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Problem-Based Learning: What and How Do Students Learn?

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Problem-based approaches to learning have a long history of advocating experience-based education. Psychological research and theory suggests that by having students learn through the experience of solving problems, they can learn both content and thinking strategies. Problem-based learning (PBL) is an instructional method in which students learn through facilitated problem solving. In PBL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn in order to solve a problem. They engage in self-directed learning (SDL) and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. The teacher acts to facilitate the learning process rather than to provide knowledge. The goals of PBL include helping students develop 1) flexible knowledge, 2) effective problem-solving skills, 3) SDL skills, 4) effective collaboration skills, and 5) intrinsic motivation. This article discusses the nature of learning in PBL and examines the empirical evidence supporting it. There is considerable research on the first 3 goals of PBL but little on the last 2. Moreover, minimal research has been conducted outside medical and gifted education. Understanding how these goals are achieved with less skilled learners is an important part of a research agenda for PBL. The evidence suggests that PBL is an instructional approach that offers the potential to help students develop flexible understanding and lifelong learning skills.

KEY WORDS: problem-based learning; constructivist learning environments; learning processes; problem solving; self-directed learning.

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Problem-based approaches to learning have a long history. They are one of many instructional approaches that situate learning in a meaningful task, such as case-based instruction and project-based learning. In the traditions of Kilpatrick (1918, 1921) and Dewey (1938), these approaches argue for the importance of practical experience in learning. Problem-based learning (PBL) is part of this tradition of meaningful, experiential learning. In PBL, students learn by solving problems and reflecting on their experiences (Barrows and Tamblyn, 1980). PBL is well suited to helping students become active learners because it situates learning in real-world problems and makes students responsible for their learning. It has a dual emphasis on helping learners develop strategies and construct knowledge (Cognition and Technology Group at Vanderbilt [CTGV], 1997; Collins *et al.*, 1989; Hmelo and Ferrari, 1997; Kolodner *et al.*, 1996).

A review of PBL is timely because issues of flexible thinking and lifelong learning have come to the fore in discussions of classroom reform (Bransford *et al.*, 2000; Greeno *et al.*, 1996). PBL is of increasing interest to K–16 educators as demonstrated by widespread publication of books written about PBL (e.g., Duch *et al.*, 2001; Torp and Sage, 2002). Educators are interested in PBL because of its emphasis on active, transferable learning and its potential for motivating students. This article first describes PBL and distinguishes it from other experiential approaches to learning. Second, it discusses the goals of PBL. Third, the PBL tutorial process is discussed in detail. Next, the article examines what we have learned about PBL. In particular, this section examines the research regarding the goals of PBL. Finally, the article discusses the research limitations and avenues for the future.

PBL AND OTHER EXPERIENTIAL APPROACHES

PBL is focused, experiential learning organized around the investigation, explanation, and resolution of meaningful problems (Barrows, 2000; Torp and Sage, 2002). In PBL, students work in small collaborative groups and learn what they need to know in order to solve a problem. The teacher acts as a facilitator to guide student learning through the learning cycle depicted in Fig. 1. In this cycle, also known as the PBL tutorial process, the students are presented with a problem scenario. They formulate and analyze the problem by identifying the relevant facts from the scenario. This fact-identification step helps students represent the problem. As students understand the problem better, they generate hypotheses about possible solutions. An important part of this cycle is identifying knowledge deficiencies relative to the problem. These knowledge deficiencies become what are known as the learning issues that students research during their self-directed learning (SDL). Following SDL, students apply their new knowledge and

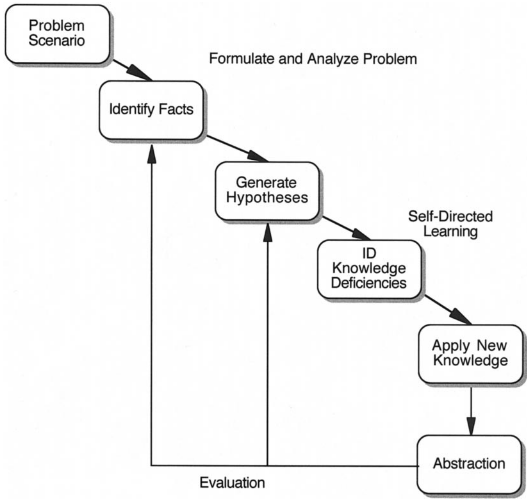

Fig. 1. The problem-based learning cycle.

evaluate their hypotheses in light of what they have learned. At the completion of each problem, students reflect on the abstract knowledge gained. The teacher helps students learn the cognitive skills needed for problem solving and collaboration. Because students are self-directed, managing their learning goals and strategies to solve PBL's ill-structured problems (those without a single correct solution), they also acquire the skills needed for lifelong learning. PBL was originally developed in medical schools and has been used in a variety of settings from middle school to professional education (Barrows, 2000; Barrows and Kelson, 1995; Barrows and Tamblyn, 1980; Gallagher *et al.*, 1992; Hmelo *et al.*, 2000; Hmelo-Silver, 2000; Torp and Sage, 2002; Williams, 1992).

PBL is one of a family of approaches that include anchored instruction and project-based science (CTGV, 1997; Krajcik *et al.*, 2000; Linn and Hsi, 2000; White and Frederiksen, 1998). As shown in Table I, all three approaches use a common problem and rely on the teacher to help guide the learning process. They differ in terms of the type and role of the problem, the problem-solving process, and the specific tools that are employed. For example, PBL uses realistic, ill-structured problems such as medical diagnosis or lesson design (Barrows, 2000; Hmelo-Silver, 2000). In this setting, the problem is the focus for acquiring knowledge and reasoning strategies. In anchored instruction, the problem is a video-based story that presents learners with a challenge at the end such as determining if a certain school project can be profitable. The problem has two roles in anchored instruction. First, it provides an apportunity for learners to apply their shared knowledge to a

Table I. Approaches to Learning Situated in Problem-Solving Experiences

	PBL	Anchored instruction	Project-based science
Problem	Realistic ill-structured problem	Video-based narrative ending with complex problem	Driving question
Role of problem	Focus for learning information and reasoning strategies	Provide shared experience so students can understand how knowledge can support problem solving Video supports problem comprehension	Focus for scientific inquiry process leading to artifact production
Process	Identify facts, generate ideas and learning issues, SDL, revisit, and reflect	Guided planning and subgoal generation	Prediction, observation, explanation cycles
Role of teacher	Facilitate learning process and model reasoning	Engage students' prior knowledge, model problem-solving strategies, provide content instruction when needed by students	Introduce relevant content before and during inquiry Guides inquiry process
Collaboration	Negotiation of ideas Individual students bring new knowledge to group for application to problem	Negotiation of ideas and strategies within small groups and whole class	Negotiation of ideas with peers and local community members
Tools	Structured whiteboard Student-identified learning resources	Video controller Problem-specific tools (e.g., maps, compasses)	Computer-based tools that support planning, data collection and analysis, modeling, and information-gathering

