Marra, R., Jonassen, D. H., Palmer, B., & Luft, S. (2014). Why problem-based learning works: Theoretical foundations. *Journal on Excellence in College Teaching, 25*(3&4), 221-238.

Why Problem-Based Learning Works: Theoretical Foundations

Rose M. Marra
David H. Jonassen
University of Missouri

Betsy Palmer
Steve Luft
Montana State University

Problem-based learning (PBL) is an instructional method where student learning occurs in the context of solving an authentic problem. PBL was initially developed out of an instructional need to help medical school students learn their basic sciences knowledge in a way that would be more lasting while helping to develop clinical skills simultaneously. Although PBL addresses this specific need, it is also based in sound educational theories and paradigms. The author addresses those theoretical foundations of PBL, which, in turn, help readers to understand why PBL can be effective as well as enable them to diagnose and improve PBL applications when things are not going quite as planned.

Introduction

Problem-based learning (PBL) is an instructional method that drives all learning via solving an authentic problem. The idea of "basics first" goes out the window in PBL; rather, one learns the basics in the context of a meaningful, but ill-structured problem solving activity. A cohesive body of research is beginning to show the effectiveness of PBL (see Hung, Jonassen, and Liu, 2008). Authors in this special issue, respectively, provide readers with a treatment of the basics of PBL (Love, Dietrich, Fitzgerald, & Gordon) and a review of PBL research (Albanese & Dast).

PBL was initially developed out of an instructional need—wanting to help medical school students learn basic sciences knowledge in a way that would be more lasting while helping to develop their clinical skills simultaneously. While a specific need was being addressed, PBL has its basis in sound educational theories and paradigms. This article will help the reader to understand the theoretical foundations of PBL; we are beginning to know that PBL can work, and examining the educational theory upon which it is based can help us understand why as well as enable us to diagnose and improve PBL applications when things are not going quite as planned.

PBL Overview

History of PBL

Problem-based learning has its implementation roots in the field of medical education starting in the 1950s (Savery & Duffy 1995). It grew from dissatisfaction with the traditional medical education practice at McMaster University in Canada (Barrows, 1996; Barrows & Tamblyn, 1980). These PBL pioneers criticized traditional health science education for its lecture format and heavy emphasis on memorization of fragmented biomedical knowledge at the expense of helping students develop the clinical problem-solving skills required for a lifetime of practice and learning (Albanese & Mitchell, 1993; Barrows, 1996).

This first PBL curriculum implemented many of the characteristics that typify PBL today. Students worked in small groups where they interacted with simulated patients who had complex and meaningful medical problems. They used patient interviews, records, and selected laboratory results to identify learning issues and develop a diagnosis and treatment plan (Barrows & Tamblyn, 1976; Torp & Sage, 1998). This may seem like the students were metaphorically "thrown into boiling water," but in a PBL environment, student learning is supported and coached by a faculty member whose role is to facilitate discussion-based learning by asking questions and monitoring the problem-solving process (Barrows, 1985, 1986, 1996; Hmelo, 1998). If students are "stuck," they can go to the facilitator for guidance and resources. Rather than learning basic science knowledge via memorization, textbooks, and lectures (methods that have a high "forgetting curve"), students learn these basics during the meaningful, hands-on task of solving clinical problems (Barrows, 1985, 1986;

Hmelo, 1998). This student-centered approach has a long tradition prior to PBL, including Dale's Cone of Experience (Dale, 1969). Dale's Cone illustrates that learners tend to retain 90% of what they hear and do, an idea that is at the core of PBL.

Key Focus of PBL

A primary assumption of PBL is that when we "solve the many problems we face everyday, learning occurs" (Barrows & Tamblyn, 1980, p. 1). Although such a statement may appear self-evident, this assumption is in conflict with our public education system, which primarily implements learning only in formal education settings—perhaps implying that once we leave school, we cease to learn.

Proponents of PBL believe, as did Popper (1994), that "Alles leben ist Problemlösen" (all life is problem solving). If this is true, then life is filled with learning opportunities. In addition to the importance of lifelong learning, PBL proponents posit the centrality of problems in learning. That is, learning is initiated by an authentic, ill-structured problem. Ill-structured problems are those that have multiple or unknown goals, solution methods, and criteria for solving them. In PBL-based classes, students encounter the problem before learning. This approach is countered by centuries of formal education practice, wherein students are expected to "master" content before they ever encounter a problem and attempt to apply the content to it.

