Educational Research Review 4 (2009) 118–141

Contents lists available at ScienceDirect

Educational Research Review

journal homepage: www.elsevier.com/locate/EDUREV

The 9-step problem design process for problem-based learning: Application of the 3C3R model

Woei Hung*

University of North Dakota, Instructional Design & Technology, Education Building Room 218, 231 Centennial Drive STOP 7189, Grand Forks, ND 58202-7189, United States

ARTICLE INFO

Article history:
Received 12 May 2007
Received in revised form
21 November 2008
Accepted 8 December 2008

Keywords:
Problem-based learning
Instructional design
Curriculum development
Problem solving

ABSTRACT

The design of problems is crucial for the effectiveness of problem-based learning (PBL). Research has shown that PBL problems have not always been effective. Ineffective PBL problems could affect whether students acquire sufficient domain knowledge, activate appropriate prior knowledge, and properly direct their own learning. This paper builds on the 3C3R problem design model, which is a systematic conceptual framework for guiding the design of effective and reliable problems for PBL. To help practitioners apply the 3C3R model, this paper introduces a 9-step problem design process. The initial steps guide an instructional designer through analyses on learning goal, content, and context to help select problems. Later steps ensure that the problem appropriately affords the specifications identified in the analyses. The last two steps incorporate a reflection component, as well as ensure the integrity of the 3C3R components in the problem.

1. Introduction

Problem-based learning (PBL) is perhaps the most innovative instructional method conceived and implemented in education. It aims to enhance students' application of knowledge, problem solving skills, higher-order thinking, and self-directed learning skills. Its implementation began in medical education (Barrows & Tamblyn, 1980; Schmidt, 1983), and then gradually spread to various disciplines in higher education and K-12 education settings (Barrows, 2000; Dochy, Segers, van den Bossche, & Gijbels, 2003; Gallagher, Stepien, & Rosenthal, 1992; Hmelo-Silver, 2004; Hmelo, Holton, & Kolodner, 2000; Torp & Sage, 2002; Williams & Hmelo, 1998).

Fifty years after PBL was first implemented, its effectiveness as an instructional method has been a question open to debate. Advocates of PBL maintain that it is more effective than traditional methods in alleviating students' problem of inert knowledge as well as enhancing students' problem solving and self-directed learning skills (Barrows, 1996; Dods, 1997; Dolmans & Schmidt, 1994; Dombrowski, 1997; Kamin, O'Sullivan, Younger, & Deterding, 2001; Norman & Schmidt, 1992), while the skeptics argue that PBL is costly and ineffective because it requires more of students and instructor's time to obtain similar learning outcomes (see Farnsworth, 1994). Even recently, Kirschner, Sweller, and Clark (2006) have continued to argue that PBL is less effective than traditional methods because its approach of providing minimum guidance is not compatible with human cognitive architecture. In addition to these theoretical research disagreements about the effectiveness of PBL, the empirical research also echoes these disagreements with contradicting results. Several meta-analyses on empirical studies in PBL were conducted in the past decade (see, for example, Albanese & Mitchell, 1993; Berkson, 1993; Colliver, 2000; Dochy et al., 2003; Gijbels, Dochy, van den Bossche, & Segers, 2005; Vernon & Blake, 1993). The findings of these meta-analyses

* Tel.: +1 701 777 3486; fax: +1 701 777 3246.
E-mail address: woei.hung@und.edu.

1747-938X/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.edurev.2008.12.001

were mixed and inconclusive. The inconclusive or even contradictory results from these meta-analyses did not cease the battle between the advocates and opponents of PBL.

The effectiveness of an instructional method is a result of complex inter-causal relationships of numerous known and unknown variables involved in the instruction/learning processes. It may be a distant hope that we obtain a conclusive answer to the question of whether an instructional method is effective solely based on the end results of an implementation. There is little doubt that numerous factors contributed to the mixed results. Identifying these confounding variables and taking them into account could help elucidate a better picture of how an instructional method works; how effective it is; in what way and why. In attempting to do so, Gijbels et al. (2005) incorporated the format of assessment as an independent variable in their meta-analysis of the PBL studies. They found that PBL was most effective when the assessment of the studies focused on the students' understanding of connection between principles and concepts.

Another potential variable that could also affect the effectiveness of PBL is the design of PBL problems. Four studies showed that the correspondence rates between instructors' objectives and students' generating learning issues were only about 62% (Coulson & Osborne, 1984; Dolmans, Gijselaers, Schmidt, & van der Meer, 1993; O'Neill, 2000; van Gessel, Nendaz, Vermeulen, Junod, & Vu, 2003). These low correspondence rates signal that the design of problems might have contributed to some ineffective PBL implementations in the past. Problems are at the heart of PBL. It is a reasonable conjecture that the design of PBL problems may play a critical role in affecting the effectiveness of the PBL curriculum. This paper proposes a 9-step PBL problem design process based on the 3C3R PBL problem design model (Hung, 2006) for guiding PBL educators and instructional designers to systematically design effective PBL problems. In the following, I will briefly discuss the nature of PBL and its development and research, followed by a discussion of some of the PBL implementation issues that pertain to the design of problems. Then I will discuss the 3C3R PBL problem design model and its application—the 9-step design process in detail.

2. The nature and development of PBL

Traditional pedagogies, such as lecturing and demonstrating solutions to problems, very often result in students being capable of solving "textbook problems," but unable to apply the knowledge to solve real life problems (Brown, Collins, & Duguid, 1989; Mayer, 1996; Perkins & Salomon, 1989). PBL is one of the several instructional methods that have been developed to remedy the problem. PBL takes a completely different approach in facilitating students' learning. Instead of initiating the learning process by presenting learning content for the students to memorize and comprehend, PBL mimics the natural human learning process. That is, learning is initiated when a problem is encountered. In seeking solutions to the problems, the person learns the skills as well as the knowledge that revolves around the problem and the environment (contextual knowledge) in which the problem takes place.

Hoffman and Ritchie (1997, p. 97) defined PBL as "a student-centered pedagogical strategy that poses significant, contextualized, real-world, ill-structured situations while providing resources, guidance, instruction, and opportunities for reflection to learners as they develop content knowledge and problem skills." PBL courses/curricula organize knowledge to be taught around the problems that the learners will encounter in their personal lives or professional careers. In PBL, the learners are situated with ill-structured authentic problems in which they are challenged to be active problem-solvers. The ultimate goals of problem-based learning are to guide the learners toward "meaning-making over fact-collecting" (Rhem, 1998, p. 1), as well as to become self-directed learners (Torp & Sage, 2002).

2.1. Characteristics of problem-based learning

The most distinct characteristic that makes PBL different from other instructional methods is problem-centered content structure. In addition, Barrow's (1986) four educational objectives of PBL, which are contextualization, reasoning process, self-directed learning skills, and motivation to learn, also characterize and account for the strength of PBL.

The learning process in PBL starts with solving problems, instead of content. Barrows and Tamblyn (1980, p. 1) explained that learning in PBL "results from the process of working toward the understanding or resolution of a problem so it is important that the problem is encountered first in the learning process." In PBL, students are no longer receiving the learning content from the instructor in a "textbook" logical sequence. Rather, the content is organized as a problem or a series of problems. The knowledge needed for solving the problem and the related information evolved from the problem formulate the scope of the content in PBL.

Furthermore, PBL utilizes authentic problems. This approach naturally contextualizes the problem, the learning content, and the knowledge and skills learned throughout the course. Traditional instruction usually presents content information and assesses students with context-free problems. Unfortunately, traditional method results in students' inability to link the knowledge learned to real life practice. These deficiencies consequently contribute to their difficulties in transferring knowledge learned in real life situations (Brown et al., 1989; Perkins & Salomon, 1989; Spiro, Coulson, Feltovich, & Anderson, 1988).

The reasoning process is another important element in PBL. Learning in a PBL environment is no longer as simple as fact-collecting. Instead, PBL learners have to engage in inquiry processes in which critical and creative thinking skills are the key for the learners to accomplish the problem solving tasks imposed upon them. As Dunlap and Grabinger (1996) suggested, these cognitive processes and abilities required for engaging in problem-based learning activities promote the learner's higher-level thinking skills, and consequently, result in deeper understanding and better application and transfer of the knowledge in the future.

Helping the learner become self-directed is also one of the ultimate goals of PBL. Savery and Duffy (1996) asserted that in problem-based learning environments, the learner must develop his or her own learning skills and strategies to successfully fulfill the learning tasks. The learning activities embedded in the learning process encourage and elevate the learner's self-regulation and metacognition during and/or after the learning process. Mayo, Donnelly, Nash, and Schwartz (1993) suggested that the instructor or tutor should serve as a "metacognitive guide." These self-directed learning skills are particularly important because they are the essence of independent problem solving competence and lifelong learning.

Problem solving, as Keller (1987) suggested, is an instructional approach inherently challenging and motivating. Desire to conquer obstacles and solve problems is human nature. This intrinsic motivational component helps increase students' desire to learn and sustains their interest throughout the course of the learning. Creating a sense of ownership is another motivational factor of problem-driven learning. PBL, according to Dunlap and Grabinger (1996), engages the learner in learning activities by establishing his or her ownership of the problems and the responsibility of decision making about the learning process. To successfully solve a problem, the learner has to see the problem as his or her own (von Glasersfeld, 1995). As a result, the learner is taking responsibility for overcoming the obstacle.

2.2. The development of PBL

PBL was originally conceived and implemented in response to students' unsatisfactory clinical performance (Barrows, 1996; Barrows & Tamblyn, 1980) resulting from the emphasis on memorization of fragmented biomedical knowledge in traditional health science education. The widely adopted format of PBL was first developed in medical education at McMaster University in the 60s and 70s (Barrows, 1996). Since its first implementation, PBL has become a prominent instructional method in medical and health science education throughout the world, such North America, Netherlands, England, Germany, Australia, New Zealand, and India (Hung, Jonassen, & Liu, 2008).

With the positive results from implementing PBL in medical education, PBL has also been embraced by other disciplines in higher education, such as architecture (Donaldson, 1989; Maitland, 1998; Ostwald, Chen, Varnam, & McGeorge, 1992), business administration (Arts, Gijselaers, & Segers, 2002; Godat, 2007; Merchand, 1995), chemical engineering (Woods, 1996), law schools (Driessen & van der Vleuten, 2000; Kurtz, Wylie, & Gold, 1990; Pletinckx & Segers, 2001), leadership education (Bridges & Hallinger, 1996; Cunningham & Cordeiro, 2003), nursing (Barnard, Nash, & O'Brien, 2005; Higgins, 1994), and teacher education (Oberlander & Talbert-Johnson, 2004), science courses (Allen, Duch, & Groh, 1996), biochemistry (Osgood, Mitchell, & Anderson, 2005), calculus (Seltzer, Hilbert, Maceli, Robinson, & Schwartz, 1996), chemistry (Barak & Dori, 2005; Ram, 1999), economics (Garland, 1995), geology (Smith & Hoersch, 1995), and psychology (Reynolds, 1997).

PBL has also been gaining momentum in K-12 settings. In introducing PBL into K-12 education, Barrows and Kelson (1993) systematically developed PBL curricula and teacher-training programs for all high school core subjects. Since then, PBL has been promoted by a number of scholars and practitioners for use in basic education (Arends, 1997; Glasgow, 1997; Jones, Rasmussen, & Moffitt, 1997; Kain, 2003; Savoie & Hughes, 1994; Stepien, Senn, & Stepien, 2000; Torp & Sage, 2002; Wiggins & McTighe, 1998). Various results of implementations of PBL in K-12 settings have been widely reported. First, PBL has been shown to be effective in conveying a variety of content areas, for example, mathematics (Cognition and Technology Group at Vanderbilt – CTGV, 1993), science (Linn, Shear, Bell, & Slotta, 1999; Kolodner et al., 2003), literature (Jacobsen & Spiro, 1994), history (Wieseman & Cadwell, 2005) and microeconomics (Maxwell, Mergendoller, & Bellisimo, 2005). PBL can also be used effectively in a wide variety of student populations, for example, gifted elementary, middle, and high school students (Dods, 1997; Gallagher, 1997; Gallagher, Sher, Stepien, & Workman, 1995; Stepien & Gallagher, 1993; Stepien, Gallagher, & Workman, 1993), as well as low-income students (Stepien & Gallagher, 1993).