relevant problem. Second, the video supports ongoing problem comprehension as problems often require 15–20 steps for solution. In project-based science, the problem is a driving question such as "where does my garbage go?" The problem is the focus for scientific inquiry as students must determine how they will answer their question. In terms of process, PBL uses the specific PBL learning cycle shown in Fig. 1. Anchored instruction emphasizes planning and subgoal generation so the students can make the problem-solving task manageable. In project-based science, students engage in scientific inquiry cycles as they design experiments, make predictions, observations, and then construct explanations of why their prediction was or was not correct. In terms of tools, PBL uses a simple tool, a structured whiteboard with lists of facts, ideas (i.e., hypotheses), learning issues, and action plans (discussed later) to help structure the students' problem solving and learning. In contrast, project-based science uses a variety of computer-based tools to scaffold students problem solving. These include metacognitive scaffolding, planners, and modeling tools (Krajcik *et al.*, 2000; Linn and Hsi, 2000). Anchored instruction uses tools to help learners control which aspects of the video they want to review and includes a variety of problem-specific assessment tools (CTGV, 1997). Collaborative learning is an important aspect of all three methods. All of these methods have proven effective (e.g., CTGV, 1997; Hmelo, 1998; Krajcik *et al.*, 2000; Linn and Hsi, 2000; White and Frederiksen, 1998).

There are at least two key issues that go to the heart of all of these approaches to learning through problem solving. First, all the approaches emphasize that learners are actively constructing knowledge in collaborative groups. Second, the roles of the student and teacher are transformed. The teacher is no longer considered the main repository of knowledge; she is the facilitator of collaborative learning. The teacher helps guide the learning process through open-ended questioning designed to get students to make their thinking visible and to keep all the students involved in the group process. In anchored instruction and project-based science, the teacher does some direct instruction, often when students need information for the problem-solving activities. The SDL emphasis is a distinguishing feature of PBL. In PBL, students become responsible for their own learning, which necessitates reflective, critical thinking about what is being learned (Bereiter and Scardamalia, 1989). In PBL, students are asked to put their knowledge to use and to be reflective and self-directed learners.

GOALS OF PBL

Problem-based curricula provide students with guided experience in learning through solving complex, real-world problems. PBL was designed with several important goals (Barrows and Kelson, 1995). It is designed to help students

1) construct an extensive and flexible knowledge base;
2) develop effective problem-solving skills;
3) develop self-directed, lifelong learning skills;
4) become effective collaborators; and
5) become intrinsically motivated to learn.

Constructing extensive and flexible knowledge goes beyond having students learn the facts of a domain. It involves integrating information across multiple domains. Such knowledge is coherently organized around the deep principles in a domain (Chi *et al.*, 1981). It is also flexibly conditionalized to the extent that it can be fluently retrieved and applied under varying and appropriate circumstances (Bransford *et al.*, 1990). Increasingly flexible knowledge develops as individuals apply their knowledge in a variety of problem situations (CTGV, 1997; Kolodner, 1993).

Common sense suggests that to encourage students to develop flexible knowledge and effective problem-solving skills we must embed learning in contexts that require the use of these skills. Laboratory experiments have demonstrated that this is indeed the case (e.g., Needham and Begg, 1991; Perfetto *et al.*, 1983). Classroom-based research supports these findings as well (Gallagher *et al.*, 1992; Hmelo, 1998; Hmelo *et al.*, 2000; Schwartz and Bransford, 1998). Discussing problems in a PBL group (before beginning to research learning issues) activates relevant prior knowledge and facilitates the processing of new information (Schmidt *et al.*, 1989). Students are better able to construct new knowledge when they can relate it to what they already know (Bransford and McCarrell, 1977).

Achieving the second goal, the development of effective problem-solving skills, includes the ability to apply appropriate metacognitive and reasoning strategies. For example, hypothetical–deductive reasoning is an appropriate strategy for medical problem solving whereas analogical or case-based reasoning may be more appropriate in many design domains such as architecture (Kolodner, 1993; Kolodner *et al.*, 1996). Metacognitive skills refer to the executive control processes of planning one's problem solving, monitoring one's progress, and evaluating whether one's goals have been met (Schoenfeld, 1985).

Metacognitive strategies are also important for the third goal of developing self-directed, lifelong learning skills. These are the skills that enable autonomous learning. There are several subskills involved in SDL (Hmelo and Lin, 2000; Zimmerman, 2002). First, learners must have a metacognitive awareness of what they do and do not understand. Second, they must be able to set learning goals, identifying what they need to learn more about for the task they are engaged in. Third, they must be able to plan their learning and select appropriate learning strategies. In other words, they must decide on a course (or courses) of action to reach these goals. Finally, as they implement their plan, learners must be able to monitor and evaluate whether or not their goals have been attained.

The fourth goal of being a good collaborator means knowing how to function well as part of a team. This encompasses establishing common ground, resolving discrepancies, negotiating the actions that a group is going to take, and coming to an agreement (Barron, 2002). These tasks require an open exchange of ideas and engagement by all members of the group (Cohen, 1994; Wenger, 1998). Explaining one's ideas is important for productive collaboration and also serves to enhance learning (Webb and Palincsar, 1996). The goal of becoming a good collaborator and the process of learning collaboratively are often woven together.

The final goal of PBL is to help students become intrinsically motivated. Intrinsic motivation occurs when learners work on a task motivated by their own interests, challenges, or sense of satisfaction. Creating an engaging problem is simple for medical students because they all share the intrinsic goal of becoming physicians. Similarly, gifted high school students tend to be highly motivated and have the cognitive skills that allow them to be confident in tackling some complex task. Determining an appropriate problem for less skilled students requires that the problem designers understand what is developmentally appropriate, interesting to a heterogeneous group of students, and moderately challenging without being overwhelming. Several features of PBL support increased motivation for learning. Students are more motivated when they value what they are learning and when their educational activity is implicated in personally meaningful tasks (Ferrari and Mahalingham, 1998; Leontiev, 1978). Students are also more motivated when they believe that the outcome of learning is under their control (Bandura, 1997; Dweck, 1991).

To be intrinsically motivating, problems should provide students with the proximal and tangible goal of applying their knowledge to solve a concrete problem. This type of goal is more motivating than are more distant, abstract goals that may seem insurmountable (Bandura, 1997). Classroom contexts that reward students for deep understanding, independent thought, and action are also more motivating than many traditional classroom structures that reward comparative performances (Ames, 1992; Biggs, 1985; Ramsden, 1992). PBL instruction techniques assume that all these goals are achieved as part of the PBL learning cycle.

