Scaffolding Disciplined Inquiry in Problem-Based Environments

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Abstract

Problem-based learning (PBL) has been advocated in K-12 contexts as a means to promote understanding, integration, and retention of concepts (Gallagher, 1997; Gallagher, Sher, Stepien, & Workman, 1995). Through analysis of the problem, students acquire both relevant knowledge and problem-solving skills (Barrows & Tamblyn, 1980). However, implementing problem-based learning presents several challenges to the learner, who may become overwhelmed in this unfamiliar context (Land, 2000). Scaffolds, defined as tools, strategies, or guides, may be one means of supporting learners in PBL. In this review, we present a number of scaffolding strategies endorsed by teachers, designers, and researchers. Specifically, scaffolds have the potential to support learner performance by accomplishing at least three crucial goals: 1) initiating students’ inquiry; 2) aiding learners with concept integration and addressing misconceptions; and 3) promoting reflective thinking. The primary focus of our paper is to explore how scaffolds can serve to support each of these purposes, and to present examples that might assist researchers, instructional designers, and teachers who advocate PBL as a beneficial instructional approach.

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Problem-Based Learning

Problem-based learning (PBL) has been advocated as a means to promote understanding, integration, and retention of concepts (Gallagher, 1997; Gallagher, Sher, Stepien, & Workman, 1995). Originally formalized in medical schools in the 1970s to engage students in problem-solving activities similar to those encountered in practice, PBL combines learning theories about problem solving with the case study approach (Gallagher, 1997). Students are presented with problems embedded in relevant, resource-rich contexts (Hoffman & Ritchie, 1997) and assume the role of primary researchers. They work in small groups to analyze the problem, consider possible solutions, develop a plan, and evaluate the outcome (Kaufman & Mann, 1997).

Models of problem-based learning range from limited implementations, which present a question or case, to broad implementations, where students define and research their own problems in collaboration with a teacher or practicing professional (Barrows, 1986; Pierce & Jones, 2002). Regardless of which model is used, there are at least five essential characteristics of these approaches: 1) engaging students in an ill-structured problem, 2) introducing students to the problem before they have acquired content-relevant knowledge, 3) allowing students to work collaboratively, 4) supporting students throughout the problem-solving process, and 5) promoting student reflection following the presentation of their solutions to the problem. We describe each of these elements in more detail below.

The first element of PBL centers on engaging students in a problem for the purposes of promoting active investigation and inquiry (Stepien & Pyke, 1997). An effective, motivating problem must be appropriately complex, ill-structured, and relevant (Duch, 2001; Hmelo & Ferrari, 1997). Within an ill-structured problem, there are multiple pathways to the solution(s), as well as more than one solution (Barrows, 1985; Mason & Mitroff, 1981).

Second, it is essential students encounter the problem before all knowledge relating to the central problem has been acquired, rather than as a post-instruction synthesizing activity. Through analysis of the problem, students acquire both relevant knowledge and problem-solving skills (Barrows & Tamblyn, 1980). This feature distinguishes PBL from other problem-oriented environments (Albanese & Mitchell, 1993; Arts, Gijelaers & Segers, 2002).

Third, students must work together, reflecting the general belief that collaboration in inquiry-based settings can enhance learning outcomes (Qin, Johnson, & Johnson, 1995; Schmidt & Moust, 2000). During collaborative problem solving, students construct theories toward a solution or resolution (Blumenfeld, Marx, Soloway, & Krajcik, 1996). According to the Cognition and
Technology Group at Vanderbilt, “…cooperative problem-solving groups enhance opportunities for generative learning … students have the opportunity to form communities of inquiry that allow them to discuss and explain, and hence learn, with understanding” (1992, p. 68). The primary goals of collaboration in PBL are two-fold: to activate individuals’ prior experience or knowledge in related areas, and to promote clarity regarding the direction(s) the group should take through refining what is not understood (Kelson & Distlehorst, 2000; Schmidt & Moust, 2000; Wilkerson, 1996).

