes. Part of this research should focus on the adaptations and kinds of scaffolding that might be needed as PBL is used in settings that have larger numbers of groups, differing disciplines (and disciplinary norms), and students of younger ages and with more variable prior knowledge.

2. Research on Evaluation and Assessment of PBL

The effectiveness of PBL with respect to other curricula should be assessed by measuring the components of PBL settings rather than by focusing on PBL programs as a whole. For instance, some PBL programs emphasize the structure of blocks and some focus on integrating technology into the PBL program. Thus, when evaluating or assessing PBL, these components should be highlighted. Further, systematic assessment should go beyond associated knowledge structures or its effectiveness in promoting specifically recognized PBL skills, such as reasoning, problem solving, and decision making, as well as the "soft skills" of self-directed learning and collaboration. The greater tension for PBL may be in the assessment of "process" such as the quality of contributions to the group rather than the standard measurement of student "products" such as written assignments or exams. There is also a tension in creating the kind of embedded formative and summative assessments that are consistent with the values of PBL but that are also psychometrically valid measures of student learning.

3. Research on Supporting PBL on Larger Scales

One question that is important for using PBL on a large scale is figuring out how to distribute scaffolding among facilitators, technology, and other contextual features (Hmelo-Silver et al., 2009). Further, research can focus on designing technology for distributing expertise to facilitators; for sharing and distributing PBL cases to large audiences via online technology; for digitizing PBL tutorials by expert teachers and distributing them to schools; and for digitalized PBL tutorials as teacher development tools.

Implications for the Learning Sciences

Addressing these research areas has the potential to inform learning sciences more broadly. Many of the characteristics of PBL are relevant to other learning sciences-informed instructional approaches:

- Facilitation in PBL is related to the broader issues in supporting student agency in student-centered learning environments.
- Understanding how different scaffolds and representations mediate student learning in PBL as well as other approaches to inquiry.
- Roles for technology in creating contexts, scaffolding, and discursive spaces in PBL would also apply to supporting other forms of inquiry and guided discovery.
- Understanding the nature of generative problems in PBL is part of a broader discussion of design principles.

Exploring the synergies and creating conversations about both common ground and important differences should contribute to our goals of better understanding learning and designing more effective learning environments.

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