2.3. Issues in learning with PBL

Regardless of its increasing popularity, there is skepticism about the effectiveness of PBL. For example, Farnsworth (1994) summarized the criticisms that PBL is an ineffective instructional method because learners have to gather information through self-directed learning and it is costly because it requires more faculty and time to conduct the course. Kirschner et al. (2006) also claimed that PBL is less effective than traditional methods because its approach of providing minimum guidance is not compatible with human cognitive architecture. Despite the inconclusive research results on the effectiveness of PBL discussed earlier and the debates between advocates and skeptics, what have we learned from the PBL implementation and research over the past several decades? In the following, I will discuss two major issues that concern PBL researchers and educators.

2.3.1. Basic/factual knowledge acquisition

Enormous amounts of research, including several meta-analyses, have been conducted in answering this question over the past several decades (see, for example, Hung et al., 2008). Two of the most quoted meta-analyses, Albanese and Mitchell (1993) examined PBL research from 1972 to 1992 and Vernon and Blake (1993) examined PBL research from 1970 to 1992. Both meta-analyses concluded that the PBL research findings were mixed and inconclusive. The two meta-analyses agreed that in general, traditional curriculum students perform better on basic science knowledge acquisition, while PBL students perform better on clinical knowledge acquisition and reasoning. Dochy, Segers, van den Bossche, and Gijbels' meta-analysis of 43 PBL studies conducted in year 2003 supported Albanese and Michell's and Vernon and Blake's finding about PBL students' knowledge acquisition. However, when comparing students' performance on progress tests under PBL and traditional curriculum, Verhoeven et al.'s (1998) findings only partially agreed with Albanese and Mitchell's and Vernon and Blake's findings. They found that the traditional students obtained better scores on basic science while PBL students performed better on social science. Also, to their surprise, the PBL students did not outperform non-PBL students in clinical science in the first and second years in their programs. Lastly, Berkson's (1993) and Colliver's (2000) PBL literature reviews did not find strong evidence to support the superiority of PBL in acquisition of either basic or clinical knowledge.

As to the issue of adequacy of basic knowledge acquisition, Hoffman and Ritchie (1997) explained that the adequacy of factual/basic knowledge acquisition may be traded for developing problem solving and reasoning skills because of the limited timeframe constraint and students' energy in PBL courses. The insufficiency of content knowledge acquisition issue has been a serious concern among teachers (Angeli, 2002), as well as students (Lieux, 2001; Schultz-Ross & Kline, 1999). Although PBL students' gain in the content area was not significantly less than traditional students as the PBL research suggested (see, for example, medical fields, Albanese & Mitchell, 1993; Vernon & Blake, 1993; quantity food production and service, Lieux, 2001; diabetes education, Schlundt, Flannery, Davis, Kinzer, & Pichert, 1999; and American study, Gallagher & Stepien, 1996), it is a concern that merits PBL researchers' attention.

2.3.2. Transition to PBL

Another PBL implementation issue is that most students who are new to PBL reportedly experience discomfort and frustration at the initial stage of learning (see, for example, Dabbagh, Jonassen, Yueh, & Samouilova, 2000; Fiddler & Knoll, 1995; Hoffman & Ritchie, 1997; Jost, Harvard, & Smith, 1997; Schultz-Ross & Kline, 1999). These negative experiences are most likely due to the students' habits of mind toward learning. The traditional "feeding-and-regurgitating" instructional methods (Langer, 1997) fail to cultivate students' self-directed learning skills, and consequently they are hesitant or even resistant to taking an active role in learning processes. The drastic change of roles in their own learning causes them to be uneasy in their PBL learning process. Moreover, students need to possess a certain degree of self-directedness to successfully accomplish the learning tasks in PBL, which poses a great challenge for those who are not naturally self-directed learners. Although most PBL studies have shown that students developed positive attitudes toward the end of the term (Dabbagh et al., 2000), the painful transition and adjustment are a long and slow process (Schmidt, Boshuizen, & de Vries, 1992) and may be detrimental to learning.

3. PBL problem design

As mentioned in the introduction, a number of confounding variables could affect the effectiveness of PBL that is manifested in the measurement of students' learning outcomes. The format of assessment is one of them (Gijbels et al., 2005). The problem design could be another one. Regarding the issue of insufficient content knowledge, some critics have argued that PBL problems require students to consider only limited content in order to develop a deeper understanding about the topic. Such practice may likely result in limiting students' exposure to broader content that may be a part of a course or curriculum but not be directly related to the causes or solutions of the problem under investigation (Hung, Bailey, & Jonassen, 2003). On the other hand, the opposite situation is also a possible cause for PBL students' less than desirable level of basic knowledge acquisition performance. An ineffective PBL problem may require students to investigate and study an exceeding amount of information that is not part of the intended content but is required for solving the problem. Another type of ineffective PBL problem is when the problem does not clearly guide students to research and study the intended content knowledge.

To investigate how effective PBL problems are, Coulson and Osborne (1984) conducted a study to evaluate how well the student-generated learning issues (PBL students actively identify learning objectives from the problem) matched the intended learning issues specified by the instructors on which the PBL problems were supposed to be based. They reported a correspondence rate of 62% between faculty-intended objectives and student-generated learning issues from the Problem-based Learning Modules (PBLMs) when testing a group of 72 medical students. Likewise, Dolmans et al. (1993) obtained similar results from their three studies. On average, only 64% of intended content was identified by the student-generated learning issues in these three studies (results ranged from 27% to 100%). Furthermore, within the student-generated learning issues that were unexpected by the instructors, only 47% were relevant to the intended learning content. Similar studies by O'Neill (2000) and van Gessel et al. (2003) reported a 62% correspondence rate between faculty objectives and student-generated learning issues. One important and likely reason for these low correspondence rates, according to Dolmans and her colleagues (1993), is ineffective problem design. These studies showed that, in the course of several decades since its introduction, the effectiveness of PBL problems seems to be questionable and is worth a close look.

PBL problems could be ineffective because they might afford inappropriate (that is, insufficient, excessive, or off-topic) content coverage, impose inappropriate problem solving skill requirements (over or below learners' abilities), or include unintended ambiguous information in the problems. Because of these deficiencies, ineffective PBL problems could influence students' activation of prior knowledge and their group processing (Perrenet, Bouhuijs, & Smits, 2000), cause difficulty in generating learning issues that the problems are designed to cover (Dolmans et al., 1993), and affect students' self-directed learning (Gijselaers & Schmidt, 1990), which in turn, influences students' content acquisition and overall learning experience. Thus, the design of problems could certainly influence the effectiveness of PBL courses and curriculum (Duch, 2001; Lee, 1999; Trafton & Midgett, 2001).

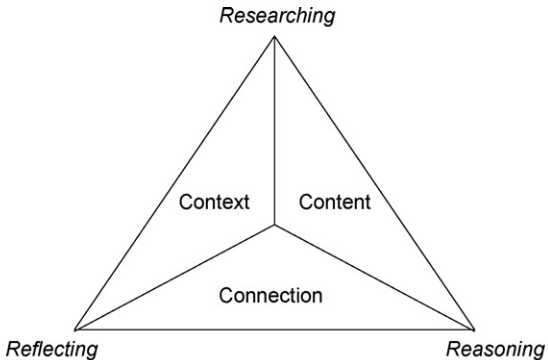


Fig. 1. 3C3R PBL problem design model.

Hung (2006) developed the 3C3R PBL problem design model as a conceptual framework for guiding the design of reliable and effective PBL problems for all levels of learners by addressing the specific characteristics of PBL and its implementation. The present paper attempts to build on that model to show how it can be put into action using a 9-step problem design process. This process provides instructional designers and teachers with a practical process to design effective, reliable, and appropriate PBL problems. The initial steps guide an instructional designer through analyses on learning goal, content, and context to help select problems. Later steps ensure that the problem appropriately affords the specifications identified in the analyses. The last two steps incorporate the reflection component, as well as ensure the integrity of the 3C3R components in the problem. I first briefly describe the 3C3R model and then discuss the 9-step design process in more detail.

4. 3C3R model: the conceptual framework

The 3C3R PBL problem design model consists of two classes of components (see Fig. 1): core components and processing components. Core components are content, context, and connection; these three C's relate to the content/concepts learning focus in PBL. Processing components – the three R's – comprise researching, reasoning, and reflecting, which support the cognitive processes of problem solving skills and self-directed learning.

4.1. Core components of 3C3R model

The core components of the 3C3R model are concerned with structuring content knowledge, contextualizing domain knowledge, and building a conceptual framework around the topic under study. The first core component is content. As discussed earlier, in general, PBL students performed slightly less well than traditional students on content tests (Albanese & Mitchell, 1993; Friedman et al., 1992; Levesque, 1999; Vernon & Blake, 1993). The research attributes these results in part to PBL's emphasis on depth of content and higher-order thinking skills, suggesting that breadth of content and factual knowledge might have been sacrificed (Albanese & Mitchell, 1993; Gallagher & Stepien, 1996; Hung et al., 2003). The content component aims to reconcile this issue by addressing the essence of a sound content design of a PBL problem. The second core component is context. Barrows (1986) asserted that students' knowledge base should be organized in a form of being ready to use in clinical context. Also, situating learning in a practical context, Prawat (1989) argued, will help the learners become more aware of how the knowledge is used. More importantly, context often influences problem solvers' reasoning processes and solutions because of their professional primary concerns (Flesher, 1993). Thus, in a specific field, the learner needs specific situational or contextual knowledge that is implicit but crucial to becoming an effective problem solver. Contextual validity, the degree of contextualization (Hays & Gupta, 2003), and motivation (or relevance) are three important aspects in considering context component of PBL problems. The third core component is connection. PBL curriculum typically consists of a series of problems that encompass different sections of the curriculum. By developing a knowledge base that is "packaged" as a collection of cases or problems, the students can effectively retrieve relevant knowledge to solve problems they encounter. However, the students are not learning the subject conceptually if the problem cases are all independent of each other in their knowledge bases. Thus, if the concepts and information within the domain are not explicitly interconnected, students' "packaged" knowledge could become "compartmental" (see Spiro et al., 1988) and this could make the transfer of knowledge difficult.

4.2. Processing components of the 3C3R model

The three processing components of 3C3R model are researching, reasoning, and reflecting. They support mindful and meaningful engagement in scientific inquiry and problem solving processes during the course of PBL. The processing components (1) direct the students toward the intended learning goal(s); (2) adjust the level of cognitive processing required in accordance with the cognitive readiness of the learners; and (3) alleviate the initial discomfort students might experience with PBL.

The first stage of the problem solving process is understanding the problem (Bransford & Stein, 1984; Polya, 1957) by researching necessary information within the domain. This component guides learners toward the intended content and then prevents them from deviating from the intended objective because of the openness of ill-structured problems. The second component, reasoning, promotes the application of the knowledge acquired from the research process and the development of the learners' problem solving skills. Because the learners must analyze information and generate and test hypotheses and solutions to the problems, they will have to put their knowledge into practice instead of just memorizing it. When engaging in the cognitive activities required in the reasoning process, the problem solver processes the somewhat raw knowledge into meaningful, applicable, and conceptually integrated knowledge. The third processing component is reflecting. In Barrows and Myers' (1993) PBL process, reflection is a crucial element that helps learners achieve optimal learning outcomes and become self-directed, lifelong learners. By reflecting on the knowledge they have constructed throughout the problem solving process, the learners have the opportunity to systematically and conceptually organize and integrate their knowledge of the domain. The reflecting component guides the learners to assess the effectiveness and efficiency of their own learning as a whole. In short, carefully considering these 3C3R components can help instructors design more effective PBL problems. (For the full scope of the 3C3R model, please refer to Hung, 2006).

5. The 9-step process of designing 3C3R in PBL problems

The 9-step PBL problem design process is intended to help instructional designers and educators use the 3C3R PBL problem design model. The 9 steps of the design process are as follows.