THE PBL TUTORIAL PROCESS

The PBL learning cycle (shown in Fig. 1) is enacted through the tutorial process that begins with the presentation of a problem and ends with student reflection. A PBL tutorial session begins by presenting a group of students with minimal information about a complex problem (Barrows, 2000). From the outset, students must question the facilitator to obtain additional problem information; they may also gather facts by doing experiments or other research (Torp and Sage, 2002). For example, when middle-school children were asked to build artificial lungs, they performed experiments to determine how much air the lungs had to displace (Hmelo *et al.*, 2000). At several points during their problem solving, students typically pause to reflect on the data they have collected so far, generate questions about those data, and hypothesize about underlying causal mechanisms that might help explain the data. Students also identify concepts they need to learn more about in order to solve the problem, labeling these concepts as "learning issues." After considering the problem with their naïve knowledge, students independently research the learning issues they have chosen. They then regroup to share what they have learned, reconsider their hypotheses, and/or generate new hypotheses in light of their new learning. When completing the task, learners deliberately reflect on the problem to abstract the lessons learned about the problem and about their SDL and collaborative problem-solving processes.

While working through the problem, students use whiteboards to record their evolving ideas. Figure 2 shows an example of how engineering students used whiteboards while determining the cause of a chemical spill (Hmelo *et al.*, 1995). The whiteboard is divided into four record-keeping columns to facilitate problem solving. The *Facts* column holds information that the students gleaned from the problem statement such as what the problem is and where it occurred. The *Ideas* column serves to keep track of their evolving hypotheses about solutions, such as reducing the storage of hazardous chemicals. The students place their questions for further study into the *Learning Issues* column. In this example, students identify issues related to the technology for storing hazardous chemicals. They use the *Action Plan* column to keep track of plans for resolving the problem or obtaining additional information such as calling a government agency. The four columns provide scaffolding communicating the problem-solving process in PBL (Hmelo and Guzdial, 1996). The whiteboard serves as a focus for negotiation of the problem and as a forum for students to co-construct knowledge. The whiteboard helps students externalize their problem solving and allows them to focus on more difficult aspects of the problem-solving process. It provides a model of a systematic approach to problem solving and supports student planning and monitoring as they identify what needs to be recorded on or later removed from the board.

Facts	Ideas	Learning Issues	Action Plan
Hazardous chemical Near population center	Minimize onsite storage Provide safety training Improve early warning systems	What are the safety standards for cyanide storage? What technology is available to safely store hazardous chemicals?	Call EPA to find out standards

Fig. 2. An example of PBL whiteboard.

The PBL tutorial process helps support knowledge construction as students are guided through their learning and problem-solving processes. As students begin to discuss a problem with a naïve understanding, they activate their prior knowledge, which helps prepare them for learning (Schmidt *et al.*, 1989). It also facilitates the social construction of knowledge as learners work in small groups using their inquiry skills to solve real-world problems (Greeno *et al.*, 1996). For example, medical students learn in the context of authentic patient problems, using the inquiry and discourse skills of medical practice. From a purely cognitive perspective, learning experiences are organized to foster the students' understanding of concepts through problem-solving activities (Greeno *et al.*, 1996). However, from a sociocultural perspective, knowledge is constructed through social interactions. Increasingly, this perspective acknowledges that social practices of inquiry and learning support the development of students as capable learners and knowers (Lampert, 2001). Thus, curricula are organized to support the development of disciplinary patterns of discourse and representations of a domain, emphasizing the importance of formulating and evaluating questions, problems, arguments, and explanations. To further explore the components of the tutorial process, the following sections focus on the role of the problem, the role of the facilitator, collaborative learning in PBL, and reflection in PBL.

The Role of the Problem

Cognitive research and practical experience with PBL have made important strides in identifying the characteristics of a good problem (Barrows and Kelson, 1995; Gallagher *et al.*, 1992; Kolodner *et al.*, 1996). To foster flexible thinking, problems need to be complex, ill-structured, and open-ended; to support intrinsic motivation, they must also be realistic and resonate with the students' experiences. A good problem affords feedback that allows students to evaluate the effectiveness of their knowledge, reasoning, and learning strategies. The problems should also promote conjecture and argumentation. Problem solutions should be complex enough to require many interrelated pieces and should motivate the students' need to know and learn. As students generate hypotheses and defend them to others in their group, they publicly articulate their current state of understanding, enhancing knowledge construction and setting the stage for future learning (Koschmann *et al.*, 1994). Such problems should help students become engaged in the learning process based on their initial understanding. The problems in a PBL curriculum are chosen so that concepts are visited in a number of problems across the entire curriculum (Hmelo-Silver, 2000; Koschmann *et al.*, 1994). For example, preservice teachers might apply information-processing concepts to a problem on individual assessment, another on group assessment, and yet again as part of an instructional redesign task (Derry *et al.*, 2002; Hmelo-Silver, 2000). It is also likely that aspects of motivation would be considered in some or all of these problems.

Good problems often require multidisciplinary solutions. For example, planning a long trip on the Appalachian Trail requires using knowledge and skills from several content areas to solve the problem (e.g., math and life sciences). The necessity of gathering knowledge from a wide range of sources allows students to see how knowledge is a useful tool for problem solving. Good problems also foster communication skills as students present their plans to the rest of their class. Multidisciplinary problems should help build extensive and flexible knowledge because information is not learned in isolation.

The Role of the Facilitator

Having good problems is a necessary but not sufficient condition for effective PBL. The facilitator role is critical to making PBL function well. With its emphasis on learning through problem solving and on making key aspects of expertise visible, PBL exemplifies the cognitive apprenticeship model (Collins *et al.*, 1989). In PBL, the teacher/facilitator is an expert learner, able to model good strategies for learning and thinking, rather than an expert in the content itself. The facilitator scaffolds student learning through modeling and coaching, primarily through the use of questioning strategies (Hmelo-Silver and Barrows, 2003). Facilitators progressively fade their scaffolding as students become more experienced with PBL until finally the learners adopt many of the facilitators' roles. The facilitator is responsible both for moving the students through the various stages of PBL and for monitoring the group process. This monitoring assures that all students are involved and encourages them both to externalize their own thinking and to comment on each other's thinking (Hmelo-Silver, 2002; Koschmann *et al.*, 1994). The PBL facilitator (a) guides the development of higher order thinking skills by encouraging students to justify their thinking and (b) externalizes self-reflection by directing appropriate questions to individuals. The facilitator plays an important role in modeling the problem solving and SDL skills needed for self-assessing one's reasoning and understanding. Although the facilitator fades some of his or her scaffolding as the group gains experience with the PBL method, s/he continues to monitor the group, making moment-to-moment decisions about how best to facilitate the PBL process. The facilitator directly supports several of the goals of PBL. First, s/he models the problem solving and SDL processes. Second, the facilitator helps students learn to collaborate well. An underlying assumption is that when facilitators support the learning and collaboration processes, students are better able to construct flexible knowledge.

There are several important issues in understanding how to facilitate and why it is so difficult for a facilitator who is comfortable with one group and a small number of students to then monitor a typical classroom with several groups and many students. Facilitation is a subtle skill. It involves knowing when an appropriate question is called for, when the students are going off-track, and when the PBL process is stalled. In a study of an expert PBL facilitator, Hmelo-Silver (2002) found that he accomplished his role largely through metacognitive questioning and questioning that focused students' attention and elicited causal explanations. The facilitator used a variety of strategies to support his goal of getting medical students to construct causal models of a patient's illness. He asked students to explain their reasoning to the point where they realized that the limitations of their knowledge necessitated creating a learning issue. Another strategy was to ask students how hypotheses related to the patient's signs and symptoms in order to encourage the students to elaborate causal mechanisms. This study demonstrated that an expert facilitator has a flexible set of strategies that can be tailored to different stages of the PBL process.