The primary characteristics of a PBL learning environment are as follows:

- **Problem-focused:** Learners begin learning by addressing simulations of an authentic, ill-structured problem. The content and skills to be learned are organized around problems rather than as a hierarchical list of topics. Thus, knowledge is learned in the context of the problem, and there is a reciprocal relationship between knowledge and the problem. Knowledge building is stimulated by the problem and applied back to the problem.
- **Student-centered:** Faculty do not dictate the learning activities, but rather serve in a supportive role.
- **Self-directed:** Students individually and collaboratively assume responsibility for generating learning issues and processes through self-assessment and peer assessment

and access their own experiential knowledge and learning materials. Required assignments are rarely given.

- **Self-reflective:** Learners monitor their understanding and learn to adjust strategies for learning.
- **Facilitative:** Instructors are facilitators (not lecturers) who support and model reasoning processes facilitate group processes and interpersonal dynamics, probe students' knowledge deeply, but do not interject content or provide direct answers to questions.

In the following sections, we explicate the theoretical underpinnings of PBL and explore how these influence ways successfully to support students engaged in PBL.

Theoretical Underpinnings of PBL

Constructivism

Fundamentally, PBL is based on constructivist assumptions about learning. Constructivism can be described in terms of five tenets about knowledge, meaning making, and learning (Jonassen, 1991).

Knowledge is constructed via interactions with the environment.

Humans as learners are perceivers and interpreters who construct their own interpretations of the physical world through cognitive, interpretive activities that construct mental models. This sense making process involves accommodating new ideas and phenomena with existing beliefs and the knowledge representations that have already been created. The knowledge that is constructed by a learner consists of not only the ideas (content), but also knowledge about the context in which it was acquired, what the knower was doing in that environment, and what the knower intended from that environment. What separates humans from lower forms of life (as far as we know) is intentionality and the ability to articulate those intentions.

Reality (the sense that we make of the world) is in the mind of the knower.

The sense making process described above produces a perception of the external, physical world that is unique to the knower; this representation is based on that learner's unique set of experiences that have produced a unique combination of beliefs about the world. This does not mean that we cannot share our reality with others. It does mean that knowledge is *not* an external entity that exists in the physical world to be acquired or transmitted.

Meaning and thinking are distributed among the culture and community in which we exist and the tools we use.

As we engage in learning communities (such as the interactions among learners in a PBL environment), our knowledge and beliefs about the world are influenced by that community and their beliefs and values. For instance, our knowledge of the world is influenced by the activities in which we are engaged at work. The beliefs and knowledge of our fellow practitioners or learners influences our thinking. Learning, then, is seen by Duffy and Cunningham (1996) as changes in one's relation to the culture(s) to which one is connected. Our knowledge and belief is distributed among the participants in these communities (Salomon, 1993). This interaction and interdependence is played out particularly in PBL, as learners rely on the experiential knowledge of other team members to help accomplish tasks or articulate beliefs or stances needed to solve the PBL problem.

Knowledge is anchored in and indexed by relevant contexts.

The ideas that we know and the skills that we have acquired consist, in part, of the situation or context in which they were acquired or have been applied (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Schank, Fano, Bell, & Jona, 1993/1994). That is, the context of knowledge acquisition is part of the knowledge that is used by the knower to explain or make sense of the idea. This means that abstract rules and laws, divorced from any context, have no meaning. What we really understand about skills is the *application* of those skills. We store these applications as stories (Schank, 1986), which become a primary medium of conversation and meaning making among humans. Constructivism argues that skills will have more meaning if they are acquired initially and consistently in meaningful contexts. Unless ideas can be applied, they have no meaning. Merely teaching facts and explaining concepts without contextualization prevents indexing those ideas to the features of the situation in which they are relevant (Schank et al., 1993/1994).

Knowledge construction is stimulated by a question or need or desire to know.

What produces the knowledge construction process is a dissonance between what is known and what is observed in the environment. Resolving the dissonance that is intrinsic to problems students face in PBL is for them the essence of knowledge construction—and thus, of learning. We can memorize ideas that others share with us, but to seek actively to make meaning about phenomena involves some dissonance between what we know and what we want or need to know. Confronting this dissonance in a PBL ensures some ownership on the part of the learner. This is an especially critical attribute of PBL, wherein learners are immediately engaged in understanding and solving authentic problems that they are intrinsically motivated to solve.