Fourth, the instructor or tutor supports students throughout the problem-solving process. “Coach,” “guide,” or “facilitator” are metaphors used to convey the fundamental nature of the instructor’s role in PBL, and to differentiate it from the more traditional didactic role (Chaves, Lantz, & Lynch, 2001). The instructor models expert problem-solving behavior (where applicable) and monitors the groups’ progress, encouraging active participation and commenting on students’ ideas (Hmelo & Ferrari, 1997; Illinois Mathematics and Science Academy, 2002). Additionally, instructors provide feedback (at time, in iterative forms) to deepen understanding and product quality (Barron et al., 1998; Gallagher, 1997).

Fifth, students participate in self-evaluation and reflection following the problem-solving process. Reflection helps students relate new knowledge to prior understanding, and understand the thinking and learning strategies they have used (Chaves et al., 2001; Gallagher, 1997; Hmelo & Ferrari, 1997). The goal is to help students solidify and deepen their understanding of the concepts and skills (Stepien & Pyke, 1997). As noted by Hemelo and Ferrari, “[Reflection] provides an opportunity for students to consolidate and abstract what they have learned” (p. 416).

Implementing problem-based learning presents several challenges to the learner. For example, students unfamiliar with this context may become overwhelmed in assuming a different, more active role (Land, 2000). Herrenkohl and Guerra (1998) found students often refrain from active interaction with their groups, and instead solicit correct answers from the teacher. Thus, it may take novice students time to adjust to the new, self-directed learning environment (Schmidt, Henny, & de Vries, 1992).

In the typical problem-based medical model, expert tutors are provided for each student group to address some of the challenges encountered by teachers and students. The role of these trained tutors is to facilitate the learning process, provide feedback, and promote students’ collaboration (Schmidt & Moust, 2000). As a result, students are able to receive expert guidance, but do not have to depend on one teacher for this guidance.

However, one barrier to successful PBL implementation is the “lack of a sufficient number of skilled facilitators” (Hmelo-Silver, 2004, p. 261). This is especially true within traditional primary and secondary school environments where time and resource constraints disallow providing expert tutors for each group. Thus, it becomes necessary to examine other means of supporting, or scaffolding, students’ efforts (Hmelo-Silver, 2004; Simons & Klein, 2004).
Scaffolding

Scaffolds represent one means of supporting learners in complex or unfamiliar environments. Scaffolds are tools, strategies, or guides that support students in gaining higher levels of understanding that would be beyond their reach without the scaffolds (Jackson, Stratford, Krajcik, & Soloway, 1996). Wood, Bruner, and Ross (1976) defined effective scaffolding as “…controlling those elements of the task that are initially beyond the learner’s capability, thus permitting him to concentrate upon and complete only those elements that are within his range of competence” (p. 9). Bruner (1984) further asserted that scaffolding is a major component of any instructional activity, one that precedes learners’ internalization of the knowledge, concepts, and skills associated with any instructional goal.

According to Rommetveit (1974), successful scaffolding requires learners and teachers to possess a shared understanding of the task; the teacher’s primary goal is helping learners to develop their own personal conceptualization of the task. In this manner, the instructor continually balances supporting and challenging learners. The goal centers on making the learning task sufficiently challenging, rather than making the task easy for the learner. In fact, within some contexts, scaffolds may render the task more challenging, namely in content domains where students tend be satisfied with superficial solutions and explanations that do not accurately reflect the complexity of the content domain (Reiser, 2004).

Scaffolds may assume multiple forms depending on the learning environment, the content, the instructor, and the learners. In fact, these multiple definitions can create confusion in the area of educational research because different researchers often invoke a different meaning in reference to scaffolding (Lepper, Drake, & O’Donnell-Johnson, 1997). For example, the term is used to characterize the domain of teachers’ actions in support of learners’ efforts (Berk & Winsler, 1995; Hogan & Pressley, 1997; Roehler & Cantlon, 1997). Saye and Brush (2002) defined these as “soft scaffolds,” which are dynamic and require teachers to “continuously diagnose the understandings of learners and provide timely support based on student responses” (p. 82). In contrast to soft scaffolds, Saye and Brush also define “hard scaffolds,” which refer to “static supports that can be anticipated and planned in advance based on typical student difficulties with a task” (p. 82). Hard scaffolds serve to provide learner support at various stages known to be difficult, thus freeing the teacher to perform additional soft scaffolding. Saye and Brush assert that both hard and soft scaffolds are key components to students’ success.

