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## Supporting Problem Solving in PBL

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## Supporting Problem Solving in PBL

*David Jonassen*

### Abstract

Although the characteristics of PBL (problem focused, student centered, self-directed, etc.) are well known, the components of a problem-based learning environment (PBLE) and the cognitive scaffolds necessary to support learning to solve different kinds of problems with different learners is less clear. This paper identifies the different components of a PBLE, including a problem to solve, worked examples, case studies, analogues, prior experiences, alternative perspectives, and simulations. Additionally, different cognitive scaffolds necessary to help students interpret and use those components include analogical encoding, causal relationships, argumentations, questioning, modeling, and metacognitive regulation. Recommendations are provided for matching components and scaffolds with learners' needs when solving different kinds of problems.

## The Nature of Problems

There are many issues in implementing PBL into various curricula. An important issue has to do with the extent of the curriculum that is converted to PBL. Many reports illustrate the effect of single PBL modules inserted in courses including biomedical engineering (LaPlaca, Newstetter, & Yoganathan, 2001), chemical engineering (Cline & Powers, 1997), software engineering (Armarego, 2002; Mitchell & Delaney, 2004), and thermal physics (van Kampen, Nanahan, Kelly, McLoughlin, & O'Leary, 2004). Other implementations have converted existing semester-long courses to PBL courses, such as software engineering (Dunlap, 2005) and materials science (Henry, Jonassen, Winholtz, & Khanna, 2010). Some of the most successful implementations of PBL have employed PBL throughout an entire curriculum, enabling students to develop the study strategies and self-regulation skills necessary for success in a PBL environment. Because PBL represents a significant shift in learning for most students, they require support in adapting their learning methods. We cannot assume that learners are naturally skilled in problem solving, especially complex and ill-structured problems such as those required in most PBL programs.

Another important issue focuses on the nature of the problem being solved and the nature of the learners. Figure 1 illustrates external and internal factors that affect problem solving. As depicted in Figure 1, external factors that affect problem solving include the perspective, dynamicity, structure, difficulty, and context. Based on these differences, Jonassen (2000) suggested a typology of problems on a continuum from well-structured to ill-structured, including story problems, rule using/rule induction, decision making, troubleshooting, diagnosis-solution, strategic performance, policy, design, and dilemmas. Factors that are internal to the learners include the learner's levels of prior knowledge, experience, reasoning ability, various cognitive styles, and epistemic beliefs (Jonassen, 2007). It is important to note that these are not hard categories. Problems may be represented in different categories, depending on the nature of the learning desired. For example, most of the ill-structured problems (diagnosis, policy, design, etc.) can be represented as decision-making problems.

**Story Problems.** Students in formal education most often learn to solve story problems in mathematics and the sciences. Story problems typically present a set of values embedded within a shallow story context at the end of textbook chapters. Story problems are normally solved when learners identify key values in the short scenario, select the appropriate algorithm, apply the algorithm to generate a quantitative answer, and hopefully check their responses (Sherrill, 1983). These are the most common kind of problems solved in formal education settings. Unfortunately, too many educators believe that learning to solve story problems will naturally transfer to complex, everyday problems (Jonassen, 2000). They do not.