Step 1: Set goals and objectives
Step 2: Conduct content/task analysis
Step 3: Analyze context specification
Step 4: Select/generate PBL problem
Step 5: Conduct PBL problem affordance analysis
Step 6: Conduct correspondence analysis
Step 7: Conduct calibration processes
Step 8: Construct reflection component
Step 9: Examine inter-supporting relationships of 3C3R components

PBL embraces the instructional philosophy of constructivism. However, constructivist instruction should not be equated with free-form, unguided inquiry learning or unstructured, unplanned instruction. Ausubel (1962, 1968) warned that unstructured, unplanned discovery learning could also result in rote learning. More recently, Kirschner et al. (2006), explored why constructivist, discovery, and problem-based learning failed to accomplish what they promise. They attributed the failure to the use of minimal guidance in these instructional methods. An alternative explanation for the observed disappointment may be that these instructional methods themselves are not the problem, but rather that they are misunderstood. To respond to a common misinterpretation that PBL is "a free educational happening with students learning whatever they wish," Barrows (1996) stated that "the curricular linchpin in PBL – the thing that holds it together and keeps it on track – is the collection of problems in any given course or curriculum with each problem designed to stimulate student learning in areas relevant to the curriculum" (p. 8). Kolodner (2002) echoes Barrows' argument by stating that "simply putting hands-on, inquiry-based, constructivist, or what-have-you activities in place doesn't *ensure* learning. . .it takes very careful orchestration to ensure that the masses of students will take away from the activities as much as they should" (p. 123). Thus, constructivist instruction, including PBL, in fact requires more intensive analysis and planning to create a rich learning situation that guides and engages students in learning activities designed to help them construct the intended knowledge and skills. More importantly, comprehensive analysis and planning enables teachers/tutors to guide students' learning more flexibly and holistically. Without a complete cognitive map and understanding of the capacity of the PBL problem, the teacher/tutor is likely to guide the students with his or her own preference of solving the problem instead of guiding the students to tackle the problem from different angles.

The 9-step method builds intensive analysis into the design process to ensure that the design of the PBL problem appropriately and holistically affords students' learning in all aspects of content acquisition, problem solving skills, and self-directed learning. The first three steps are a front-end analysis of the PBL module. Steps 4 and 5 are the analysis of the selected PBL problem. Steps 6 and 7 are the analysis of affordance and adjustment of the PBL problem. Step 8 describes the design of reflecting component. Finally, Step 9 examines the integrity of 3C3R components of the problem. The purposes of these analyses and adjustments are not to prescribe students' learning processes or outcomes; rather, they are intended to promote the effectiveness of PBL problems by ensuring they are properly designed.

5.1. Step 1: Set goals and objectives

Many researchers agree that the first step in designing PBL problems is to specify goals and objectives for the course/curriculum (Drummond-Young & Mohide, 2001; Uyeda, Madden, Brigham, Luft, & Washburne, 2002). Learning goals and objectives help teachers or instructional designers outline the breadth and depth of content and, consequently, provide a structure for aligning the scope of the problem with the curriculum standards (Trafton & Midgett, 2001). When specifying learning goals and objectives, the designer should carefully consider three aspects—domain knowledge, problem solving skills, and self-directed learning skills (see Appendix A, Example 1 provides a full design document of a PBL problem).

While specifying the scope of the domain knowledge is the first necessary step in all instructional design methods (Gagné, Wager, Golas, & Keller, 2005; Jonassen, Tessmer, & Hannum, 1999), this step is especially critical in designing PBL problems because it provides a reference point for guiding the rest of process. This step improves the reliability of PBL problems by outlining the intended learning goal in relation to domain content.

Another important aspect of PBL learning objectives is problem solving skills. The designer should determine what difficulty levels of problem solving the learners are expected to develop during the course of learning. These objectives should be devised based on the students' current cognitive readiness. They also provide reference for calibrating the researching and reasoning components in PBL problems in later steps.

While it is understandable that younger learners lack self-directed learning skills (Brown, 1978; Thomas, Strage, & Curley, 1988), the same phenomenon has also been found in some adult learners (Boote, 1998; Smith, 2000). Learners who lack such learning skills exhibit a greater degree of initial resistance to PBL (Dabbagh et al., 2000; Fiddler & Knoll, 1995; Hoffman & Ritchie, 1997; Jost, Harvard, & Smith, 1997; Woods, 1996). Self-directed learning is also one of the most common difficulties PBL students face, as reported by Schmidt et al. (1992). Therefore, to avoid potential detrimental effects on students who are under-prepared to self-direct their own learning, instructional designers should identify the learners' current cognitive capabilities and their experiences with PBL to devise reasonable expectations of their development of self-directed learning skills.

5.2. Step 2: Conduct content/task analysis

The second step of the 3C3R PBL problem design process is content/task analysis. As Jonassen et al. (1999) suggested, task/content analysis is critical regardless of what instructional method is employed. One way to accomplish this step is to identify the content as one of four categories: concepts, principles, procedures, or factual. According to Sugrue (1995), concepts, principles, and/or procedures are the critical domain knowledge that an effective problem solver must possess. Concepts are the core ideas within a domain. Principles are defined by Sugrue (1995, p. 29) as "the rules that involve relationships among the concepts." Because PBL problems usually involve several concepts, the learners must conceptually interconnect them based on the principles in order to apply the concepts to solve a complex problem. Also, sometimes procedural knowledge is necessary for executing the solution, for example, solving a math word problem requires procedural knowledge of basic mathematical operations. Finally, factual domain knowledge is the information a learner needs to apply concepts. This category of content establishes the breadth of the learners' domain knowledge. The distinction between concepts and factual knowledge is that a concept is the fundamental understanding of a given phenomenon, and the factual knowledge is the information that enables the practical use of the concept. For example, the concept of π is the ratio of the circumference of a circle to its diameter, and the factual knowledge of π is that its value is 3.14159265.

5.3. Step 3: Analyze context specification

Situating learning processes in an authentic context is one of the key features of PBL (Barrows, 1994; Duch, 2001; Hmelo & Ferrari, 1997; Koschmann, Myers, Feltovich, & Barrows, 1994; Hmelo, 1998; Torp & Sage, 2002). Projected context is apparent when designing PBL problems for professional training or higher education curricula, for example, medical education, vocational education, or college engineering schools (see Appendix A, Example 2, Step 3). K-12 curricula or university general education curricula, on the other hand, focus on providing general foundations of knowledge. Therefore, the applications of the content knowledge can be rather general (see Appendix A, Example 1, Step 3).

When designing problems for a curriculum that is not profession-specific, the instructional designers can identify several possible applicable contexts and then select the one that would be most appealing to the learners. This identification of projected context helps instructional designers look for possible real life problems to use. If the projected context is profession-specific, the instructional designer also would need to identify the factors that affect the professionals' practice in the field. For instance, in Example 2 (Appendix A), the weather conditions, the time of day, and the season, are factors that influence how the mountain rescuers process information differently from when engaging in other types of rescue. The common categories of factors could include, for example, the location where the problem will take place (e.g. a hospital or ambulance), resource availability, the nature of the task (e.g. troubleshooting faults in design, manufacturing, or maintenance), or the culture of the workplace.

5.4. Step 4: Select/generate PBL problem

The first three steps in this design process are the front-end analysis of the course content and context area. They equip the instructional designer with a frame of reference for the breadth and depth of the content, problem solving skills, and the context that a specific PBL course or module intends to accomplish. The next step is selecting a problem. In this step, the instructional designer should start searching a pool of candidate real life problems within the context previously specified in Step 3 and then select one problem that best affords the results of the front-end analysis. The selected PBL problem needs to be appealing to the learners to keep them motivated (Hung, 2006). The factors that the designer can consider to determine the problem's degree of appeal include its relevance to the learners' future career, personal interests, immediate threats (Biggs, 1989), or geographical proximity (Hung & Holen, under review). If no real life problems exist within the projected context that satisfy the specifications from the front-end analysis, the instructional designer could consider similar problems or cases in other related contexts and generate a problem that fits the projected context.

5.5. Step 5: Conduct PBL problem affordance analysis

The next step is to construct a full description of the problem to analyze its problem affordance. By constructing a full description of the problem, the designer can depict a comprehensive problem space (Newell & Simon, 1972). This depiction helps to determine (1) whether the problem properly affords the learning goal; (2) whether the key knowledge involved in solving the problem matches the intended content knowledge; (3) whether the contextual information in the problem is sufficient to situate the learning in an authentic context; and/or (4) whether the connection component of the problem is properly designed.

This full description of the problem can also promote effective tutoring. de Grave, Dolmans, and van der Vleuten (1999) maintained that expert knowledge was a key factor for effective tutoring. A guide for the tutor generated based on this analysis can help non-expert tutors guide the learners more effectively toward the critical content knowledge and help them coach more advanced learners to further explore the problem. For expert tutors, the guide can also help them improve their tutoring skills. Kaufman and Holmes (1998) found that expert tutors tended to lecture or give explanations instead of guiding students through the problem solving process. This phenomenon might result from experts' knowledge tending to be tacit (Bloom, 1986), which could prevent them from articulating their own reasoning processes. This tutor guide can help expert tutors articulate their reasoning processes and devise effective strategies or questions to guide students' problem solving processes.

This description of the problem should include all the details involved in solving the problem, including the current state and goal state of the problem, known key variables, unknown variables (the missing links), context description, the most viable reasoning path and solution (or the known reasoning path and solution if this problem has been solved), and any alternatives to all of the above elements. The analysis of alternatives can also reveal the depth of the PBL problem by examining the extent of the ill-structuredness of the problem (Hung, 2006). Four aspects of problem affordance analysis are described below.

5.5.1. Domain knowledge

To reveal the domain knowledge afforded by the problem, the designer should start by analyzing the concepts, principles, procedures (Sugrue, 1995), and factual information that evolve around the most accepted interpretation of the problem/case, hypothesis, and solution to the problem. This set of domain knowledge is called core knowledge (see Step 5 in Example 1). After the core domain knowledge is identified, the instructional designer should also analyze the domain knowledge that revolves around the alternative paths of solving the problem, which is called peripheral domain knowledge. Identifying core and peripheral knowledge allows the designer to examine content effectiveness of the PBL problem. If the intended domain knowledge is not afforded through the most viable (or conventional) path of solving the problem, the students may not be able to identify it as a learning issue, which would render the problem ineffective. The core knowledge of the problem should afford the intended content knowledge, while the peripheral knowledge provides additional depth and breadth for students' learning.

5.5.2. Problem solving skills analysis

The next task is analyzing the cognitive processes of solving the problem – specifically researching and reasoning – involved in solving the problem. Researching processes include understanding the problem (Bransford & Stein, 1984; Polya, 1957) and researching necessary information. To understand the problem, the problem solver has to recognize the current state of the problem (in Example 1, lack of funds for a field trip), the known (e.g., a discount on the school bus fee) and unknown information (e.g., options for fundraising items), and the goal state of the problem (raising sufficient funds for a field trip). The instructional designer also needs to examine the reasoning component of the problem. The first cognitive task in the reasoning process is the preliminary processing of the information collected from the researching process, including screening and comprehending applicable information (concepts and/or principles) and identifying what needs to be researched further. By processing this information, the learners establish their domain knowledge base.

The next cognitive process is identifying inter-causal relationships and generating hypotheses. To identify inter-causal relationships among the variables, a problem solver needs to construct a conceptual map (e.g., in Example 1, determine the relationship between school bus fee and the discount, or between school bus fee and the total expense), create a logical solution path (e.g. find logical links between the available seed money, the school bus fee after discount, admissions, and the number of students to find out how much money each student needs to raise), or pinpoint the faulty parts of the problem (for diagnosis or troubleshooting types of problems). This causal reasoning process is critical to developing a deeper understanding of the concepts and principles, as well as to generating hypotheses. To generate a sound hypothesis, a problem solver needs to identify a potential cause–effect relationship between two or more key variables and the underlying explanations for the causal relationship. This information can help designers with the calibration process in the later step.

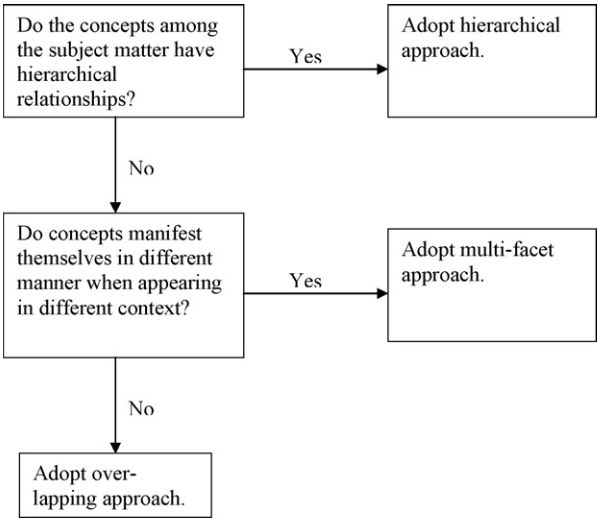


Fig. 2. Procedure for selecting appropriate connection.