Within problem-based learning contexts, scaffolds have the potential to support learner performance by accomplishing at least three crucial goals: 1) initiating student’s inquiry; 2) aiding learners with concept integration and addressing misconceptions; and 3) promoting reflective thinking. The primary focus of our paper is to explore how scaffolds can serve to support each of these purposes, and to present examples that might assist researchers, instructional designers, and teachers who advocate PBL as a beneficial instructional approach.
Initiating Students’ Inquiry

Research has shown that learners – especially those new to PBL – tend to have difficulty during the initial stages of inquiry (Kolodner et al., 2003; Simons & Klein, 2004; Simons, Klein, & Brush, 2004). This pattern appears consistent across multiple levels of students, from primary to post-secondary. In a study of pre-professional students enrolled in PBL-focused programs, student interviews reflected frustration stemming from the ambiguity of not receiving clear directions and not knowing the right amount of information to study (Abrandt Dahlgren & Dahlgren, 2002). Simons and Klein (2004) reported similar findings in a study of seventh-grade students engaged in a multimedia science PBL unit; students struggled with knowing how to get started, and focused instead on finding the videos and animations contained within the available resource database.

Assisting learners as they begin the inquiry process appears key to their success, and there are various ways to accomplish this. One approach is to engage learners from the outset, which Wood et al. (1976) term “recruitment,” a two fold process that involves enlisting the learners’ interest and presenting the requirements of the task. Within Learning by Design (Kolodner et al., 2003), students begin exploring a design problem with a “messing about” activity in which they construct an initial model or device, based primarily on prior knowledge and intuition. Students record their observations and collaboratively generate ideas and questions. These are captured on a whiteboard and used to frame their subsequent activities. The “messing about” activities are both open-ended and student-driven. In contrast, Baumgartner and Reiser (1998) incorporate “staging activities,” which can be primarily teacher-facilitated. For example, the teacher might show an example project from a previous year or demonstrate a scientific principle. For example, in a unit entitled Composites Module, the teacher demonstrated the effect of reinforcing ice with shredded toilet paper to show that this composite was stronger than ice alone. Whether teacher- or student-driven, the commonality among these approaches involves sparking learners’ interest at the beginning of the inquiry process, thereby prompting learners to ask questions, predict outcomes, and make observations.

In addition to sparking learners’ interest, many designers advocate narrowing or constraining the task to make it more manageable (Kolodner et al., 2003). Wood et al. (1976) refer to this process as reducing the degrees of freedom; in other words, this involves “reducing the size of the task to the level where the learner could recognize whether or not he had achieved a ‘fit’ with the task requirements” (p. 98). Some have likened these techniques to the use of “training wheels” on a bicycle (van Merrienboer, Kirschner, & Kester, 2003). For example, one multimedia PBL unit for middle-school students, Up, Up & Away! contained a “Hints” section that was divided into two components to align with the two project requirements – designing a balloon that could circumnavigate the earth and planning a travel route (Brinkerhoff & Glazewski, 2004). Each hint began with a question to help students get started: “If I’ve never designed a balloon before, where do I start?” and “If I’ve never planned a balloon trip before, where
do I begin?” Teachers with whom we have worked also employ a variety of techniques in order to constrain the task, including distributing the grading rubric in advance, collaborating with students to create the grading rubric, presenting a series of interim deadlines, and providing graphic organizers.