Situated Learning

A related perspective posits that PBL has its roots in theories of situated learning (Hung, 2002). Situated learning or situated cognition was proposed by Brown et al. (1989) and argued that meaningful and lasting learning takes place best when it is embedded in a social and physical context as similar as possible to that in which the learning would be applied. This idea was in contrast to the way most formal learning took place at that time (and still, unfortunately, does)—that is, devoid of authentic context and far removed from any aspect of actually using what is to be learned. Situated cognition proposes that the contextual setting of knowledge is essential and that meaning making is rooted in the relationships that we construct between ourselves as learners and our surrounding situations and interactions (Hung, 2002). Stated another way, knowledge is, at its root, produced via interactions between the mind and the world in which it is situated.

In a PBL, the "situation" or the meaningful context is to a large degree provided by the ill-structured problem the learners are solving. This learning situation is similar to what we do in our everyday and professional lives, where we are continuously solving ill-structured problems. Because meaning is derived by learners from the contexts in which they are working or learning—ideas abstracted from contexts and presented as theories have little, if any, meaning to learners—knowledge that is anchored, or "situated" in specific contexts is more meaningful, more integrated, better retained, and more transferable. One reason for this phenomenon is the means by which students represent their understanding (Jonassen, 2006). Specifically, knowledge constructed for solving problems results in task-related procedural knowledge and phenomenological (the world as we consciously experience it) knowledge types. These are richer, more meaningful and memorable representations.

Drawing on both situated cognition and constructivist beliefs about learning as the bases for PBL is quite feasible given the strong parallels between the two systems of belief. Both argue that knowledge is not simply a separate thing to be had by the learner, but rather that it arises from the interaction of the mind with the world our mind encounters. These encounters can occur between ourselves and the things with which we interact (for instance, the lawn mower we are trying to fix), with more traditional sources of information (for instance, books and material on the Internet), and certainly with other individuals. These are, indeed, the types of interactions fostered by PBL.

Discussion: Implications for Supporting PBL

The PBL mode of learning introduces new roles for both faculty and students. However, one of the benefits of exploring the theoretical foundations of an instructional methodology is that those foundations can tell us something about how to support teaching and learning in this modality. In the next section, we discuss some of these instructional means of supporting student success in PBL environments and how they are grounded in the theoretical frameworks described above.

PBL and Metacognition

Metacognition is the awareness of one's own knowledge, of one's actions, and of one's current "cognitive or affective state" (Hacker, Dunlosky, & Graesser, 1998, p. 3). Thus, metacognition can include students' knowledge of what they know, what they do not know, how they learn new knowledge or skills, and what strengths and weaknesses they have in regard to their area of study. Metacognition is an important meta-level set of cognitive strategies that enables learners to perform better. Flavell (1976, 1979) distinguished two characteristics of metacognition: knowledge of cognition and self-regulation of cognition. Knowledge of cognition includes knowledge of task, strategy, and personal variables. That is, metacognitive knowledge includes knowledge of the skills required by different tasks, strategic knowledge (knowledge of alternative learning strategies and when to use them), and self-knowledge (knowledge of one's abilities and the abilities of others) (Flavell, 1987).

The self-regulation aspect of metacognition includes the ability to monitor one's comprehension and control one's learning activities. Self-regulation describes activities that regulate and oversee learning, such as planning (predicting outcomes, scheduling strategies) and problem-monitoring activities (monitoring, testing, revising and re-scheduling during learning). Self-regulation also involves evaluation (appraising the effectiveness of regulation) (Schraw & Moshman, 1995; Sperling, Howard, Staley, & Dubois, 2004; Zimmerman, 2002; Zimmerman & Moylan, 2009).

Although well-developed metacognitive skills can positively contribute to student success in almost any type of learning activity (Bransford, Brown, & Cocking, 2001; Prince, 2004), the need for metacognitive skills increases in student-centered pedagogies such as PBL. In traditional instructor-centered pedagogies, regulation of learning tasks is structured by the teacher. In contrast, as pedagogies such as PBL become more student-centered, students become increasingly responsible for self-regulation of their learning. Hmelo-Silver (2004) describes the fundamental nature of metacognition to successful PBL experiences, indicating that while PBL develops problem-solving skills, those skills cannot develop without the development of "appropriate metacognitive and reasoning strategies" (p. 240). For instance, students must be aware of what they do and do not understand, and from that understanding be able to set goals and identify tasks that will help them accomplish those goals. Although some students may "naturally" adapt to this additional responsibility and experience positive effects on learning outcomes, others may struggle, resulting in a negative impact on their learning (Prince, 2004). A successful PBL experience requires support for students—particularly those new to PBL—to develop the necessary metacognitive skills. Later in this article, we describe some specific strategies that can be used for this purpose.