5.5.3. Context analysis

When a profession-specific context is identified in Step 3, the instructional designer should analyze the contextual information in the problem in terms of special or professional considerations unique to the situation or workplace where this problem takes place (see Example 2). This context analysis should uncover explicit as well as implicit information regarding the special/professional considerations embedded in the problem.

5.5.4. Connection analysis

Finally, the designer needs to evaluate the connection component of the problem when it is one of the modules or lessons in a PBL curriculum. Interconnecting different concepts is required in almost all real life problem solving activities (Stanley, 2002). The conceptual interconnection is crucial in helping learners establish their framework of knowledge. When designing PBL curriculum, the 3C3R model suggests three different approaches – hierarchical, overlapping, and multi-faceted – for designing the connection component in problems of different subject areas, depending upon the nature of the subject. The decision of which approach to use should be made at a curriculum design level (see Fig. 2). In this step, the designer should examine whether the problem is conceptually interconnected with other related problems and whether it uses the appropriate approach.

5.6. Step 6: Conduct correspondence analysis

Correspondence analysis is an essential mechanism for ensuring the reliability and effectiveness of the PBL problem in the 9-step design process. This analysis helps detect whether the problem corresponds to the intended content coverage and the learner's skills level. The problem that overly exceeds the intended content coverage or requires problem solving skills that are beyond the learners' cognitive ability is referred to over-affording. On the other hand, the problem that inadequately covers the intended content area or requires a lower level of problem solving skills than intended is referred to under-affording. Both over- and under-affording result in ineffective PBL problems. Over-affording PBL problems are likely to overwhelm and frustrate the learners. Furthermore, exceeding coverage could distract the learners from the intended content. Conversely, under-affording PBL problems provide insufficient content for achieving learning goals or do not promote students' problem solving skills. To conduct correspondence analysis, the designer reviews content, researching and reasoning, and/or context components of the problem.

5.6.1. Content correspondence analysis

One way of conducting content correspondence analysis is by using a correspondence chart to reveal the degree of correspondence between the intended content area and the affordance of the PBL problem. Example 1 (Step 6) illustrates this analysis: the top row of the chart shows the key intended content area (concepts, principles, or procedure) identified in Steps 1 and 2. The left-hand column of the chart is the core knowledge of the problem, as well as the peripheral knowledge (the alternatives) identified in Step 5. Then, by matching the core and peripheral knowledge afforded by the PBL problem (the left-hand column) to the intended content (the top row), the problem can be evaluated as a well-aligned problem, over-affording problem, or under-affording problem. A well-aligned problem will show an approximate match between the elements in the left column and the top row (i.e. no items will be left unchecked in either the left column or the top row). However, the over-affording problem has a surplus of unchecked items in the left column, while the under-affording problem has a surplus of unchecked items in the top row of the chart. Using these results, the designer could modify the problem to afford the intended learning content more properly in the next step (calibration process) if needed. Another function of the correspondence analysis chart is to provide information for the instructional designer to manage the depth of the problem. Extra breadth and depth of content coverage may be needed for more advanced learners in a group of mixed-ability learners.

5.6.2. Researching and reasoning correspondence analysis

A similar analysis should also be conducted to reveal the correspondence between the researching and reasoning processes required for solving the PBL problem and the problem solving skills specified in the learning objectives (see Example 1 and 2). This analysis prepares the designer for the next step to calibrate the level of researching and reasoning processes that is appropriate for the learner characteristics.

5.6.3. Context correspondence analysis

When the subject matter is profession-specific, the designer needs to evaluate the correspondence between the factors that influence professional practices identified in Step 3 and the profession considerations required for solving the PBL problem identified in Step 5. The instructional designer can adjust the amount of contextual information in the problem to avoid over- or under-contextualizing the problem (Hung, 2006). This analysis is not necessary for subject matters in general education.

5.7. Step 7: Conduct calibration processes

Based on the correspondence analyses, the problem can then be calibrated as needed and transformed into the problem presentation. Content, context, researching, and reasoning are the four components involved in the calibration process to craft a problem that is well-aligned to the intended content and learners' characteristics.

5.7.1. Content component calibration

One way to adjust an under-affording PBL problem is by extending the scenario of the problem. If the peripheral knowledge of the problem covers the portion of the intended content that is not covered by the core knowledge of the problem, the problem can be revised to incorporate conditions that will require the peripheral knowledge to be used to solve the problem. On the other hand, an over-affording problem may be adjusted by focusing on the portion of the problem that involves most of the intended content. This can be achieved by (1) emphasizing the targeted portion of the problem; (2) removing any description that would distract the learners from the target; or (3) adding explicit statements to guide the learners to target. The full description of the PBL problem should then be revised to reflect this calibration.

5.7.2. Context component calibration

The key to the context calibration is ensuring that an appropriate amount of contextual information is included in the problem to situate the learning in an authentic, profession-specific context. In this way, the learners will consider the factors naturally as the professionals do. Designers need to add more specific contextual information for an under-contextualized problem to situate the learners effectively in the profession-specific constraints or considerations. Likewise, the opposite adjustment should be made to over-contextualized problems to avoid overwhelming the learners with unnecessary contemplation while they are solving the problem. The context component calibration also fine-tunes the researching and reasoning components of the problem, as Martin and Beach (1992) suggested that the nature of the context influences the reasoning process of a problem solver.

5.7.3. Researching and reasoning component calibration

Up to this point, the PBL problem is a content/context-calibrated full description of the problem. Next, the full description of the problem case must be transformed into a "problem" to be solved. To do so, some of the critical information needs to be removed. How much and what information needs to be removed from the description depends on what level of difficulty is needed, which is guided by the problem solving skills objectives specified in Step 1. The correspondence analysis of the processing components (from Step 6) is the reference designers use to guide the calibration process and decide what information needs to be removed or kept in the problem presentation. The designer can set the problem difficulty level by creating an appropriate number of missing links in the problem presentation. When facing the missing links, the learners will have to piece the puzzle together by researching necessary information and reasoning through the logical interlinks among the various pieces of information to solve the problem.

A simple guideline for designers creating these missing links in the problem presentation is that when the difficulty level of researching and reasoning a piece of critical information is beyond the problem solving skills objectives, then this information should be presented to the learners; otherwise it should be removed. The information that remains in the problem presentation should only include the basics (that is, the current state and goal state of the problem) and the amount of information appropriate to the learners' level as hints or guides for directing the learners to the most viable (or common) reasoning and solution path. The designer should also remove the alternatives, that is, alternative interpretations of the problem, reasoning processes, hypotheses, and solutions in the full problem case description. The information about the alternatives could be included in the tutor guide for them to advise more advanced learners to explore the domain further.

Table 1
Relations among the core and processing components in 3C3R model.

	Content	Context	Connectin
Researching	▪ acquiring content knowledge	▪ directing researching	▪ integrating knowledge acquired
Reasoning	▪ processing content knowledge ▪ applying content knowledge	▪ directing reasoning	▪ integrating knowledge acquired
Reflecting	▪ evaluating acquisition/ processing of content knowledge	▪ directing reflecting	▪ integrating knowledge acquired

Note: ==> **supports**

5.8. Step 8: Construct reflection component

Reflection is one of the major features of PBL (Barrows & Myers, 1993). Reflection can be and is usually carried out by PBL tutors (Gallagher, 1997; Perrenet et al., 2000). Incorporating a reflection component as part of the problem solving task can help cultivate learners' self-directed learning skills and habits. The design of the reflecting component should focus on (1) acquisition of all the necessary knowledge; (2) adequate depth of study; (3) effective and efficient research methods; (4) logical and effective reasoning processes; (5) conceptual integration of knowledge; and (6) effective problem solving strategies.

The reflecting component can be one of two types: formative and summative. A formative reflective process should occur throughout the PBL course along with the processes of researching and reasoning. A formative reflection process can help the learners engage in self-reflecting processes as well as receive feedback from the instructor to guide self-assessment (see Example 1). Interactive journal writing (Andrusyszyn & Davie, 1997) (for example, the problem can include a statement such as "you need to keep a journal and report to your supervisor on a weekly basis.") and weekly progress meetings are examples of a formative reflecting component in the problem. The summative reflection in PBL problems guides the learners to engage in a reflection activity on their overall learning and problem solving process. This summative reflection could be in the form of (1) including a reflection element in the PBL problem (for example, incorporating "you need to provide a comprehensive final report that includes the process of how you solved the problem,. . ." in the problem presentation) or (2) offering follow-up problems or questions. The self-directed learning skills objectives should guide the design by determining the form of reflection and how prescriptive the reflecting component should be in the problem presentation.

5.9. Step 9: Examine inter-supporting relationships of 3C3R components

The last step of the 9-step design process is examining the integrity of the 3C3R components. The content, context, connection, researching, reasoning, and reflecting components in PBL problems are not independent of each other. Rather, they are complementary and mutually support each other. Therefore, when designing PBL problems, this supportiveness among the six components is critical to maximizing the effect of each component within the PBL problem as a whole (see Table 1). At this stage, the instructional designer should ensure the 3C's and 3R's properly support one another. These interrelationships among the six components should also be used to evaluate the integrity of the PBL problem during its final inspection (see Examples 1 and 2).

6. Conclusion

PBL has been one of the most widely adopted instructional methods across various disciplines and professional studies, all age groups of learners, and around the globe. It is also one of the most empirically researched instructional methods in education. Despite the mixed results from this vast body of research, it is generally agreed that problem-based learning is effective in enhancing students' abilities of applying domain knowledge in real-world settings, proficiency in independently solving problems, and self-directed learning skills. On the other hand, issues such as problem-based learning students performing slightly less well in basic knowledge acquisition than traditional students, or the transitional adjustment difficulties for students and instructors who are new to this instructional method might have cast doubt on its effectiveness. Problem design is one of the factors that could have contributed to these issues.

In problem-based learning, learning is initiated by and evolves from solving problems. Undoubtedly, the design of the problems plays a critical role in influencing students' acquisition of domain knowledge, problem solving skills, and learning experiences with a problem-based learning curriculum. Given that, it is imperative to ensure the quality of problems used in problem-based curriculum. The 3C3R problem design model was developed to provide instructional designers with a conceptual framework to systematically design effective problems, and hopefully, enhance the effectiveness of problem-based learning instruction. The 3C components (content, context, and connection) of the design model address the static properties of a problem in terms of intended content to be learned, the specific and unique contextual factors to be considered, and the conceptual connections of the problems within the curriculum, while the 3R components (researching, reasoning, and reflecting) deal with dynamic properties of the problem by analyzing the problem's cognitive processing requirements for the students. The 9-step design process presented in this paper is a further effort in operationalizing the model into a practical design process. This design process offers a step-by-step description and rationale for how to systematically design problems by considering the six pivotal components in problems. The 9-step design process guides the designer to optimize the problem by analyzing and calibrating the six components of the problem to create a rich, motivating, learner-characteristic appropriate learning situation.

The 3C3R model and 9-step design process not only serves as a conceptual framework for designing effective problems, it also provides a research framework for studying the effects of adjusting the amount of information given in the problem on the students' learning process over the course, such as understanding the problem, identifying intended learning objectives (which consequently determine the students' researching and reasoning processes), making the logical connections between the dots along the problem solving path to solution, and so forth. All of which have significant impacts on the students' cognitive processing during the course of solving the problem, such as the construction of the problem space and what actions to take (e.g. decision on what information to research, how to reason through the problem space). Understanding these cognitive properties and processes in a problem-based learning experience would help inform instructional designers and educators of more effective and efficient methods or techniques to facilitate students' learning processes, as well as shed light on future research in human learning, problem solving, and instruction.