An important issue in moving beyond this model of PBL is one of scale. The role of the facilitator is extremely important in modeling thinking skills and providing metacognitive scaffolding. The medical school environment is privileged in being able to provide a facilitator for each small group. It is less clear how this might translate into other environments. Hmelo-Silver (2000) has successfully managed to facilitate multiple groups, using a *wandering* facilitation model. In this model, the facilitator rotates from group to group, adjusting the time spent with each of the groups in the classroom according to their needs. By looking at large poster sheets created by each group and hung on the classroom walls, she was able to dynamically assess the progress of each of the groups and adjust her facilitation efforts accordingly. In addition, students rotated through the facilitator role with the help of prompt cards that gave examples of different techniques that could be used at different stages of the PBL process. This is a lower level of scaffolding than is possible in a one-facilitator-per-group model so some adaptations of PBL are needed to accomplish some of the facilitation functions. For example, reflection rarely happens in groups without a facilitator and so alternative mechanisms, such as structured journals, are needed to ensure reflection (Hmelo-Silver, 2000). This *wandering facilitation* strategy was used with undergraduate students who are a more varied group than medical students but are still more mature than elementary and secondary students. Further research is needed to explore strategies that can be used to facilitate PBL with less mature learners in a typical classroom of 25 or more students.

Collaborative Learning in PBL

Collaborative problem-solving groups are a key feature of PBL. One assumption of PBL is that the small group structure helps distribute the cognitive load among the members of the group, taking advantage of group members' distributed expertise by allowing the whole group to tackle problems that would normally be too difficult for each student alone (Pea, 1993; Salomon, 1993). The notion of distributed expertise is particularly relevant in PBL because as the students divide up the learning issues they become "experts" in particular topics. Furthermore, research suggests that the small group discussions and debate in PBL sessions enhances problem solving and higher order thinking and promotes shared knowledge construction (Blumenfeld *et al.*, 1996; Brown, 1995; Vye *et al.*, 1997).

In PBL groups, the students often work together to construct collaborative explanations. Most PBL groups need some help to collaborate effectively. In the traditional PBL model (i.e., Barrows, 2000), a facilitator helps ensure that all students are involved in the discussion. In the absence of a dedicated facilitator, there are a variety of techniques that might help establish productive collaboration. For example, scripted cooperation, reciprocal teaching, and the use of student roles have all been used to support effective collaborative learning with K–16 students (O'Donnell, 1999; Palincsar and Herrenkohl, 1999). Although none of these techniques have been tested in a PBL classroom, the technique of assigning students to different cognitive roles was used in a fourth-grade inquiry science classroom (Palincsar and Herrenkohl, 1999). These cognitive roles included predicting and theorizing, summarizing results, and relating predictions and theories to results. These roles, much like a facilitator, help ensure that all group members are cognitively engaged (Hmelo-Silver, 2002). Use of some of these well-researched techniques might facilitate effective collaboration within PBL settings.

Reflection in PBL

Reflecting on the relationship between problem solving and learning is a critical component of PBL and is needed to support the construction of extensive and flexible knowledge (Salomon and Perkins, 1989). This reflection should help learners understand the relationship between their learning and problem-solving goals. Thus, each problem-solving task is not an end in itself but rather a means to achieve a self-defined learning goal (Bereiter and Scardamalia, 1989). Reflection helps students (a) relate their new knowledge to their prior understanding, (b) mindfully abstract knowledge, and (c) understand how their learning and problem-solving strategies might be reapplied. PBL incorporates reflection several times throughout the tutorial process and when completing a problem. Students periodically reflect on the adequacy of the *Ideas* they have recorded on the whiteboard and their own knowledge relative to the problem. At the completion of a problem, students reflect on what they have learned, how well they collaborated with the group, and how effectively they directed their learning. As students make inferences that tie the general concepts and skills to the specifics of the problem that they are working on, they should construct a more coherent understanding (Chi *et al.*, 1989). Key to developing such understanding is reflection on their knowledge and strategies. The reflection process in PBL is designed to help students make these inferences; identify gaps in their thinking; and transfer their problem-solving strategies, SDL strategies, and knowledge to new situations. The literature on transfer shows that individuals have a difficult time transferring general principles from one task to another, even when the knowledge is perfectly relevant to someone who understands both tasks (Gick and Holyoak, 1980, 1983; Novick and Holyoak, 1991; Williams *et al.*, 1993). Reflection should increase the probability of transfer (Salomon and Perkins, 1989).

Critical reflection can give students a basis for improvement. This next example demonstrates that students can be critical about themselves and others during the end of a problem reflection session. They freely acknowledged both their strengths and their weaknesses as Delia, a 2nd-year medical student, did in this excerpt:

> Well, I'll go first because we'll just go around . . . I think I did a pretty good job with this case. I think for my knowledge, I think I covered . . . a good breadth of issues, and I think I covered the issues on the learning issues list well, I think I could have gotten a little bit more in depth into some of them, especially, you know . . . vitamin B12 deficiency was a thing I ran across, you know we kind [of] ruled it down, but I ran across it when I was looking at some differentials, and I studied it a little bit but didn't get all the way down into the details of it, so I'm gonna want to go back and do that, especially the biochemistry . . ., I think also with the neurosyphilis I'd like to look a little bit more into that because I'm really weak in understanding how that works . . . but I think, I did a good job with the differential diagnosis and figuring out what we needed to know in order to rule things in and out. I thought I did a good job with that when I was studying, and it worked well for the case . . .. (Hmelo-Silver and Barrows, 2002)

Delia noted that she needed to go back and look up some of the biochemistry concepts and she reflected on her SDL. The other students offered their specific feedback. For example, Carol pointed out that

> One thing I thought you did really well was that you understood which tests were needed and why they were needed and how they were done and what they would tell us. I thought that was really one of your strengths in this case. (Hmelo-Silver and Barrows, 2002)

Jim, however, noted that

> I did feel you seemed to anchor a little bit on the olivopontocerebellar atrophy, you seemed to bring that up a lot, but at the same time you did generate several hypotheses and you seemed to listen to other people's explanations of why they thought something else was more likely, or whatever . . . I didn't notice you interrupting that much. (Hmelo-Silver and Barrows, 2002).

These student reflections refer to specific behaviors exhibited by Delia, both those that she did well and those that needed improvement. Both positive and negative comments from students provide others in their group with information they can use to improve their effectiveness as collaborators and their self-directed learning, such as using a particular general textbook to get an overview before consulting a more specialized text.

Most groups need help to reflect on their learning (Hmelo-Silver, 2000). A dedicated facilitator can support student reflection, but in larger groups and with younger learners there are other techniques that may be helpful. One approach to improving student reflection is the use of structured journals. In the context of using PBL with middle-school students, Puntambekar and Kolodner (1998) developed structured diaries to support student reflection. Approaches such as these need further evidence of their effectiveness before advocating their widespread incorporation into PBL models.