PBL and Cases

We have previously introduced the concept of situated learning as a theoretical basis for PBL. Theorists and educators have struggled with ways to provide these *in situ* experiences in PBL. Although Brown et al. (1989) argued for implementations that were based on a cognitive apprenticeship (adapting the principles of a traditional apprenticeship to cognitive skills), providing students with cases is another way of accomplishing the *in situ* PBL setting (Jonassen, 2010).

Cases are fundamental to PBL implementations. That is, problems are represented as cases, and cases are used in various ways as instructional support. Cases are one of the primary ways that situated learning theory is implemented in PBL. Authentic cases are the way that the learning is "situated" in a real-world setting and, additionally, the means by which students situate the basic knowledge (for example, basic sciences for medical school, engineering fundamentals for the engineering students) they are learning as part of the case. There are, however, different kinds of cases and different ways of using them in a PBL (Jonassen, 2010). Figure 1 illustrates the functions that cases may have in a PBL. It shows that example cases and cases to analyze serve primarily as instructional supports, whereas the case as a PBL problem to solve is the basis for students' learning of content and skills (Jonassen, 2010).

Cases as Examples and Experiences to Analyze

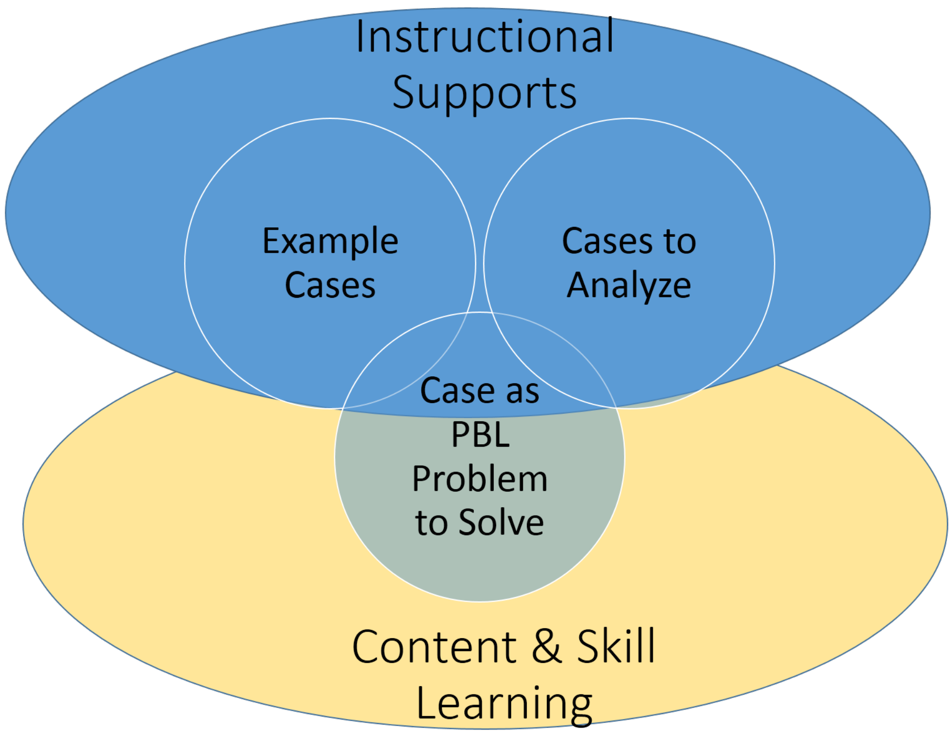
Cases other than the primary instructional case can function as instructional supports for students in PBL. Cases as examples can be used as one way to support students in a PBL. This instructional tactic is consistent with all models of instructional design (Branch, 2009; Gagne & Briggs, 1974) that insist on the inclusion of examples in instruction. The role of examples is to serve as concrete models of ideas being represented abstractly. A PBL case example that is worked out to a complete solution and perhaps annotated to illustrate the problem-solving process can support PBL students in their current problem-solving activities (Jonassen, 2003).