Extensive research and evaluation will be needed to test and validate the robustness of the model on the usefulness of the model and design process for guiding instructional designers and educators' problem design processes, as well as the effectiveness of the problems designed using this model and design process. In terms of practicality of the model and design process, a positive preliminary result has been obtained in Goodnough and Hung's (2008) study of a group of elementary school teachers utilizing the model and 9-step design process. More research along this line is still needed for further validating the model. Future research on using the model and the 9-step process to help design effective problems used in problem-based learning will need to focus on understanding the relationships between problem design, required cognitive processes, and learning outcomes. The immediate research questions include, how effective would the problems designed using this model be in directing students to acquire intended domain knowledge; consider contextually unique factors in problem solving processes; integrate conceptual interrelationships among the concepts in the domain knowledge; scaffold the students' abilities of researching for information and reasoning the problem and solutions; and also cultivate their habit of mind in actively engaging reflection throughout their learning process. More research questions will emerge when we delve into this research area.

Appendix A

Example 1

Documentation of a PBL problem design: utilizing the 9-step process
Target learners: 5th grade students
Subject: Mathematics

Step 1 – Set goals and objectives

Instructional goal: Fifth grade students will apply knowledge of algebra in solving real life problems. (Note: This instructional goal reflects Arizona State Mathematics Standards, Strand 3, Concept 3.)

Objectives: The 5th grade students will demonstrate and perform the following knowledge and tasks at a level of 90% accuracy.

Domain knowledge objectives

Terminal objective: analyze, represent, and solve mathematical situations and structures using algebraic representations.
Enabling objective 1: solve expressions involving decimals and the four basic operations.
Enabling objective 2: solve one-step equations with one variable represented by a letter or symbol (e.g. $15 = 45/N$).
Enabling objective 3: use variables in contextual situations.

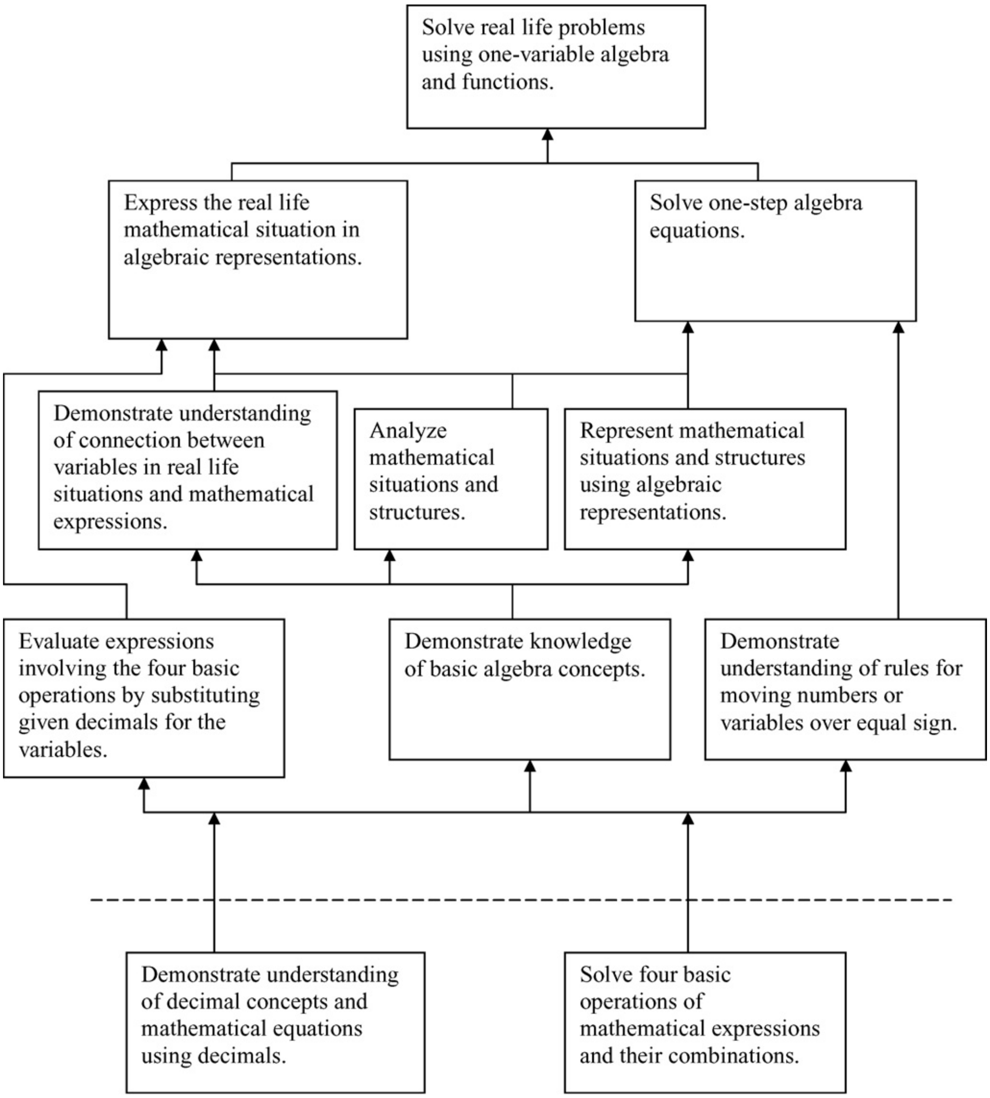
Problem solving skills objectives

1. With moderate-to-aggressive assistance, identify and gather all necessary information
2. With moderate-to-aggressive assistance, conduct simple hypothesis generation and testing
3. With moderate-to-aggressive assistance, select most viable solution

Self-directed learning skills objectives

1. With aggressive assistance, generate learning issues
2. With moderate-to-aggressive assistance, reflect on learning process

Step 2 – Conduct content/task analysis



Step 3 Analyze context specification

Projected context	Factors that influence Researching and Reasoning processes
General	Since no specific projected context can be identified, this section is not applicable

Step 4 – Select/generate PBL problem

List of potential problems:

1. Running a bakery: Student(s) have inherited a building from a deceased aunt who left specific instructions to turn the building into a family bakery, and must make a 5% profit at the end of one month.
2. Have a fund-raiser to pay for a field trip the Desert Museum. The students will have to help with this fund raising activity.

Decision: Fund raising problem is selected because this is something that the students are familiar with, it is relevant to their needs (going on a field trip), and appealing to them.

Step 5 – Conduct problem affordance analysis

Problem: Mrs. Holliday, your biology teacher, and I have decided to take this class to the Desert Museum for a field trip four weeks from now. After discussing this with Mrs. Holliday, we thought that having you ask your parents for money to go on the trip might be a burden for them, so we decided to have a fund-raiser to pay for our trip. Mrs. Holliday and I will pitch in $50 to help start the fund. You, as a group, need to earn the rest of the money for the trip.

In order to solve this problem, the following is the most common problem solving process as to this particular problem (with alternatives when applicable).

Full description:

1. Understanding the problem:
   a. Problem state (current state): a group of 23 fifth grade students lack funding for a day trip to Tucson to visit the Desert Museum. The students need to raise sufficient funds to support their trip.
   b. Goal state: raising sufficient funds to support a field trip for a group of 23 fifth grade students to the Desert Museum in Tucson.
   c. Known variables: duration of the trip (hours), a school bus can be used for the trip, however, there is a fee for ordering the bus. The school will provide financial support for 30% of the cost of transportation.
   d. Unknown variables: need to identify how much the total cost of the trip is, what constitutes the total cost of the trip (the admission fee, transportation, lunch, more?), what items might be possible to sell, what items will produce the most profit in a short period of time, who will be the target customers, what is a reasonable price for the items, what organizations or venders might supply the items, how much do the potential items identified cost, etc.
2. Problem solving processes:
   a. To figure out how much money needs to be raised, we need to first figure out how much the total cost of the trip is.
   b. The costs for the trip could include entry fees, transportation, and lunch. To save on costs, the students will bring their own lunch.
   c. To find out the total cost of the trip, we need to add up all the costs, which include the entry fees (entry fee per student times the number of students, *two prices depending on the season*), transportation ((1–30%)*the cost of one day use of school bus).
      i. Alternative: discount = transportation*30%, then final transportation cost = transportation − discount.
      ii. Alternative: convert 30% to 0.3 may be easier for calculation.
   d. Research information for unknown variables – need to find out how much the entry fee per student is, how much the transportation costs are.
   e. Calculate an estimated total cost for the trip (the total entry fees + transportation cost).
   f. Figure out how much money needs to be raised.
   g. With seed money of $50 that the teachers pitch in, there are two ways to figure out total cost:
      i. We can calculate the amount of money needed by devising an equation that represents
         1. Money needed to be raised [*M*] + $50 = $ total cost [result from 2e])
         2. *M* + $50 = $total cost
            a. Alternative: Money needed to be raised (instead of using a symbol) = $ total cost − $50 [teacher may want to encourage students not to use this method, so they will have more practice with the basic operations of algebraic representation.]
         3. Solve the equation: we first have to *isolate* the variable *M* by moving 50 from the left to the right. To do so, we must *add the opposite* (or add −50 to the right sides), then we see that *M* + 50 − 50 = $total cost − 50. Next we do *Combining like terms* on each side, the + 50 and −50 *cancel*, and the equation becomes *M* = $total cost − 50.

h. To decide what fund raising activities to do, we need to identify what makes the most profit in a short period of time.
i. First of all, we need to identify fund raising options/activities.
j. Eliminate improper options/activities.
k. Inquire/ask organizations or venders about cost to purchase their items.
l. Analyze the profits for each candidate option.
m. Compare and identify the option with the best profits.
n. The profits from fund raising have to be equal to or greater than *M*.
o. A hypothesized scenario: the students decide to sell candy bars, which are 25 cents a piece. We need to decide on a reasonable selling price for the candy bars so we can obtain the best profit. (Alternative: use $0.25 dollar (or whatever the amount is), instead of 25 cents to require students to work with decimals.)
   i. Use T chart to list all the different prices versus how many candy bars need to be sold to reach *M*
   ii. To calculate how many candy bars that need to be sold for each hypothesized price in the T chart, solve (number of candy bars [*N*] * price = *M*) (apply the solving principles/procedure in 2.g.i.3)
p. When deciding the sales price, also consider how, although a high price may reach *M* fast, fewer people may buy items priced too high.
q. Decide the selling price.
r. Now we need to figure out how many candy bars each student is responsible for selling. To do so,
   i. get the *N* of the price decided from the T chart
   ii. calculate (the number of candy bars each student needs to sell = *N*/23)

3. After sales are over, we need to calculate how much the actual profit is.
   a. Calculate the actual cost for purchasing candy bars
      i. Count the number of candy bars purchased from the vender
      ii. The actual cost = (number of candy bars purchased) * (the unit price)
   b. Calculate the actual sale
      i. Count the number of candy bars sold
         1. get the number of candy bars each student sold
         2. add the number of candy bars sold for all students
      ii. The actual sale = (number of candy bars sold) * (sale price)
   c. Calculate the actual profit
      i. The profit = (actual sale) − (actual cost)
   d. Determine whether or not we raised enough funds for the trip
      i. If the profit $\geq M$, then yes (conditional statement)
      ii. If the profit $< M$, then no
4. If we have reached the fund raising goal, then Mrs. Holliday will arrange the trip. If not, Mrs. Holliday will seek help from the school to make up any shortage of funds, and then arrange the trip.

Domain knowledge needed for solving the problem:

- Concepts used in solving the problem:
  - basic algebra concepts
  - basic algebraic representations
  - profits
  - greater than, less than, equal to
  - concept of percentage
  - concept of decimals (peripheral)
- Principles used in solving the problem:
  - Solving
    - Isolate
    - Add the opposite
    - Combining like terms
    - Cancel
- Procedures used in solving the problem:
  - basic mathematical operations
  - solving one-variable algebraic equations
  - procedure for basic operations involving decimals (peripheral)
- Factual information needed for solving the problem:
  - Entry fee per student (season)
  - Cost of transportation (bus)
  - Possible activities for fund raising
  - Venders

Problem solving skills analysis:

- Identify what known variables are: see above.
- Identify what unknown variables are: see above.
- Do research to find the unknown variables identified.
- Figure out the total funds needed
- Research possible fund raising activities.
- Figure out the best way to reach the goal based on the information gathered (hypotheses generation process) and generate the most viable solution.
- Execute the solution
- Examine the outcome of solution.

Step 6 – Conduct correspondence analysis

Table 1. Content correspondence analysis chart.