WHAT HAVE WE LEARNED ABOUT PBL

This section considers the evidence about each of the purported goals of PBL. Much of the evidence comes from research in medical schools and gifted education although there are a few studies involving other populations. There are many innovative descriptions of using PBL in various settings: educational administration, business, educational psychology, engineering, chemistry, various undergraduate disciplines, and K–12 education (Boud and Felletti, 1991; Bridges, 1992; Duch *et al.*, 2001; Hmelo-Silver, 2000; Hmelo *et al.*, 1995; Ram, 1999; Stepien and Gallagher, 1993; Torp and Sage, 2002), but there is less empirical evidence as to what students are learning and how. The questions that need to be addressed in such a literature include the following: Do students construct an extensive and flexible knowledge base, do they become better problem-solvers, what kind of self-directed learners do they become, how do they collaborate (and what factors affect their collaboration), and are they intrinsically motivated? The next sections address the evidence as to whether students actually achieve these goals.

Constructing Extensive and Flexible Knowledge

The results on what students learn from PBL are mixed. Much evaluation of PBL has examined traditional academic outcome measures such as examination scores. In general, several meta-analyses have demonstrated that PBL students scored slightly lower than traditional medical students on multiple-choice measures of academic achievement such as the National Board of Medical Examiners (NBME) Part I, which examines basic science knowledge (Albanese and Mitchell, 1993; Goodman *et al.*, 1991; Mennin *et al.*, 1993; Vernon and Blake, 1993). However, meta-analyses also showed that PBL students performed slightly better than traditional medical students at tasks related to clinical problem solving such as NBME II and on ratings and tests of clinical performance (Albanese and Mitchell, 1993; Vernon and Blake, 1993). The effect sizes were small on the NBME II and moderate when performance ratings were used. Although multiple-choice tests measure knowledge, they may not get at the type of extensive and flexible knowledge aligned with the goals of PBL. In a more recent meta-analysis, Dochy *et al.* (2003) found that there was no effect of PBL on measures of factual knowledge, however studies of knowledge application demonstrated a moderate effect size favoring PBL students compared with traditional students. More complex measures of flexible knowledge application may be more sensitive to the effects of PBL.

Recent studies have examined how PBL students performed on a problem-solving task (Hmelo, 1998; Hmelo *et al.*, 1997; Patel *et al.*, 1991, 1993). Patel *et al.* (1991, 1993) asked traditional and PBL students to provide diagnostic explanations of a clinical problem. The PBL students' explanations, although more error-prone, were also more elaborated than those of the medical students in traditional curricula. This result is consistent with research that demonstrated that as people are first attempting to apply new knowledge, they do not always do it well (Lesgold *et al.*, 1988; Novick and Hmelo, 1994). Chi *et al.* (1994) suggest that errors are a necessary step in learning to apply new knowledge. By articulating incorrect knowledge, learners have the opportunity to revise their false beliefs when they are confronted with correct knowledge. The research suggests an advantage in having a well-elaborated knowledge structure that contains some errors instead of having little elaborated knowledge that cannot be applied.

Problem-based and traditional students were studied longitudinally over the 1st year of medical school as they constructed causal explanations of six different problems, covering a variety of different diseases (Hmelo, 1998). This was a quasi-experimental study that compared students who self-selected into traditional and PBL tracks at a midwestern medical school. The students generated causal explanations for each of two problems at each of three testing sessions that occurred during the 1st week of classes, and again after 3 and 7 months. The students' explanations were scored for accuracy, coherence, and use of science concepts. The students did not differ on any of these measures at the initial testing session. The students in the PBL curriculum were more likely to produce accurate hypotheses and coherent explanations than students in the traditional curriculum. In addition, they were more likely to use science concepts in their explanations. This suggests that the PBL students were constructing knowledge that they could bring to bear in accurately solving problems. Their science knowledge was flexible in that they were able to transfer it to new problem situations.

The accuracy effect appears robust. When students in PBL and traditional curricula were compared in terms of diagnostic accuracy for 30 case vignettes, PBL students were more accurate than students in a traditional curriculum (Schmidt *et al.*, 1996). Thus, these quasi-experimental studies in medical schools tend to support the hypothesis that PBL students are able to construct knowledge, provided that the assessments measure knowledge in problem-solving contexts rather than in the context of multiple-choice examinations.

PBL has been applied in undergraduate education as well. In an innovative engineering course in sustainable technology, students used PBL in multidisciplinary teams (Hmelo *et al.*, 1995). Students were given pretests and posttests assessing both factual knowledge and problem-solving skills. The students demonstrated increases on both measures. When PBL was used to teach statistical reasoning to undergraduates, Derry *et al.* (2000) demonstrated that students showed learning gains for some, but not all, of the course content using a pre–post design. In a course for preservice teachers using video problems and a web-based information resource, Derry *et al.* (2002) found evidence that their PBL approach led to transfer and flexible use of course concepts. Learning outcomes were measured using a problem-based assessment. Students viewed a video that showed a student being interviewed before and after instruction along with some excerpts from the instruction. Their task was to explain why the student featured in the video failed to learn. The results demonstrated that students applied more relevant concepts and produced more sophisticated explanations at posttest than at pretest. Schwartz and Bransford (1998) conducted a controlled study of students in an undergraduate psychology course. They compared students in three groups: (a) students who just solved problems, (b) students who read a textbook chapter prior to attending a lecture, and (c) students who solved problems prior to attending a lecture. They found that students who solved problems prior to the lecture performed better on a problem-solving task than students who read the chapter or those who just solved problems. This finding suggests that attempting to solve a problem helps create a readiness to learn from a lecture.

Rather than looking at outcomes, Hmelo-Silver (2000) examined the artifacts that students produced in a problem-based educational psychology course and found that students identified appropriate course concepts and used them in multiple problems. The students' initial understanding of a concept was often a vague knowledge display with little connection to the problem they were working on as in this example:

> Basic knowledge is the main focus of another group's approach to teaching but it can only be accomplished through memory. By going back to basic concepts and incorporating new ideas, memory is a necessary attribute in the success of knowledge based learning. Memory is the processes [*sic*] by which information is encoded, stored, and retrieved. Long term memory becomes the goal of the students in this teaching approach. Information in long term memory is practically unlimited in both capacity and duration but on the other hand, long term memory is hard to achieve [*sic*]. Through constant use of information, long term memory is possible because schemas are formed about how situations will occur based on past experiences. Schemas, therefore, become a template of knowledge on which information is organized . . .. (Hmelo-Silver, 2000, p. 51)

In this excerpt, the students provided a limited and abstract description of basic information-processing concepts. Later in the course, the same students applied information-processing concepts in a more sophisticated way.