Once students are involved and engaged in the inquiry process, a significant barrier has been overcome. Now that the task is more clearly defined for the learner and the problem, while still ill-structured, is manageable, the next consideration involves finding ways to aid learners with concept integration and to avoid (or correct) potential misconceptions.

**Aiding with Concept Integration and Addressing Misconceptions**

It is important to remember one of the primary reasons researchers and designers advocate problem-based learning as an effective pedagogical approach—that is, to help learners gain a deeper understanding of content through the process of doing. However, progress toward this goal has led to mixed results. While research findings tend to favor PBL over traditional environments when it comes to student outcomes such as motivation (Albanese & Mitchell, 1993; Norman & Schmidt, 1992; Rideout et al., 2002), problem-solving, and self-direction outcomes (Blumberg, 2000; Gallagher, Stepien, & Rosenthal, 1992; Stepien, Gallagher, & Workman, 1993), the findings tend to favor more traditional environments when it comes to measures of content knowledge (Albanese & Mitchell, 1993; Vernon & Blake, 1993). To date, this appears to be one of the most significant shortcomings of PBL.

The Learning by Design (LBD) researchers have employed a number of strategies (many of which are described in more detail below) to address this shortcoming, and conclude, “Not surprisingly, the degree to which students connect science to their designs seems to depend on the extent to which teachers model … science talk and the degree to which they require students to rigorously adhere to the requirements of the … rituals” (Kolodner et al., 2003, p. 539). According to the LBD designers, rituals “… [make] the expectations for any activity clear and succinct …” so that students and teacher can effortlessly engage in them (p. 513).

One way of aiding with concept integration in PBL is to incorporate more systematic ways of helping students make the connection between their inquiry activities and the content. The developers of WISE (Web-based Inquiry Science Environments) employ the term “making thinking visible” to refer to strategies that enable students to reveal what and how they are thinking within a specific content domain (Linn, Clark, & Slotta, 2003). For example, as part of the WISE approach, students post online responses at various stages in their inquiry, which are saved for accessibility at a later date by the student or the teacher. Following this, prompts are used to help students connect their ideas to project topics, such as, “How do we use all of this information to solve the problem?” (Linn et al, p. 528). This, then, supports knowledge integration by directly asking students to “link and connect ideas” (Linn et al., p. 527). However, it is important to note that
these types of scaffolding strategies do not necessarily have to be technological; one middle-school teacher used sticky notes to elicit students’ thinking during PBL activities. At the end of each class period, students posted responses and/or questions they still had. The teacher gathered these, organized them, and responded to them the following day. These and similar strategies help teachers “see” what their students are thinking.

A second way to aid with concept integration is to directly reinforce the content and learning goals. The LBD group accomplishes this through “rules of thumb,” which are student-generated rules used to explain their observations. Rules of thumb are posted, tested, and refined throughout the inquiry process, based on students’ findings and new observations. The teacher guides the discussion and challenges students to support their theories with evidence, but refrains from correcting assumptions until students have had the opportunity to test their rules. At that time, the teacher might engage in what Schwartz and Bransford (1998) called a “time for telling,” which involves directly telling the rule in the form of a lecture or mini-lesson. In their research, Schwartz and Bransford (1998) found that students who engaged in an inquiry-based problem prior to a lecture performed significantly better than those who only solved the problem (with no follow-up lecture) and those who read the chapter prior to the lecture. The authors proposed that the inquiry activity created a readiness to learn, which allowed students to retain more of the content from the lecture than their peers. While lecture is not a commonly endorsed practice in PBL, at times it reflects the best and most efficient manner to reinforce content.

Finally, once it is clear what and how students are thinking, it is important to elicit and address student misconceptions or biases (Land, 2000). Linn, Shear, Bell, and Slotta (1999) suggested this might be accomplished through “pivotal ideas” by first having students articulate their own beliefs about a phenomenon and highlighting inconsistencies in their thinking. For example, Linn et al. (1999) noted that students naively tend to hold beliefs based on intuition or bias, such as believing that items that “feel” hot must have a correspondingly higher temperature (e.g., metal vs. plastic); their explanations do not account for properties of conduction on insulation, which can be modified through inquiry experiences. In fact, the LBD group gives naïve thinking a central role within the inquiry process, capitalizing on the value of failure and refinement: “Because one’s first explanations might not be complete or accurate, CBR [case-based reasoning] gives iterative refinement a central role. … Central to CBR is the notion that we revise and refine our explanation (and thus, our knowledge) over time. We explain and index any experience we can at the time…” (Kolodner et al., 2003, p. 503).