Domain knowledge (researching)	*Overall goal*: analyze and represent mathematical situations and structures using algebraic representations								Prerequisites	Beyond scope of objectives
	Concept				Principle		Procedure			
	Variables (symbols)	Basic algebra	Mathematical situations and structures	Concept of decimals	Basic algebra representation	Solving	Solving one-step with one variable algebraic equation	Four operations involving decimals		
Core										
Concept (c)										
–Concepts of basic algebra	√	√	√		√	√	√			
–Basic algebraic representation	√		√		√	√	√			
–Isolate		√				√	√			
–Add the opposite		√				√	√			
–Combining like terms		√				√	√			
–Cancel		√				√	√			
–Concept of percentage									√	
–Convert real life situations into mathematical expression			√							
–Profits			√						√	
–Cost			√						√	
–Profitable price			√							√
–Sale			√						√	
–Greater than, less than, equal to									√	
Principle (PL)										
–Best profit			√							√
–Solving									√	
–Conditional statement			√						√	
–Order of operations							√		√	
Procedure (PD)										
–Basic operations							√		√	
–Basics of algebra			√				√			
–Percentage operation									√ (may not master)	
Factual information (F)										
–Entry fee									√	
–Transportation									√	
Peripheral										
C										
–Decimals				√						
–Arithmetic									√	
P										
–Basic operations involving decimals								√		

Table 2. Correspondence analysis between problem-solving cognitive processes and learning objectives.

Cognitive processes	Description	PSO-1 Identify and gather all necessary information need to research with assistance	PSO-2 Conduct simple hypothesis generation and testing with assistance	PSO-3 Select most viable solution
Researching and reasoning processes				
Symptoms recognition/problem identification	–Raising sufficient funds for a field trip	√		
Known variables identification	–Total cost of the trip (Entry fees + Transportation (school supports 30% of the cost)	√		
	–Seed money of $50	√		
Unknown variables identification	–How much is the total needed for covering the cost in addition to the seed money and the 30% discount of the transportation cost (M + $50 = total cost)	√		
	the options of fund raising activities	√		
	–Number of items need to sell	√		√
Information/data searching	–Cost for entry fees	√		
	–Cost for transportation	√		
	the options of fund raising activities (venders or organizations)	√	√	
	–Inquire the cost of the options/activities	√		
Information/data analysis	–Find out appropriate entry fee rate (there are two rates depending on the season)	√		
	–Eliminate infeasible fund raising options/activities		√	
	–Analyze the gross profit of each candidate fund raising option	√		√
	–Calculate the estimated total cost of the trip	√		√
Reasoning path	1. Need to know the total cost for the trip 2. Need to know the actual cost after subtracting the seed money and 30% discount for transportation	√		√
Hypotheses generation and testing	–Use T-chart to analyze the number of items needed to be sold to reach the goal of fund needed		√	
Reasoning path and solutions generation	1. Once the item to be sold is decided, need to know the total number of the items needed to be sold			
	2. Need to know the number of items to be sold for each student			√

Problem context analysis: The context of this problem is general and applies to the students' everyday lives. Also, a field trip is generally appealing to students, therefore, the context can satisfy the motivational aspect of this PBL problem design.

Conclusion of correspondence analysis:

1. Domain knowledge:
   a. The degree of correspondence between the intended objectives and the scope of the PBL problem reaches a desirable level.
   b. Non-corresponding portion:
      i. The core domain knowledge in the PBL problem may not necessarily cover the objective "Evaluate expressions involving the four basic operations by substituting given decimals for the variables." Decimal concept may be used if alternative path is taken. The presentation of the problem should guide students to take this reasoning and solution path.
      ii. Several concepts (profits, profitable price, best profits) may be beyond the scope of the objectives.

2. Contextual information: The contextual information of the problem properly supports the projected context.
3. Problem solving and self-directed learning skills:
   a. Researching component: There are several pieces of information that the students need to research, compare (e.g. entry fee, transportation, fund raising options, etc.), and make a decision about what item to sell. To achieve the problem solving skill objectives, these pieces of information should be researched by the students, however, with sufficient guiding information to help the students initiate the researching process. The problem should give initial hints to guide the students to seek out this information.
   b. Reasoning component: the students need to reason: how to get (calculate) an estimated total cost for the trip, how to calculate how much profit is needed to cover the cost of the trip and the cost of obtaining the sale items, what mathematical concepts, principles, and procedures need to be used to obtain the numbers mentioned above, what items will produce the best profits (high price will produce better profit but fewer number of items may be sold, and vise versa), generate hypotheses about the possible profits for each candidate item, and select the best items to sell.

Results—the following are the elements that need to be calibrated in the problem presentation:

1. Domain knowledge:
   a. Convert the percentage (30%) component to decimals.
   b. Give brief explanations of the concepts (profits, cost, profitable price, best profits) in the problem presentation.
   c. The presentation of the problem should guide students to take this reasoning and solution path by requiring students to use dollar as unit to perform the calculation so that decimal representations and operations will be part of the requirement for solving the problem.
2. Problem solving and Self-directed learning skills:
   a. Based on problem solving skills and self-directed learning skills objectives (note: the objectives are devised based on that the targeted audience is 5th graders and this is the first experience with PBL), the following information should be given to guide their problem solving and self-directed learning process:
      i. Researching component:
         1. what information do they need to research (e.g. entry fee, transportation, fund raising options,) [give one as an initiating hint—transportation, then ask questions to guide students to identify other information that needs to be researched.]
         2. what mathematical concepts, principles, and procedures will they need to know to solve the problem [interlink with 2.a.ii.3].
      ii. Reasoning component:
         1. how to get (calculate) an estimated total cost for the trip [prompt the students to this reasoning path with guiding questions]
         2. how to calculate how much profits are needed to cover the cost of the trip and the cost of obtaining the sale items [prompt the students to this reasoning path with guiding questions]
         3. what mathematical concepts, principles, and procedures need to be used to obtain the numbers mention above [ask these questions as guiding questions]
         4. what items will produce the best profits (high price will produce better profit but fewer number of items may be sold, and vise versa) [5th grader may not be aware of this concept, this information, therefore, should be included in the problem presentation),
         5. generate hypotheses about the possible profits for each candidate items, and select the best selling items [giving hints to guide students to engage in this process by asking explicit questions as guiding questions].

Step 7 – Conduct calibration process

Problem: Mrs. Holliday, your biology teacher, and I have decided to take this class to the Desert Museum in Tucson for a field trip four weeks from now. After discussing this with Mrs. Holliday, we thought that having your parents pay for the trip might be a burden on them. So, we decided to have a fund-raiser to pay for our trip. Mrs. Holliday and I will pitch in $50 to help start the fund. You, as a group, need to help with this fund-raiser. Our goal is to raise enough money to support our field trip to the Desert Museum in Tucson. We will be taking a school bus for the trip, however, there is a fee for ordering the bus. The school will provide 30% of the cost of transportation, which can also be expressed as 0.3. We also need to think about what other costs there may be for the trip to figure out the total cost of the trip. So, we need to figure out how much the total cost of the trip will be, so we know what to sell to raise funds. To figure out how much money needs to be raised, we need to figure out how much the total cost of the trip is. To save money, you will need to bring your own lunch. How can we figure out the total cost for the trip? How much money do we need to earn to cover the cost of the trip, in addition to obtaining the fund-raiser items to sell?

What can we sell that will raise enough funds? How can we find out this information? Also, since we only have four weeks to raise the money, we may want to sell something that will make a big profit in a short period of time. So, we'd better think about what can be sold at a high price that a lot of people will want to buy. If we sell an item that is too expensive, then there will be only a few people who can afford it, and we won't make as much money as we wish. So, let's also think about what a reasonable price for the item would be. What is a good way to help us make this decision? And after we finish our sales, we need to figure out how much we made. Is it enough to cover our trip? So that all of us are on the same page, we will use the dollar (vs. cents) as the unit for our calculation. Let's work together so we can have a fun field trip!

Step 8 – Constructing reflection component

Problem: Mrs. Holliday, your biology teacher, and I have decided to take this class to the Desert Museum in Tucson for a field trip four weeks from now. After discussing this with Mrs. Holliday, we thought that having your parents pay for the trip might be a burden on them. So, we decided to have a fund-raiser to pay for our trip. Mrs. Holliday and I will pitch in $50 to help start the fund. You, as a group, need to help with this fund-raiser. Our goal is to raise enough money to support our field trip to the Desert Museum in Tucson. We will be taking a school bus for the trip, however, there is a fee for ordering the bus. The school will provide 30% of the cost of transportation, which can also be expressed as 0.3. We also need to think about what other costs there may be for the trip to figure out the total cost of the trip. So, we need to figure out how much the total cost of the trip will be, so we know what to sell to raise funds. To figure out how much money needs to be raised, we need to figure out how much the total cost of the trip is. To save money, you will need to bring your own lunch. How can we figure out the total cost for the trip? How much money do we need to earn to cover the cost of the trip, in addition to obtaining the fund-raiser items to sell?

What can we sell that will raise enough funds? How can we find out this information? Also, since we only have four weeks to raise the money, we may want to sell something that will make a big profit in a short period of time. So, we'd better think about what can be sold at a high price that a lot of people will want to buy. If we sell an item that is too expensive, then there will be only a few people who can afford it, and we won't make as much money as we wish. So, let's also think about what a reasonable price for the item would be. What is a good way to help us make this decision? And after we finish our sales, we need to figure out how much we made. Is it enough to cover our trip? So that all of us are on the same page, we will use the dollar (vs. cents) as the unit for our calculation. Let's work together so we can have a fun field trip!

I am going to divide you into five groups. Each group will need to work on every step of this fund raising project because we want to gather as many ideas as possible to help us select the best way to do this. You should work with your group during the week, and we will have meetings each Fridays to see how each group is doing. During the meeting, you and your group will need to report your progress and how you came up with your ideas and why you made your decisions, and think of any better ways to do what you are doing.

OK, enough talking, let's get to work!

Step 9 – Examine Inter-supporting relationships of 3C3R components

	Content	Context	Connectin
Researching	Sufficiently support content knowledge acquisition.	Sufficiently support directing researching	Sufficiently mutually support integrating knowledge acquired by conning to prior knowledge.
Reasoning	Sufficiently support content knowledge acquisition and application.	Sufficiently support directing reasoning.	Sufficiently mutually support integrating knowledge acquired by conning to prior knowledge.
Reflecting	Does not support evaluating acquisition/ processing of content knowledge. Need revision.	Does not support directing reflecting. However, since the context component is general in this problem, it does not need revision.	Sufficiently mutually support integrating knowledge acquired by requiring students to reflect on their problem solving process.

Note: ==> supports

Conclusion: Revise reflecting component to support content component.

Final draft of problem presentation

Problem: Mrs. Holliday, your biology teacher, and I have decided to take this class to the Desert Museum for a field trip four weeks from now. As Mrs. Holliday and I discussed our options, we found that having you ask your parents for money to go on the trip may be a burden for your parents. So, we decided to have a fund raiser to pay for our trip. Mrs. Holliday and I will pitch in $50 to help start the fund. You, as a group, need to help with this fund raising. So, our goal for this fund raiser is to raise sufficient funds to support our field trip to the Desert museum in Tucson. We will be taking a school bus for the trip, however, there is a fee for ordering the bus. The school will provide financial support for 30% of the cost of transportation, which can also be expressed as 0.3. We may also need to think about other possible costs for the trip to figure out the total cost of the trip. So, we need to figure out how much the total cost of the trip is, and what to sell to raise funds. To figure out how much money needs to be raised, we need to figure out how much the total cost of the trip is. To save on costs, you will need to bring your own lunch. How can we find out the total cost of the trip? How much do we need to make to cover the cost of the trip and obtaining the items to sell?

What should we sell to raise enough funds? How can we find out this information? Also, since we only have four weeks to raise the money, we may want to sell something that will make the most profit in a short period of time. So, we better think about what items can be sold at higher price but still a good number of people will buy it. If we sell an item that is too expensive, then only a few people can afford it, and we won't make as much money as we wish. So, let's also think about what item to sell and what is a reasonable price for the items. What will be a better way to help us make this decision? And after we finish the selling, we also need to figure out what much do we make. Is it enough for covering our trip? Let's work together and so we can have a fun field trip!

I am going to divide you into 5 groups. Each group will need to work on every step of this fund raising project because we want to have as many ideas as possible to help us select the best way to raise money for our field trip. You should work with your group during the week, and we will have meetings on Fridays to see how each group is doing. During the meetings, you and your group will need to report your progress, share with the other groups how you found your information and how you have used or plan to use the information to solve our problem. You will also share how you came up with your ideas and why you made your decisions. You will also need to think about whether or not there might be a better way of doing what you are doing.