A similar use of cases to support PBL learning is to practice analyzing cases in preparation for their ultimate PBL case problem solving. This case study method is usually done as an activity for its own purposes. That is, students are to analyze the completed case and respond in a certain fashion. The case study method *might* be used as part of students' PBL processes if they were prompted by an instructor/facilitator to look at a particular already-solved case in order to apply lessons from this case to their current problem solving activity. In essence, the case study method provides analogues for students to apply to their own problem solving, thus serving as a particular type of case "exemplar."

Cases as Problems to Solve

Cases as problems to solve are the essence of a PBL. This article and other articles in this issue have already described the usage of cases in PBL. PBL normally replaces traditional content-based curriculum with a set of problems that integrate the content into practice. In PBL classes, students work in groups supported by a process tutor to solve authentic (clinical) problems or simulations of practice that drive student learning. Students

Figure 1
Relationships Between Case Functions in PBL



assume responsibility for their learning by interpreting case problems self-reflectively, generating learning issues and objectives throughout the case, determining their own assignments, accessing learning materials, monitoring their own learning, and applying their knowledge back to the problem. In PBL programs, cases are merely the vehicle for initiating reflective, self-directed learning but are central and essential to that learning process.

Using Theory to Improve PBL

We know that cases and student use of metacognition and self-regulation skills are necessary for a well-functioning PBL environment, and we know that these instructional means are based on the theoretical underpinnings of PBL. But where does all this leave us as faculty members in the midst of trying to implement and improve PBL for our students? Entire books have been written on this topic (see Amador, Miles, & Peters, 2007; Woods, 1994); however, in this section we will briefly address strategies based on the theoretical and implementation foundations discussed that can help to continually improve PBL environments. These strategies are based on the principles of formative evaluation—evaluation designed to monitor and improve a product or process that is still available to be modified.

Problems are a critical aspect of a PBL. They embody the *in situ* nature of PBL and are the basis for the construction of knowledge. They exist to trigger the learning process and are the basis for student learning activities. Creating an effective problem is, thus, essential for successful PBL. Dolmans, Snellen-Balendong, Wolfhagen, and Van der Vleuten (1997) outlined seven principles of problem design. They described that problems should (1) simulate real life, (2) lead to elaboration, (3) encourage integration of knowledge, (4) encourage self-directed learning, (5) fit in with students' prior knowledge, (6) interest students, and (7) reflect the faculty member's learning objectives. Jonassen and Hung (2008) focused on one of the problem characteristics originally indicated by Shaw (1976)—problem difficulty—and defined it to be characterized by problem complexity and problem structuredness. According to Jonassen and Hung (2008), *problem complexity* refers to the breadth, difficulty level, intricacy, and interrelatedness of problem space, while *problem structuredness* represents the intransparency, variety of interpretations, interdisciplinary, and interdisciplinary nature of problems.

Working to instantiate these ideas about problem characteristics into practice, Jacobs, Dolmans, Wolfhagen, and Scherpbier (2003) developed and validated a questionnaire to assess the degree of complexity and structuredness of PBL problems and how students differentiated between these characteristics. Their results indicate that although students could clearly differentiate between simple and well-structured problems, these students were not able to discern ill-structured from complex problems.

Perhaps more helpful to designing PBL problems with characteristics that will support successful PBL implementations, Des Marchais (1999) used a Delphi technique with six PBL experts who were asked to identify three criteria considered most essential for the design of problems. The study identified that the two most important criteria were that the problem should stimulate thinking or reasoning and lead to self-directed learning in students. Sockalingam and Schmidt (2011) turned to PBL students and used reflective essays to ascertain their perceptions of the characteristics of well-designed PBL problems. Students identified 11 problem characteristics that helped lead them to desired learning outcomes. They said the problem should (1) lead to learning, (2) trigger interest, (3) be of suitable format, (4) stimulate critical reasoning, (5) promote self-directed learning, (6) be of suitable clarity, (7) be of appropriate difficulty, (8) enable application or use, (9) relate to prior knowledge, (10) stimulate elaboration, and (11) promote teamwork.