Although content learning is one of the key reasons for using a PBL approach, it is relatively easy for both teachers and students to lose sight of this goal and to focus, instead, on the interesting activities that need to be completed. The strategies described above can assist both teachers and students in their efforts to connect these engaging activities to the relevant content that is being addressed. Furthermore, reflective activities, which require students to articulate what they
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are learning, can play an important role in concept integration. Because reflection serves other important roles as well, it is described as a separate section below.

**Promoting Reflective Thinking**

Research has shown that reflection is a vital component of problem-based learning (Chaves et al., 2001; Gallagher, 1997; Hmelo & Ferrari, 1997). Reflective thinking “helps students make connections between their problem-solving goals, the processes involved in achieving those goals, and the content they are learning, and helps them abstract out processes and explanations that apply beyond the problem they are working on. It pushes them to consider how they are applying what they know and what they are learning” (Kolodner et al., 2003, p. 506). However, learners are not automatically reflective and, therefore, require guidance and support (Land & Zombo-Saul, 2003) in order to engage in effective reflection. That is, learners have a tendency to focus on the task, experiment, or the project rather than on conceptual understanding of the key principles (Reiser, 2004). In addition, learners often find it difficult to manage their inquiry activities, and are not necessarily able to devote sufficient attention to reflection. As Krajcik and his colleagues (1998) asserted, “The concern with completing school work makes students hesitant about devoting time to revisiting ideas and improving their work. [This] suggests that class time be allocated for sharing ideas and for revision and that teachers need to work with students so that they appreciate the importance of both” (p. 343).

Researchers have found that the simple act of prompting students to reflect can enhance the transferability of content and problem solving skills (Davis, 2003). Prompting reflective thinking can take a variety of forms. One successful approach is as simple as facilitating class discussions and capturing students’ thoughts on whiteboards (Kolodner et al., 2003); this is not to imply that the skill of facilitating discussion is “simple,” but it is a practice employed consistently by most teachers. The shift occurs when teachers use reflection as a means of reinforcing cognitive and problem-solving transfer. Another strategy incorporates structured diaries or guided prompts (Davis, 2003; Hmelo-Silver, 2004). However, teachers might not want to be too directive with their prompts: Davis found that students actually incorporated more ideas, evidence, and scientific principles in their reflections when guided with “generic” prompts (e.g., “Right now, we’re thinking…”) rather than more “directed” prompts (e.g., “To do a good job on this project, we need to…”). She speculated that students who received the directed prompts may not have been able to interpret thoroughly what was needed or they may have been superficially completing the task. Nevertheless, whether they take the form of less formal discussions or more formal written activities, the use of prompts appears to enhance students’ reflective thinking.

A second approach involves modeling the completion of a task, investigation, or approach. The goals for modeling are primarily two-fold: to incorporate the language of the discipline and to prompt students to compare their own processes with an expert or another student (Collins, Brown, & Newman, 1989). According
to Collins and his colleagues, modeling allows for a “post-mortem” analysis of the problem solution, in which a type of “abstracted replay” is employed “to focus students’ observations and comparisons directly on the determining features of both their own and an expert’s performance by highlighting those features in a skillful verbal description…” (p. 458). The practical application of this approach can be live, in a small-group or whole-class context, or videotaped for just-in-time access. For example, Alien Rescue (Pedersen & Liu, 2002-2003), a multimedia-based PBL program, contains a feature in the software that allows students to view video advice from an “expert” at various stages during the process. The expert verbally describes his problem-solving strategies, such as how he selects relevant information and why he chooses to ignore other information. The authors found that students transferred these expert strategies to a different problem-solving domain, and speculated that enhancing students’ thinking during PBL helped them to participate more effectively in the environment and thus, enhanced their problem solving in the transfer situation. However, by way of caution, it seems important to note that the abstraction is not automatic for most students, and they may need support for transferring the skills and processes to other domains. Wood et al. (1976) found that modeling solutions for the learner did not lead to the learner being able to imitate the expert with precision. In fact, the learner imitated only those acts he or she could already accomplish fairly well, leading the authors to consider the role of prior knowledge and comprehension in the task. In such cases, the verbal analysis that accompanies the abstracted replay appears to take a central role (Collins et al., 1989).