OK, enough talking, let's get to work!

Example 2

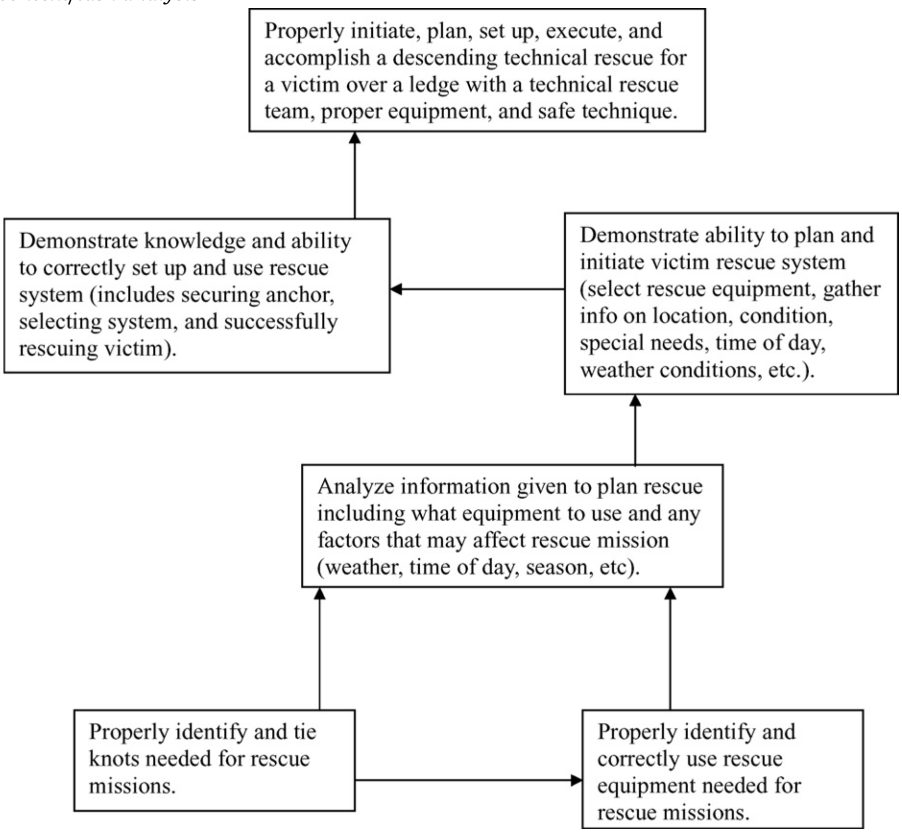
(This is only partial documentation; mainly for illustrating Step 3—Context specification for a profession-specific PBL problem. Courtesy of Jennifer Allred)

Target Learners: Technical Rescue Team (TRT) Members at Fry Fire District
Subject: Technical rescue technique(s)
Learners experience with PBL: No previous experience.
Level of difficulty for PBL: basic

Step 1 – Set goals and objectives

Terminal objective: Given a request for a victim rescue and search already completed, the student will properly initiate, plan, set up, execute, and accomplish a descending technical rescue for a victim over a ledge with a technical rescue team, proper equipment, and safe technique.

Step 2 – Conduct context/task analysis



Step 3: Analyze context specification

Projected context	**Factors that influence researching and reasoning processes**
Mountain rescue locations (e.g., cliffs, waterfalls, caves, drop-offs) requiring decent.	Length of time team has worked prior to rescue mission (is crew well rested or already tired). Weather conditions, time of day, season of year, length of time rescue is projected to require, number of team members participating in rescue. Available resources. Whether mission is a rescue or recovery and a low/steep/high angle.

Step 4 PBL problem selection/generation

List of potential problems:

1. Request for rescue of victim stuck in cave. Mission will require many hours, experience, and hard labor to complete.
2. Request for body recovery on ledge below waterfalls (victim fell to his/her death and needs to be recovered).
3. Request for victim rescue over ledge. Victim's system failed while rock climbing and is unable to ascend or descend/stuck on ledge.

Decision: Request for victim rescue over ledge (#3) because victim is a required climber and is uninjured (simply needs rescue). This problem is the "simplest" allowing learners to complete while learning skills without PBL methodology overwhelming learners.

References

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

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

Andrusyszyn, M.-A., & Davie, L. (1997). Facilitating reflection through interactive journal writing in an online graduate course: A qualitative study. *Journal of Distance Education*, *12*(1/2), 103–126.

Angeli, C. (2002). Teachers' practical theories for the design and implementation of problem-based learning. *Science Education International*, *13*(3), 9–15.

Arends, R. I. (1997). *Classroom instruction and management*. New York: McGraw-Hill.

Arts, J. A. R., Gijselaers, W. H., & Segers, M. S. R. (2002). Cognitive effects of an authentic computer-supported problem-based learning environment. *Instructional Science*, *30*, 465–495.

Ausubel, D. P. (1962). A subsumption theory of meaningful verbal learning. *Journal of General Psychology*, *66*, 213–224.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart & Winston.

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

Barnard, A., Nash, R., & O'Brien, M. (2005). Information literacy: Developing lifelong skills through nursing education. *Journal of Nursing Education*, *44*(11), 505–510.

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

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University School of Medicine.

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

Barrows, H. S. (2000). *Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University School of Medicine.

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

Barrows, H. S., & Myers, A. C. (1993). *Problem-based learning in secondary schools* (Unpublished monograph). Springfield, IL: Problem Based Learning Institute, Lanphier High School, and Southern Illinois University Medical School.

Barrows, H. S., & Tamblyn, R. (1980). *Problem-based learning*. New York: Springer.

Berkson, L. (1993). Problem-based learning: Have the expectations been met? *Academic Medicine*, *68*, S79–S88.

Biggs, J. B. (1989). Approaches to the enhancement of tertiary teaching. *Higher Education Research and Development*, *8*(1), 7–25.

Bloom, B. S. (1986). The hands and feet of genius: Automaticity. *Educational Leadership*, *43*(5), 70–77.

Boote, J. (1998). Learning to learn in vocational education and training: Are students and teachers ready for it? *Australian and New Zealand Journal of Vocational Educational Research*, *6*, 59–86.

Bransford, J. D., & Stein, B. S. (1984). *The IDEAL problem solver*. New York: W. H. Freeman.

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

Brown, A. L. (1978). Knowing when, where, and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 77–165). Hillsdale, NJ: Erlbaum.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*, 32–42.

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

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: Research and theory. *Academic Medicine*, *75*(3), 259–266.

Coulson, R. L., & Osborne, C. E. (1984). Insuring curricular content in a student directed problem-based learning program. In H. G. Schmidt & M. L. de Volder (Eds.), *Tutorial in problem-based learning: A new direction in teaching the health professions* (pp. 225–229). Assen, The Netherlands: Van Gorcum.

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

Dabbagh, N. H., Jonassen, D. H., Yueh, H.-P., & Samouilova, M. (2000). Assessing a problem-based learning approach to an introductory instructional design course: A case study. *Performance Improvement Quarterly*, *13*(3), 60–83.

De Grave, W. S., Dolmans, D. H. J. M., & van der Vleuten, C. P. M. (1999). Profiles of effective tutors in problem-based learning: Scaffolding student learning. *Medical Education*, *33*, 901–906.

Dochy, F., Segers, M., van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction*, *13*, 533–568.

Dods, R. F. (1997). An action research study of the effectiveness of problem-based learning in promoting the acquisition and retention of knowledge. *Journal for the Education of the Gifted*, *20*(4), 423–437.

Donaldson, R. (1989). A good start in architecture. In B. Wallis (Ed.), *Problem-based learning: The Newcastle Workshop* (pp. 41–53). Newcastle, Australia: University of Newcastle.

Dombrowski, L. A. (1997). *Implementation of collaborative problem-based learning in the classroom: A focus group dynamics in relation to self-esteem and skill acquisition through the generation of a Web page*. Dissertation, West Virginia University.

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

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

Driessen, E., & van der Vleuten, C. (2000). Matching student assessment to problem-based learning: Lessons from experience in a law faculty. *Studies in Continuing Education*, *22*(2), 235–248.

Drummond-Young, M., & Mohide, E. A. (2001). Developing problems for use in problem-based learning. In E. Rideout (Ed.), *Transforming nursing education through problem-based learning* (pp. 165–191). Boston: Jones & Bartlett.

Duch, B. (2001). Writing problems for deeper understanding. In B. Duch, S. E. Groh, & D. E. Allen (Eds.), *The power of problem-based learning: A practical "how to" for teaching undergraduate courses in any discipline* (pp. 47–53). Sterling, VA: Stylus Publishing.

Dunlap, J. C., & Grabinger, R. S. (1996). Rich environments for active learning in the higher education classroom. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 65–82). Englewood Cliffs, NJ: Educational Technology Publications.

Farnsworth, C. (1994). Using computer simulations in problem-based learning. In M. Orey (Ed.), *Proceedings of the Thirty-Fifth ADCIS Conference* (pp. 137–140). Nashville, TN: Omni Press.

Fiddler, M. B., & Knoll, J. W. (1995). Problem-based learning in an adult liberal learning context: Learner adaptations and feedback. *Continuing Higher Education Review*, *59*(1/2), 13–24.

Flesher, J. W. (1993). An exploration of technical troubleshooting expertise in design, manufacturing, and repair contexts. *Journal of Industrial Teaching Education*, *31*(1), 34–56.

Friedman, C. P., de Blick, R., Sheps, C. G., Greer, D. S., Mennin, S. P., Norman, G. R., et al. (1992). Charting the winds of change: Evaluating innovative medical curricula. *Annals of Community-Oriented Education*, *5*, 167–179.

Gagné, R. M., Wager, W. W., Golas, K. C., & Keller, J. M. (2005). *Principles of instructional design* (5th ed.). Belmont, CA: Wadsworth.

Gallagher, S. A. (1997). Problem-based learning: Where did it come from, what does it do, and where is it going? *Journal for the Education of the Gifted*, *20*, 332–362.

Gallagher, S. A., Sher, B. T., Stepien, W. J., & Workman, D. (1995). Implementing problem-based learning in the science classroom. *School Science and Mathematics*, *95*, 136–146.

Gallagher, S. A., & Stepien, W. J. (1996). Content acquisition in problem-based learning: Depth versus breadth in American Studies. *Journal for the Education of the Gifted*, *19*(3), 257–275.

Gallagher, S. A., Stepien, W. J., & Rosenthal, H. (1992). The effects of problem-based learning on problem solving. *Gifted Child Quarterly*, *36*(4), 195–200.

Garland, N. J. (1995). Peer group support in economics: Innovations in problem-based learning. In W. Gijselaers, D. Tempelaar, P. Keizer, E. Bernard, & H. Kasper (Eds.), *Educational innovation in economics and business administration: The case of problem-based learning* (pp. 331–337). Dordrecht, The Netherlands: Kluwer.

Gijbels, D., Dochy, F., van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research*, *75*(1), 27–61.

Gijselaers, W. H., & Schmidt, H. G. (1990). Development and evaluation of a causal model of problem-based learning. In Z. H. Nooman, H. G. Schmidt, & E. S. Ezzat (Eds.), *Innovation in medical education, an evaluation of its present status*. New York: Springer Publishing.

Glasgow, N. A. (1997). *New curriculum for new times: A guide to student-centered, problem-based learning*. Thousand Oaks, CA: Corwin.

Godat, M. (2007). Virtual golden food corporation: Generic skills in a virtual crisis environment (A pilot study). *Journal of Educational Multimedia and Hypermedia*, *16*(1), 67–84.

Goodnough, K., & Hung, W. (2008). Designing effective problems: Evaluation of 3C3R 9-step design process. *Interdisciplinary Journal of Problem-based Learning*, *2*(2), 61–90.

Hays, R., & Gupta, T. S. (2003). Ruralising medical curricula: The importance of context in problem design. *Australia Journal of Rural Health*, *11*, 15–17.

Higgins, L. (1994). Integrating background nursing experience and study at the postgraduate level: An application of problem based learning. *Higher Education Research and Development*, *13*, 23–33.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *The Journal of the Learning Science*, *7*(2), 173–208.