Although all of these studies may be helpful for understanding what PBL problems should contain, faculty implementing PBL may still find this work lacking in specificity. Major and Palmer (2001) offer that those implementing PBL should consider two techniques for problem improvement: outside evaluation by experts and content analysis of projects.

Outside Evaluation by Experts

Similar to the Des Marchais implementation of the Delphi method, soliciting expert reviews of one's PBL problems by faculty with expertise in PBL implementations may solicit helpful feedback for faculty. While such a review can be conducted before an initial rollout of a PBL problem, it may also be conducted post implementation using student performance data as additional sources to help experts assess the effectiveness of the problem for supporting learning.

Content Analysis of Projects

Because PBL uses ill-structured problems with many possible solutions, each student group within a class may pursue a slightly different domain of knowledge. To assess the range of content knowledge learned by students in the class, instructors may need to evaluate across assignments and groups to look for the variety of resources students are collecting and the degree to which these resources do (or do not) contribute to successful problem solving and learning.

Strategies for Monitoring Students' Metacognitive Skills: The Iron Range Engineering Program

Metacognitive skills are necessary for students to succeed in PBL, but students may not enter a PBL experience with sufficiently developed metacognitive skills. To illustrate how developing metacognitive skills can be supported in a PBL environment, we turn to a specific PBL implementation. The Iron Range Engineering (IRE) program, a collaboration between Itasca Community College (ICC) and Minnesota State University Mankato, is an exemplar of the gradually growing number of engineering programs implementing PBL (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). The IRE curriculum is unusual, however, in the degree to which it implements PBL as there are no formal classes.

IRE has implemented an entire upper-division engineering curriculum using semester-long industry-based PBL projects. IRE students do not enroll in traditional courses; rather, every semester students (with the help of faculty) designate a number of specific technical and professional competencies that they propose to attain during the term. Students work with faculty to develop individualized syllabi that guide their learning activities and assessments for these competencies.

A majority of these competencies and associated learning activities are accomplished via team-based PBL projects undertaken via partnerships with regional mining, milling, and manufacturing industries. Other student learning, however, occurs individually or in student-organized small groups. Students have a wide variety of resources available to them for accomplishing their learning. These resources span the spectrum of printed materials and electronic libraries to faculty and industry experts. In both the industry-based projects and in individual learning, students must exercise metacognitive skills and be self-directed learners as they make decisions about how best to complete the learning tasks necessary to achieve competency.

IRE faculty have recognized the need to support the development of students' metacognitive skills and have introduced several means of doing so. Although most learning takes place via their industry projects, or via informal student groups, faculty have instituted for a more formalized learning activity called "learning conversations." The format of a learning conversation can vary from a small group of students working with a faculty member to get guidance on how to solve thermodynamics problems, to a more formalized, regularly scheduled gathering of all first-year students as a faculty member presents content associated with a competency that many students are trying to meet that term. Each year, as new IRE students arrive, faculty introduce them to the concept of metacognition, its value in their success at IRE and as life-long learners, and ways to develop and apply their metacognitive skills while at IRE.

As students engage in learning activities, they complete a "metacog" memo documenting their reflections on the learning processes they used, the judgments they made on the quality of the learning, and the regulative changes made based on these judgments. Some students talked specifically about the value of the metacognition memos:

> Right away, [the memos] were extremely useful [because] in a metacog memo . . . I break it down to how I learned during that competency, what methods I used . . . and I kind of rate how it worked, how well it worked for that competency. . .and kind of just reflect back on what I did, how it worked, and if I'll use it again, and what future improvements I can make. . . .

In addition to the challenges of self-regulating their learning processes, students have found time management to be a particularly difficult aspect of this program. To scaffold time management, IRE students produce a "metachron." In a process that is similar to the one employed for metacogs, students reflect on time spent on learning activities:

> . . . I find that [a metachron] helps me keep track of how I'm spending my time, not just what I'm doing, but . . . I'm able to see where my time management improvements need to be, plus I can go back and say, "Oh, I did this for those 2 hours," and then I can write down what I thought of what I did, you know, was it helpful?

Conclusions

PBL is one of several instructional methodologies being implemented in higher education settings that are student centered. In PBL environments, learning is entirely focused around solving an authentic problem, which is often presented in a case. And in contrast to traditional pedagogies, learners do not learn the "basic" first and in a separate, often inauthentic mode (for example, read "about" a theory or a model rather than use it); rather, they learn basic content in the context of solving the complex, authentic problem.