> The first thing that Mr. Johnson should have done was to introduce a unit on static electricity by asking the students what they already knew about static electricity. We suggest that Mr. Johnson create a concept map using what the students already know about static electricity from their other classes or everyday lives. "Prior knowledge is stored in the form of schemas. Teachers can activate these schemas in a number of ways including: reviewing, questioning, or developing with the students a concept map of prior knowledge" (Knowledge Web, the Prior Knowledge Use [*sic*]). A concept map is extremely important because teachers use students' prior knowledge to explain and discuss increasingly more sophisticated concepts. Prior knowledge becomes a platform upon which new understanding is constructed " (Knowledge Web, the Prior Knowledge Use [*sic*]).... When the students are done explaining to Mr. Johnson what they previously knew about static electricity, we suggested he give a brief lecture to fill in the gaps and add to the concept map what the students missed. The new knowledge that students learn from the lecture provides them with an integral tool that will allow them to make more meaningful connections when they see the experiment. (Hmelo-Silver, 2000, p. 53)

In this excerpt, the students did not describe information-processing theory directly but they were using it to show the importance of prior knowledge for new learning, indicating that they were thinking about memory at a deeper level. The concepts in the latter excerpt are connected to the problem solution that the students proposed. That was not evident in the earlier excerpt. The analyses of group whiteboards and projects demonstrated that as students gained experience with concepts (e.g., information processing), they were able to distinguish the aspects of a concept that were appropriate for use in solving particular problems.

The results from these studies of undergraduate students provide additional evidence that problem-based curricula can help students construct flexible knowledge. PBL appears to support learning in undergraduate and professional educational contexts, but what about with less mature learners? There has been little work with younger students. Related approaches such as the work with anchored instruction have shown positive learning outcomes for students using problem-solving videos (CTGV, 1997). In work with gifted high school students, Gallagher and Stepien (1996) compared student scores in a problem-based American studies course with those from students in a traditional class. The PBL students scored higher on a multiple-choice test than traditionally instructed students. In an action research study with gifted high school students, students tended to retain information presented in PBL units better than information from traditional units, despite the fact that the students thought they learned more in lecture-based units (Dods, 1997). In a study with a heterogeneous population of sixth-grade students, Hmelo *et al.* (2000), in collaboration with classroom teachers, developed a PBL unit that involved students designing artificial lungs. This design experiment demonstrated that PBL students showed greater gains on both short-answer tests and a drawing task than students in comparison classrooms. However, the students in the PBL class had some misunderstandings at the end of the 3-week unit. The results of this research suggest that adaptations might be needed to use PBL in developmentally appropriate ways and that varying kinds of scaffolding might be needed to help children learn while tackling complex problems. Thus there may be a place for direct instruction once students have developed the need to know, particularly with less uniformly skilled learners.

Developing Effective Problem-Solving Skills

One indicator of effective problem-solving skills is the ability to transfer reasoning strategies to new problems. Patel *et al.* (1991, 1993) asked traditional and PBL students to provide diagnostic explanations of a clinical problem. They showed that students in the PBL curriculum were more likely to use hypothesis-driven reasoning (as they were taught) than were students in a traditional curriculum. The students in the traditional medical school used predominately data-driven reasoning, a form of reasoning that is more characteristic of experts, but only on familiar problems (Norman *et al.*, 1994). Although experts often use this type of reasoning, it is not likely to be effective for novices. Data-driven reasoning relies on having an extensive knowledge base, which is unlikely for novices. In a laboratory experiment designed to test the notion that hypothesis-driven reasoning supports learning, Norman *et al.* (1998) found that having students learn how to read electrocardiograms using a hypothesis-driven strategy led to greater accuracy on a transfer task than using a data-driven strategy. This finding suggests that a hypothesis-driven reasoning strategy is a mechanism for learning. In two studies, students in PBL curricula transferred the hypothesis-driven reasoning strategy to unrelated problems and generated more coherent explanations than students without PBL experience (Hmelo, 1998; Hmelo *et al.*, 1997).

Another aspect of problem-solving skills is being able to define what the problem actually is, especially with ill-structured problems. This is called problem finding and is the aspect of problem solving that refers to identifying the problem. When comparing gifted students who were traditionally instructed with students in a PBL class on problem-solving skills, Gallagher *et al.* (1992) found that PBL students were more likely to include problem finding as a step when presented with a novel ill-structured problem. Although research on the influence of PBL on strategy transfer is limited, it does provide some evidence that students in PBL learn problem-solving and reasoning strategies that are transferable to new problems.

Developing SDL Skills

One of the purported benefits of PBL is its claim to prepare lifelong learners because of its emphasis on self-directed learning (SDL).

Understanding SDL is a complex phenomenon so this section has two parts. The first part examines of what it means to become a self-directed learner by reviewing qualitative studies of SDL. The second part reviews the literature that examines quantitative indicators of SDL. Some of the indicators of SDL include planning one's own learning, developing and applying strategies, and appropriately using learning resources.

Becoming a self-directed learner is a multifaceted process. When students in PBL curricula in three different disciplines were interviewed, Abrandt Dahlgren and Dahlgren (2002) found that students in two of three disciplines felt a great sense of uncertainty about what to study. Students' SDL strategies evolve over time as Evensen (2000; Evensen *et al.*, 2001) demonstrated in qualitative analyses. In both analyses, Evensen interviewed medical students from a PBL group and analyzed oral learning logs and written notes that the students kept. The first analysis used a grounded theory approach and focused on two of these students as it examined the interactions of academic self-concept, learning strategies, learning opportunities provided by the program, and evaluation mechanisms (Evensen, 2000). Both students developed strategies for coping with challenges to their self-efficacy and described the reflection on their learning and information-seeking strategies. This research provides a glimpse into the lives of two students learning to adapt to the SDL demands of a PBL program. For example, one of the students, Kyle, a successful undergraduate premed major, began the PBL program highly confident that he could easily learn anything that was "in the book," and believed that was what he needed to be successful in medical school. He chose PBL because he thought it would allow him to learn on his own without attending lectures. He enjoyed the problems but initially found it annoying that topics already studied were revisited in multiple problems. Revisiting topics also caused him to doubt whether he had adequately studied. His major strategy was to rely on reading to learn. He saw the group meetings as a good way to get the big picture of a case, to collectively decide on what was important, and to review. As time went on, Kyle began encountering material that was difficult so he needed to adjust his strategies. For the first time in his life, he had to reread text. This took more time and he realized that he needed to take good notes because he would not have time to reread the texts before exam. He also learned which topics could be skimmed and which topics needed more in-depth research. Early in the year, he was pleased to be an information resource for his group. Later, he shifted to become more of a collaborator. He realized the benefits of sharing resources. The case studies demonstrate that students bring strategies and beliefs about learning to a new situation. This is not surprising because medical students have generally been successful learners throughout their school careers. However, prior ways of learning were not transported intact to this new learning environment; rather, good self-directed learners were proactive in achieving their goals. That is, these successful learners adapted their personal strategies to the situational demands.