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

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learning about complex systems. *Journal of the Learning Sciences*, *9*, 247–298.

Hmelo, C. E., & Ferrari, M. (1997). The problem-based learning tutorial: Cultivating higher order thinking skills. *Journal for the Education of the Gifted*, *20*(4), 401–422.

Hoffman, B., & Ritchie, D. (1997). Using multimedia to overcome the problems with problem based learning. *Instructional Science*, *25*(2), 97–115.

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

Hung, W., Bailey, J. H., & Jonassen, D. H. (2003). Exploring the tensions of problem-based learning: Insights from research. *New Directions for Teaching and Learning*, *95*, 13–23.

Hung, W., & Holen, J. B. (under review). Problem-based learning: Preparing pre-service teachers for real world classroom challenges. Submitted to Teaching and Teacher Education.

Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In J. M. Spector, M. D. Merrill, J. van Merriënboer, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., Vol. 1, pp. 485–506). New York: Erlbaum.

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

Jonassen, H. D., Tessmer, M., & Hannum, W. H. (1999). *Task analysis methods for instructional design*. Mahwah, NJ: Erlbaum.

Jones, B. F., Rasmussen, C. M., & Moffitt, M. C. (1997). *Real-life problem solving: A collaborative approach to interdisciplinary learning*. Washington, DC: American Psychological Association.

Jost, K. L., Harvard, B. C., & Smith, A. J. (1997). A study of problem-based learning in a graduate education classroom. In *Proceedings of selected research and development presentation at the national convention of the association for educational communications and technology* 19th, Albuquerque, NM, February, 14–18, 1997, (ERIC Document Reproduction Service No. ED 409 840).

Kain, D. L. (2003). *Problem-based learning for teachers, grades K-8*. Boston, MA: Person Education.

Kamin, C. S., O'Sullivan, P. S., Younger, M., & Deterding, R. (2001). Measuring critical thinking in problem-based learning discourse. *Teaching and Learning in Medicine*, *13*(1), 27–35.

Kaufman, D. M., & Holmes, D. B. (1998). The relationship of tutors' content expertise to interventions and perceptions in a PBL medical curriculum. *Medical Education*, *32*, 255–261.

Keller, J. M. (1987). The systematic process of motivational design. *Performance & Instruction*, November/December, 1–8.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86.

Kolodner, J. L. (2002). Analogical and case-based reasoning: Their implications for education. *The Journal of the Learning Science*, *11*(1), 123–126.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., et al. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by Design™ into practice. *The Journal of the Learning Sciences*, *12*(4), 495–547.

Koschmann, T. D., Myers, A. C., Feltovich, P. J., & Barrows, H. S. (1994). Using technology to assist in realizing effective learning and instruction: A principled approach to the use of computers in collaborative learning. *The Journal of the Learning Sciences*, *3*(3), 227–264.

Kurtz, S., Wylie, M., & Gold, N. (1990). Problem-based learning: An alternative approach to legal education. *Dalhousie Law Journal*, *13*, 787–816.

Langer, E. J. (1997). *The power of mindful learning*. New York: Addison-Wesley.

Lee, J. (1999). Problem-based learning: A decision model for problem selection. In *Proceedings of selected research and development papers presented at the National Convention of the Association for Educational Communications and Technology* Houston, TX, February.

Levesque, J. E. (1999). A *comparison of problem-based learning and traditional lecture methods on medical student performance*. Doctoral dissertation, University of Houston, Huston.

Lieux, E. M. (2001). A skeptic's look at PBL. In B. Duch, S. E. Groh, & D. E. Allen (Eds.), *The power of problem-based learning: A practical "how to" for teaching undergraduate courses in any discipline* (pp. 223–235). Sterling, VA: Stylus Publishing.

Linn, M., Shear, L., Bell, P., & Slotta, J. D. (1999). Organizing principles for science education partnerships: Case studies of students' learning about 'rats in space' and 'deformed frogs'. *Educational Technology, Research and Development*, *47*(2), 61–84.

Maitland, B. (1998). Problem-based learning for an architecture degree. In D. Boud & G. Feletti (Eds.), *The challenge of problem-based learning* (2nd ed., pp. 211–217). London: Kogan Page.

Martin, L. M., & Beach, K. (1992). *Technical and symbolic knowledge in CNC machining: A study pf technical skills training and assessment*. Pittsburgh, PA: University of Pittsburgh, Learning research and Development Center.

Maxwell, N., Mergendoller, J. R., & Bellisimo, Y. (2005). Problem-based learning and high school macroeconomics: A comparative study of instructional methods. *The Journal of Economic Education*, *36*(4), 315–331.

Mayer, R. E. (1996). Learning strategies for making sense out of expository text: The SOI model for guiding three cognitive processes in knowledge construction. *Educational Psychology Review*, *8*, 357–371.

Mayo, P., Donnelly, M. B., Nash, P. P., & Schwartz, R. W. (1993). Student perceptions of tutor effectiveness in a problem-based surgery clerkship. *Teaching and Learning in Medicine*, *5*(4), 227–233.

Merchand, J. E. (1995). Problem-based learning in the business curriculum: An alternative to traditional approaches. In W. Gijselaers, D. Tempelaar, P. Keizer, E. Bernard, & H. Kasper (Eds.), *Educational innovation in economics and business administration: The case of problem-based learning* (pp. 261–267). Dordrecht, The Netherlands: Kluwer.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice Hall.

Norman, G. R., & Schmidt, H. G. (1992). The psychological basis of problem-based learning: A review of the evidence. *Academic Medicine*, *67*(9), 557–565.

Oberlander, J., & Talbert-Johnson, C. (2004). Using technology to support problem-based learning. *Action in Teacher Education*, *25*(4), 48–57.

O'Neill, P. A. (2000). The role of basic sciences in a problem-based learning clinical curriculum. *Medical Education*, *34*, 608–613.

Osgood, M. P., Mitchell, S. M., & Anderson, W. L. (2005). Teachers as learners in a cooperative learning biochemistry class. *Biochemistry and Molecular Biology Education*, *33*(6), 394–398.

Ostwald, M. J., Chen, S. E., Varnam, B., & McGeorge, W. D. (1992). *The application of problem based learning to distance education* (ERIC Document Reproduction Service No. ED 359 398).

Perkins, D. N., & Salomon, G. (1989). Are cognitive skill context-bound? *Educational Researcher*, *18*(1), 16–25.

Perrenet, J. C., Bouhuijs, P. A. J., & Smits, J. G. M. M. (2000). The suitability of problem-based learning for engineering education: Theory and practice. *Teaching in Higher Education*, *5*(3), 345–358.

Pletinckx, J., & Segers, M. (2001). Programme evaluation as an instrument for quality assurance in a student-oriented educational system. *Studies in Educational Evaluation*, *27*, 355–372.

Prawat, R. (1989). Promoting access to knowledge, strategies, and disposition in students: A research synthesis. *Review of Educational Research.*, *59*(1), 1–41.

Polya, G. (1957). *How to solve it: A new aspect of mathematical method*. Princeton, NJ: Princeton University Press.
Ram, P. (1999). Problem-based learning in undergraduate education: A sophomore chemistry laboratory. *Journal of Chemical Education*, *76*(8), 1122–1126.
Reynolds, F. (1997). Studying psychology at degree level: Would problem-based learning enhance students' experiences? *Studies in Higher Education*, *22*(3), 263–275.
Rhem, J. (1998). Problem-based learning: An introduction. *The National Teaching and Learning Forum*, *8*(1), 1–4.
Savery, J. R., & Duffy, T. M. (1996). Problem based learning: An instructional model and its constructivist framework. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 135–148). Englewood Cliffs, NJ: Educational Technology Publications.
Savoie, J. M., & Hughes, A. S. (1994). Problem-based learning as classroom solution. *Educational Leadership*, *52*(3), 54–57.
Seltzer, S., Hilbert, S., Maceli, J., Robinson, E., & Schwartz, D. (1996). An active approach to calculus. In L. Wilkerson & W. H. Gijselaers (Eds.), *Bringing Problem-based learning into higher education: Theory and practice* (pp. 83–90). San Francisco, CA: Jossey-Bass.
Schlundt, D. G., Flannery, M. E., Davis, D. L., Kinzer, C. K., & Pichert, J. W. (1999). Evaluation of a multicomponent, behaviorally oriented, problem-based "summer school" program for adolescents with diabetes. *Behavior Modification*, *23*(1), 79–105.
Schmidt, H. G. (1983). Problem-based learning: Rationale and description. *Medical Education*, *17*, 11–16.
Schmidt, H. G., Boshuizen, H. P. A., & de Vries, M. (1992). Comparing problem-based with conventional education: A review of the University of Limburg medical school experiment. *Annals of Community-Oriented Education*, *5*, 193–198.
Schultz-Ross, R. A., & Kline, A. E. (1999). Using problem-based learning to teach forensic psychiatry. *Academic Psychiatry*, *23*, 37–41.
Smith, P. (2000). Preparedness for flexible delivery among vocational learners. *Distance Education*, *21*(1), 29–48.
Smith, D., & Hoersch, A. L. (1995). Problem-based learning in the undergraduate geology classroom. *Journal of Geological Education*, *43*, 149–152.
Spiro, R. J., Coulson, R. L., Feltovich, P., & Anderson, D. K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In *Tenth Annual Conference of the Cognitive Science Society* (pp. 375–383). Hillsdale, NJ: Erlbaum.
Stanley, S. S. (2002). Revitalizing precalculus with problem-based learning. *The Journal of General Education*, *51*(4), 306–315.
Stepien, W. J., Gallagher, S. A., & Workman, D. (1993). Problem-based learning for traditional and interdisciplinary classrooms. *Journal of the Education of the Gifted*, *16*, 338–357.
Stepien, W. J., & Gallagher, S. A. (1993). Problem-based learning: As authentic as it gets. *Educational Leadership*, *50*(7), 25–29.
Stepien, W. J., Senn, P. R., & Stepien, W. C. (2000). *The internet and problem-based learning: Developing solution through the web*. Tucson, AZ: Zephyr Press.
Sugrue, B. (1995). A theory-based framework for assessing domain-specific problem-solving ability. *Educational Measurement: Issues and Practice*, *14*(3), 32–35.
Thomas, J. W., Strage, A., & Curley, R. (1988). Improving students' self-directed learning: Issues and guidelines. *The Elementary School Journal*, *88*(3), 313–326.
Torp, L., & Sage, S. (2002). *Problems as possibilities: Problem-based learning for K-16 education* (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.
Trafton, P. R., & Midgett, C. (2001). Learning through problems: A powerful approach to teaching mathematics. *Teaching Children Mathematics*, *7*(9), 532–536.
Uyeda, S., Madden, J., Brigham, L. A., Luft, J. A., & Washburne, J. (2002). Solving authentic science problems: Problem-based learning connects science to the world beyond school. *The Science Teacher*, *69*(1), 24–29.
van Gessel, E., Nendaz, M. R., Vermeulen, B., Junod, A., & Vu, N. V. (2003). Basic science development of clinical reasoning from the basic sciences to the clerkships: A longitudinal assessment of medical students' needs and self-perception after a transitional learning unit. *Medical Education*, *37*, 966–974.
Verhoeven, B. H., Verwijnen, G. M., Scherpbier, A. J. J. A., Holdrinet, R. S. G., Oeseburg, B., Bulte, J. A., et al. (1998). An analysis of progress test results of PBL and non-PBL students. *Medical Teacher*, *20*(4), 310–316.
Vernon, D. T. A., & Blake, R. L. (1993). Does problem-based learning work: A meat-analysis of evaluative research. *Academic Medicine*, *68*, 550–563.
von Glasersfeld, E. (1995). A constructivist approach to teaching. In L. P. Steffe & J. Gale (Eds.), *Constructivism in education* (pp. 3–16). Hillsdale, NJ: Erlbaum.
Wieseman, K. C., & Cadwell, D. (2005). Local history and problem-based learning. *Social Studies and the Young Learner*, *18*(1), 11–14.
Wiggins, G., & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.
Williams, S. M., & Hmelo, C. E. (1998). Guest editors' introduction. *The Journal of the Learning Sciences*, *7*(3&4), 265–270.
Woods, D. R. (1996). Problem-based learning for large classes in chemical engineering. *New Directions for Teaching and Learning*, *68*, 91–99.