The challenging news is that this pedagogy requires significant changes for both learners and teachers. The hopeful news is that understanding the basic theoretical premises on which PBL is founded—specifically, constructivism and situated cognition—can help practitioners be more effective in designing, implementing, and improving PBL environments. This article has explored those theoretical foundations and then applied them to help educators understand and use cases effectively to support PBL, design problems appropriate for PBL environments, and develop and use the metacognitive supports students need during PBL activities.

References

Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine, 68*(1), 52-81.

Amador, J., Miles, L., & Peters, C. (2007). *The practice of problem-based learning: A guide to implementing PBL in the college classroom.* Hoboken, NJ: Anker.

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years*. New York, NY: Springer.

Barrows, H. S. (1986). A taxonomy of problem-based learning methods. *Medical Education*, *20*(6), 481-486.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *68*, 3-12.

Barrows, H. S., & Tamblyn, R. M. (1976). An evaluation of problem-based learning in a small groups utilizing a simulated patient. *Journal of Medical Education, 51*(1), S2-S4.

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

Branch, R. (2009). *Instructional design: The ADDIE approach.* Berlin, Germany: Springer-Verlag.

Bransford, J., Brown, A., & Cocking, R. (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Brown, A., Collin, P., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Dale, E. (1969). *Audiovisual methods in teaching* (3rd ed.). New York, NY: The Dryden Press; Holt, Rinehart and Winston.

Des Marchais, J. E. (1999). A Delphi technique to identify and evaluate criteria for construction of PBL problems. *Medical Education*, *33*(7), 504-508.

Dolmans, D. H. J. M., Snellen-Balendong, H., Wolfhagen, I. H. A. P., & van der Vleuten, C. P. M. (1997). Seven principles of effective case design for a problem-based curriculum. *Medical Teacher, 19*(3), 185-189.

Duffy, T., & Cunningham, D. (1996). Constructivism: Implications for the design and delivery of instruction. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 179-198). New York, NY: Simon and Schuster.

Flavell, J. (1976). Metacognitive aspects of problem-solving. In L. B. Resnick (Ed.), *The nature of intelligence* (pp. 231-236). Hillsdale, NJ: Erlbaum.

Flavell, J. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*, 906-911.

Flavell, J. H. (1987). Speculations about the nature and development of metacognition. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 21-29). Hillsdale, NJ: Erlbaum.

Gagne, R., & Briggs, L. (1974). Principles of instructional design. New York, NY: Holt, Rinehart, Winston.

Hacker, D. J., Dunlosky, J., & Graesser, A. C. (Eds.). (1998). *Metacognition in educational theory and practice*. London, UK: Routledge.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *Journal of the Learning Sciences, 7*, 173-208.

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

Hung, D. (2002). Situated cognition and problem-based learning: Implications for learning and instruction with technology. *Journal of Interactive Learning Research*, *13*(4), 393-414.

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

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

Jonassen, D. (2003). Using cognitive tools to represent problems. *Journal of Research on Technology in Education*, *35*(3), 362-381.

Jonassen, D. H. (2006). Accommodating ways of human knowing in the design of information and instruction. *International Journal on Knowledge and Learning, 2*(3/4), 181-190.

Jonassen, D. H. (2010). Assembling and analyzing the building blocks of problem-based learning environments. In K. H. Silber & W. R. Foshay (Eds.), *Handbook of improving performance in the workplace, Vol. 1: Instructional design and training delivery* (pp. 184-226). Silver Spring, MD: International Society for Performance Improvement.

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

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

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. New York, NY: Cambridge University Press.

Litzinger, T. A., Lattuca, L. R., Hadgraft, R. G., & Newstetter, W. C. (2011).