To build a model of how students developed as self-directed learners, additional case studies were constructed (Evensen *et al.*, 2001). These case studies suggested that the more reflective learners were about SDL, the more likely they could modify or invent strategies for SDL. For example, Beth, an undergraduate theater major, learned to compensate for her lack of science background by starting with a "baby bio book" (p. 663). The simpler text helped provide the background knowledge needed to tackle the medical textbooks. Beth's strength was her desire to master the content and her confidence in her ability to catch up to other students. Beth's knowledge of her weaknesses allowed her to develop adaptive strategies to cope with her limited science background. Initially, Beth missed the traditional benchmarks of exams but over the course of the semester she compensated by purchasing an NBME exam review book and reviewing with her group. Beth built on her strengths and overcame her weaknesses as she adjusted her SDL to meet the demands of the PBL curriculum. Another student in the group, Hope, had always been successful in school by reading and taking abundant notes. She chose the PBL curriculum because it would give her the opportunity to do something different. She was initially enthusiastic and liked the idea of learning for understanding rather than memorizing. She was not confident in the group discussion, though, which challenged her self-efficacy. Rather than adapting to the demands of PBL, Hope went back to her old strategies. Evensen concluded that SDL may well be an individual characteristic but it is one that changes over time, for better or worse. As these case studies show, students understood the need for SDL but had different ideas of what this meant. For some, it was the same as independent study. Other students recognized the contrast between PBL and previous educational experiences and realized that they would need to adopt new strategies to attune to the program. The strategies they adopted interacted with their previous learning histories, self-regulated learning strategies, self-efficacy, and the features of the PBL environment.

Students' approaches to learning from problems differ qualitatively depending on their degree of self-regulation. Ertmer *et al.* (1996) conducted a qualitative study of how veterinary students approached learning from problems. Students who were low self-regulated learners (SRL) had difficulty adapting to the kind of learning required in problem-based instruction. They fluctuated in their perception of the value of learning from problems. High SRL students valued learning from problems and tended to focus on the problem analysis and reflection process. In contrast, low SRL students tended to focus on fact acquisition. Ertmer *et al.*'s results suggest that low

SRL students may have difficulty dealing with the SDL demands of a PBL curriculum.

A commonly held assumption in the PBL approach is that problem content and ensuing discussions direct SDL. In questioning this assumption, Dolmans and Schmidt (2000) asked what other curricular elements might direct SDL. The PBL students at their institution received course objectives, a limited number of lectures, tests, and suggested references. Dolmans and Schmidt reasoned that over reliance on these external elements might impede the development of SDL skills. To examine this, they gave first through 4th-year students a questionnaire with items relating to the different curricular elements. They found that both problem discussion and course objectives had the greatest positive influence on SDL. Tests and lectures had the least positive influence. Furthermore, over the 4 years of the curriculum, students increased their emphasis on the functional knowledge they would need as physicians and decreased their reliance on external elements such as tests. These results indicate that over time, students in a PBL curriculum become more self-reliant.

Developing SDL skills is a difficult and multifaceted process for students in PBL curricula. This begs the question of whether PBL students develop better SDL skills than traditional medical students. One way to study this is by examining component processes in SDL such as how students generated learning issues, planned their learning, and integrated new knowledge in problem solving. Hmelo and Lin (2000) examined these component processes by comparing medical students in traditional and PBL curricula who had completed a pathophysiological explanation task. They found that the PBL students transferred the hypothesis-driven strategies from their problem solving into their SDL as they used their hypotheses to plan their learning. Moreover, they were more likely to integrate new information into a revised explanation than traditional medical students.

In a study comparing traditional and PBL medical students in terms of the learning resources they used, Blumberg and Michael (1992) found that PBL students were more likely to use self-chosen learning resources whereas students in the conventional curriculum used faculty-chosen resources. PBL students were more likely to report selecting the material to study themselves, whereas conventional curriculum students reported reading specific teacher-generated assignments. Engineering students in a PBL course in sustainable technology increased their use of expertise other than that provided by course instructors as the course progressed and tended to use a variety of student-selected resources throughout the course (Shikano and Hmelo, 1996).

The research on SDL in PBL has largely been confined to professional students so its wider application is ripe for additional research. It is clear that all students need to grapple with the uncertainty involved in directing their own learning. For students who are poor self-regulated learners, PBL is likely to pose difficulties without appropriate scaffolding for students trying to develop SDL skills. Becoming self-directed learners is not a given as the Evensen *et al.* (2001) and Ertmer *et al.* (1996) studies demonstrate. It is not at all certain how to structure PBL for less mature learners. Scaffolding SDL is likely to be especially important for younger learners but as the research has noted, there are considerable individual differences even among adult learners.

Becoming Effective Collaborators

Another goal of PBL is to help students become effective collaborators, but there is little research that examines this directly. Rather, the research has focused on factors that affect how well students learn collaboratively. Group function is particularly important because it affects learning outcomes and intrinsic motivation (Schmidt and Moust, 2000). Schmidt and Moust's path model demonstrates that group functioning is affected by the quality of the problem and facilitator functioning but, surprisingly, not by prior knowledge. They do not include collaboration skills as part of this model.

Students in PBL curricula do attend to collaboration as DeGrave *et al.* (1996) have demonstrated. In their study, they analyzed videotape of a tutorial group and had students engage in stimulated recall while watching the video. In the group meeting, students did not appear to attend to collaboration explicitly but their stimulated recall indicated that students were sensitive to collaborative process and their own part in the collaboration.

Effective collaboration can lead to knowledge construction as students construct joint explanations. An analysis of two PBL tutorial sessions found that student discourse often focused on responding to and refining ideas that had been proposed (Hmelo-Silver, 2002). Students constructed many collaborative explanations as in this example after the facilitator asked the group to clarify one of their hypotheses:

Delia: Like pernicious anemia is a big one.
Mindy: Right. That must be the vitamin, the B.
Facilitator: What, what's pernicious anemia?
Delia: Uh, it's a deficient, deficiency of cobalamine.
Mindy: Vitamin B12, cobalamine or . . .
Jim: Or folate.
Mindy: Or folate.
Delia: Yeah, but it's not, that's not pernicious anemia. That's a, also another macrocytic anemia.

Mindy: Pernicious anemia is specifically.
Jim: Oh. You're right. That's right.
Delia: And you get anemia and you can also get peripheral . . .
Mindy: Neuropathies.
Delia: . . . neuropathies.
Facilitator: Down there too?
Carol: Technically pernicious, pernicious anemia is technically just the loss, the lack of intrinsic factor.
Delia: The loss of intrinsic factor. So you don't absorb.
Carol: And that's [unintelligible].
Delia: You don't absorb.
Carol: Right.
Mindy: Right. That's a good distinction. You see, we just . . .
Carol: As opposed to like somebody who had part of their intestine removed and can't absorb.
Mindy: Right.
Carol: But their ileum is gone and they can't absorb the B12. That's different than pernicious anemia, to vit[amin], intrinsic factor. (Hmelo-Silver, 2002, pp. 203–204)

This is collaborative because students all contributed different parts of the explanation. The facilitator triggered the explanation but then different students offered different parts of the explanation about pernicious anemia, what some signs might be (neuropathies), and what alternative explanations they can rule out. Although this case study provides an example of what is possible in well-functioning groups, helping students become effective collaborators is still an important issue for research.