Not only is it important for teachers to model successful strategies for students, but they should also consider modeling situations in which they, themselves, encounter failure. This gives teachers the opportunity to demonstrate appropriate responses to failure, as well as effective strategies for addressing the failed attempt. For example, one math teacher asked students to find difficult problems for him to solve at the beginning of each class (Collins et al., 1989). “During these sessions, he models not only the use of heuristics and control strategies, but the fact that one’s strategies sometimes fail. … Seeing experts deal with problems that are difficult for them is critical to students’ developing a belief in their own capabilities. Even experts stumble, flounder, and abandon their search for a solution until another time. Witnessing these struggles helps students realize that thrashing is neither unique to them nor a sign of incompetence” (p. 473). Furthermore it can provide students with a new set of possible strategies to use when they are faced with unexpected results during the problem-solving process.

Reflection plays a key role problem-based learning, and the strategies for enhancing reflective thinking are found in some of our most conventional classroom activities—discussions, prompts, and modeling. In scaffolding reflective thinking, students are better prepared to remember content, transfer skills, and use the language of the discipline. However, as researchers, teachers, and designers make plans to scaffold students’ efforts in PBL, there are some important considerations to weigh.
Implications and Considerations

While scaffolding is an important component in any learning environment, it appears especially important in problem-based environments. Students have been found to perform better, achieve more, and transfer problem-solving strategies more effectively when their inquiry is supported through scaffolding (Land & Zombal-Saul, 2003; Linn et al. 1999; Pedersen & Liu, 2002-2003; Reiser, 2004). However, that is not to suggest that scaffolding is without drawbacks. As noted earlier, it is difficult to scaffold student efforts. Soft scaffolding depends highly on a skillful teacher knowing when and how to support students. Hard scaffolding depends on students’ ability to recognize the support as helpful or useful, and not view it as just another “task” to be completed or as “extra work” (Oliver & Hannafin, 2000; Simons & Klein, 2004).

Furthermore, scaffolding introduces a number of tensions that the teacher or designer must weigh before proceeding. One of the biggest tensions reflects the need to constrain students’ efforts, but not control them to the point that the environment is no longer open-ended (Reiser, 2004). We want students to take responsibility and conduct independent investigations, and constraining them may prohibit their independence. Another strong tension relates to the need to simplify components of the problem and content without making them superficial (Brush & Simons, 2004; Reiser). We want students to understand the complexity of a given domain, to weigh trade-offs, and to understand principles of cause and effect. At some point, we must consider when we have simplified a domain to the point that it is no longer accurately reflected.

It is clear that scaffolding can support student success in PBL, especially when we consider they may not otherwise initiate their own inquiry, understand or integrate new content, or think reflectively (Davis; 2003; Reiser, 2004; Simons & Klein, 2004). However, it is important to remember that the success of these scaffolds depends, to a great extent, on the ability of teachers to both create and apply them in the classroom. Just as students may not be inclined to use the scaffolds that are provided, teachers may not understand the value of implementing such supports or may need help creating scaffolds that do not overly simplify or constrain the problem. If using student scaffolds is going to have the impact expected or hoped for, researchers and designers will also need to consider how to scaffold teachers’ efforts to create the type of scaffolds that can best support students’ learning.
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