Engineering education and the development of expertise. *Journal of Engineering Education, 100*(1), 123-150.
Major, C., & Palmer, B. (2001). Assessing the effectiveness of problem-based learning in higher education. *Academic Exchange Quarterly, 5*(1) 8-9.
Popper, K. (1994). *Alles leben ist problemlösen*. Munich, Germany: Piper Verlag.
Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231.
Salomon, G. (1993). On the nature of pedagogic computer tools: The case of the wiring partner. In S. P. LaJoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 179-198). Hillsdale, NJ: Erlbaum.
Savery, J. R., & Duffy, T. M. (1995) Problem-based learning: An instructional model and its constructivist framework. In B. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 135-150). Englewood Cliffs, NJ: Educational Technology Publications.
Schank, R. C., Fano, A., Bell, B., & Jona, M. (1994). The design of goal-based scenarios. *The Journal of the Learning Sciences 3*(4), 305-345.
Schraw, G., & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review, 7*(4), 351-371.
Shaw, M. E. (1976). *Group dynamics*. New York, NY: McGraw-Hill.
Sockalingam, N., & Schmidt, H. (2011). Characteristics of problems for problem-based learning: The students' perspective. *Interdisciplinary Journal of Problem-Based Learning, 5*(1), 6-34.
Sperling, R., Howard, B., Staley, R. & Dubois, N. (2004). Metacognition and self-regulated learning constructs. *Educational Research and Evaluation: An International Journal on Theory and Practice, 10*(2), 117-139.
Torp, L., & Sage, S. (1998). *Problems as possibilities: Problem-based learning for K-12 education*. Alexandria, VA: ASCD.
Woods, D. R. (1994). *Problem-based learning: How to gain the most from PBL.* Waterdown, Ontario, Canada: Woods.
Zimmerman, B. (2002). Becoming a self-regulated learner. *Theory Into Practice, 41*(2), 64-70.
Zimmerman, B., & Moylan, A. (2009). Self-regulation: Where metacognition and motivation intersect. In D. Hacker, J. Dunlosky, & A. Graesser (Eds.), *Handbook of metacognition in education* (pp. 299-315). New York: Routledge.

Rose M. Marra *is a professor of learning technologies at the University of Missouri (UM), where she teaches in the areas of online learning, instructional design and assessment. Dr. Marra has conducted research in online and science, technology, engineering, and mathematics (STEM) learning environments for 15 years, and she has extensive experience in problem-based learning, engineering education, assessment and evaluation, and gender equity in STEM fields. Dr. Marra has successfully led grant-funded research projects in STEM education, with over $10 million in external funding, including six National Science Foundation grants. Prior to coming to UM, Dr. Marra was on the faculty of the Penn State College of Engineering. In a past life, Dr. Marra was a software engineer for AT&T Bell Laboratories.* **David H. Jonassen** *passed away in December 2012; he was a curators' professor at the University of Missouri in learning technologies and educational psychology. Over his 40-year career, Dr. Jonassen taught at Penn State, the University of Colorado, the University of Twente - Netherlands, the University of North Carolina at Greensboro, and Syracuse University. He published 37 books and hundreds of articles, and papers on instructional design, computer-based learning, hypermedia, constructivism, cognitive tools, and problem solving. He received dozens of awards and was posthumously inducted as a Fellow of the American Educational Research Association. The last 10 years of his life were devoted to the cognitive processes engaged by problem solving and to developing models and methods for supporting those processes during learning.* **Betsy Palmer***, who passed away in May 2013, was an associate professor of education at Montana State University (MSU). Dr. Palmer taught statistics and both qualitative and quantitative research methods courses in the department of education at MSU. Within the adult and higher education program, she taught courses focusing on college student research and theory, student services, and college curriculum and teaching. Dr. Palmer's research focused on college students and the institutional practices that foster improved outcomes for students. She was particularly interested in college student personal epistemology, non-traditional pedagogical approaches, such as problem-based learning and service learning, and multicultural educational outcomes. An outstanding educator and researcher, Betsy was well published and received numerous awards and honors, including, most recently, the MSU department of education's Outstanding Research Award for 2011-2012 for her work in engineering education as well as her work in Nepal.* **Steve Luft** *is a full-time student at Montana State University working on his doctorate in Education with a specialty in Adult and Higher Education. Steve earned his master's in technical communication from Montana Tech of The University of Montana. Steve earned his undergraduate degrees in mechanical technology and drafting technology from Northern Montana College (NMC), known today as MSU-Northern. Prior to working on his doctorate, Steve spent the past 17 years at Montana Tech of The University of Montana as a tenured faculty member, department chair, and assistant and associate dean. During his time at Montana Tech, he was recognized locally as well as nationally for his efforts. Steve was nominated for Montana Tech's Outstanding Achievement Award, awarded Montana Tech's Outstanding Faculty Achievement Award, as well as a Montana Campus Compact Faculty Fellowship for his work with service learning. Steve was also nominated three times for the Carnegie Foundation U.S. Professor of the Year.*