In PBL, students are encouraged to attend to collaboration processes through their reflection and through the interdependence of learning within the group, but they do not necessarily know how to deal with the collaborative aspects of PBL effectively (Abrandt Dahlgren and Dahlgren, 2002; Evensen *et al.*, 2001). To help students learn to be better collaborators, Faidley, *et al.* (2000) developed observational and self-report instruments that could be used to provide information on group processing. The Learning Team Survey (LTS) is a self-report instrument designed to focus on behaviors and attitudes that are important to group learning. The observational checklist focuses on substantive and group processing behaviors. In a pilot study, Faidley *et al.* used the observational checklist to determine whether group differences in LTS could be explained by attending to the behavioral variables. The results demonstrated that there was a relationship between the two instruments. There was great variability in the groups studied, providing further evidence that not all groups are effective. The facilitator had a large effect on how well the group worked, consistent with the model of Schmidt and Moust (2000). Faidley *et al.* hypothesized that instruments such as LTS provide information that can lead to productive reflection and improvement in the group process.

There is not yet evidence that supports the hypothesis that PBL helps students become better collaborators (broadly defined). There is evidence that students do work together to provide collaborative explanations as demonstrated in the example from Hmelo-Silver (2002). There is also evidence that demonstrates that collaboration in tutorial groups is a key factor in student learning and motivation, but that not all groups collaborate well. Further research is needed to examine whether PBL environments help all learners become better collaborators.

Becoming Intrinsically Motivated

Enhancing student motivation is purported to be a major advantage of PBL. Because learning issues arise from the problem (in response to students' need to know), intrinsic motivation should be enhanced. Unfortunately there is little research that bears directly on this issue. Most of the research has instead examined student satisfaction or confidence. Students' reaction to a PBL course in statistical reasoning was mixed (Derry *et al.*, 2000). Some students really enjoyed the class but others resisted changing their way of learning or did not like working collaboratively. In interviews with veterinary students, Ertmer *et al.* (1996) found evidence of intrinsic motivation associated with PBL but the nature of students' motivation in PBL may depend on their academic or professional discipline (Abrandt Dahlgren and Dahlgren, 2002). In the medical school environment, across many studies, students in PBL curricula report being more satisfied with their learning and confident in their understanding than those in traditional curricula (Albanese and Mitchell, 1993; Hmelo, 1994; Vernon and Blake, 1993). There has been little if any work examining motivation among K-12 PBL students. It is important to note that in medical schools, the students are a fairly select group and the PBL curricula are well established. Moreover, PBL is used throughout the entire curriculum. In other studies, the instructional intervention was a single experimental course within a larger curriculum with competing demands from other well-structured courses. A single course may not provide the opportunity to become acclimated to a new way of learning. This makes motivation in PBL a complex issue. The results for medical students are consistent—they enjoy PBL and feel confident about their learning (Albanese and Mitchell, 1993; Hmelo, 1994; Vernon and Blake, 1993). There is little empirical data about motivation in undergraduate and K-12 education making it difficult to draw conclusions about motivation in these other contexts.

DISCUSSION

This article describes PBL, one of a family of experiential learning methods, and how students learn using this method. There is some strong evidence about the nature of knowledge construction and the development of problem-solving skills in certain settings, but there are some cautionary notes to consider. The claims of PBL advocates are not all supported by an extensive research base, and much of the research has been restricted to higher education, predominantly in medical schools. There is little research with K-12 populations. Much of the research has used case study, pre–post test, or quasi-experimental designs rather than controlled experiments. However, these different designs provide converging evidence about learning with PBL. The majority of the research on PBL examines knowledge construction, problem solving, and SDL. There is little work in the areas of motivation and collaboration. A research agenda for PBL should examine these facets of PBL more carefully. It would be naïve to believe that the medical school model of PBL could be imported into other settings without considering how to adapt it to the local context, goals, and developmental level of learners. Another barrier to using PBL in K-12 education is the constraints of classroom organization. The model of PBL in medical school involves an integrated, interdisciplinary curriculum organized around problems rather than subject domains. In most K-12 situations, teachers must assess students in specific subject areas and problems often do not map neatly onto these subject area divisions. Moreover, it requires careful planning to engage in PBL in 50-min class periods.

Certain aspects of the PBL model should be tailored to the developmental level of the learners. SDL may prove particularly difficult for younger learners who tend to have difficulty applying metacognitive strategies. Scaffolding that helps support student metacognition and reflection is particularly important at this level and has been used profitably with younger learners in project-based science (Linn and Hsi, 2000; White and Frederiksen, 1998). Understanding the nature of these adaptations and how aspects of PBL may be scaffolded for different learners are important issues for research. Moreover, there may be a place for direct instruction on a just-in-time basis. In other words, as students are grappling with a problem and confronted with the need for particular kinds of knowledge, a lecture at the right time may be beneficial. As Schwartz and Bransford (1998) demonstrated, PBL may create a "time for telling" (p. 475). How this can be incorporated into a student-centered learning environment remains an empirical question. There is a great need for evidence-based instructional strategies that demonstrate which facets of PBL are important for particular kinds of outcomes so that educators can make informed choices in adapting PBL to their particular contexts.

One barrier to using PBL in more diverse settings is the lack of a sufficient number of skilled facilitators in many settings. Classrooms have more students than one person can easily facilitate, and learning to facilitate well is a challenge (Derry *et al.*, 2001). Some techniques such as procedural facilitation, scripted cooperation, and structured journals may prove useful tools in moving PBL to other settings. In addition, the PBL activity structure might be modified to support PBL for specific teaching goals. Technology may also play an important role in adapting PBL for specific disciplines. For example, in the STEP system (Secondary Teacher Education Program), the activity structure was modified to help preservice teachers engage in instructional design as they learn about educational psychology (www.estepweb.org). The STEP system is an integrated system with videocases of classroom instruction, a hypermedia textbook, a set of problems, a virtual whiteboard, and an activity structure that guides students through PBL and the instructional design process (Steinkuehler *et al.*, 2002). The activity is divided into a sequence that starts with individual problem analysis, moves on to group SDL and problem solving, and ends with individual explanation and reflection. The whiteboard structure has been modified to include students' ideas about objectives, assessment, and activities. A space is provided that reminds students to include the psychological justification for their ideas. The same three categories emphasized in the whiteboard are the focus of the students' problem solving. The problems are video based and indexed to educational psychology concepts to help support the students' SDL. Approaches to distributing facilitation using various tools and technology need further research and evaluation to understand their strengths and limitations.

In conclusion, PBL is a pedagogical technique that situates learning in complex problem-solving contexts. It provides students with opportunities to consider how the facts they acquire relate to a specific problem at hand. It obliges them to ask what they need to know. PBL offers the potential to help students become reflective and flexible thinkers who can use knowledge to take action. Although the roots of PBL go back to Kilpatrick (1918) and Dewey (1938), PBL has the advantage of suggesting a method to promote active and reflective knowledge-building-for-action (Hmelo and Guzdial, 1996). Still, careful research is needed to understand if and how these potentials might be realized.

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