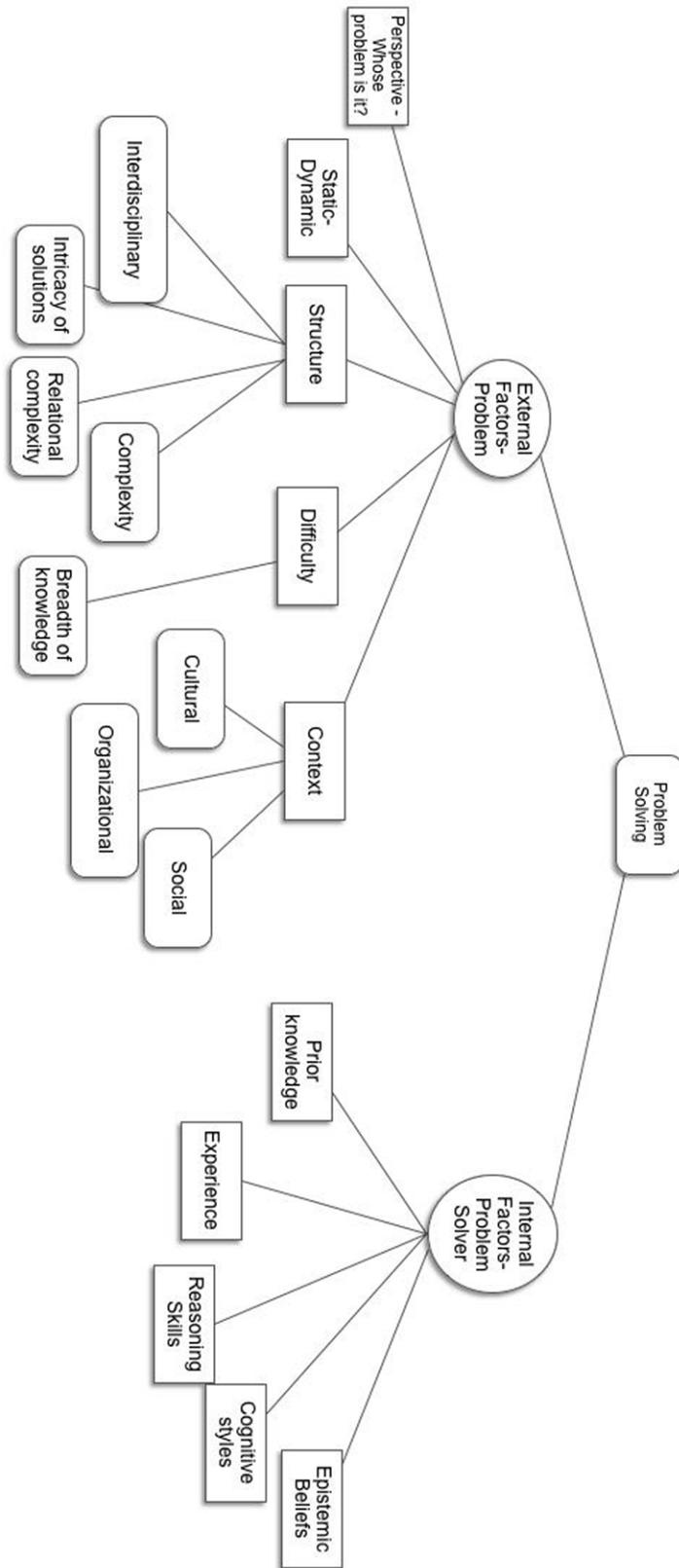


Figure 1. Factors in problem solving.

**Rule-using/Rule Induction Problems.** Rule-using problems have known solutions but multiple solution paths or multiple rules governing the process. They tend to have a clear purpose or goal that is constrained but not restricted to a specific procedure or method. Rule-using problems can be as simple as expanding a recipe to accommodate more guests or as complex as completing tax return schedules. Using an online search system to locate a library's holdings or searching a database to find relevant information are examples of rule-using problems. Rule induction problems require that learners induce the rules governing how some system operates. For example, learning how to use a new remote control or new stereo system requires figuring out how the controls affect the system functions. Starting a new job requires inducing rules about the social and power dynamics in the new work setting.

**Decision-making Problems.** Decision-making problems require individuals or social groups to decide which solution, issue, or course of action to pursue. Which health plan do we select? Which investment strategy will yield higher earnings? Though these problems have a limited number of solutions, the number of factors to be considered in deciding among those solutions, as well as the weights assigned to them, can be very complex. Although normative, rational choice models of decision making emphasize comparing, contrasting, and weighing the advantages and disadvantages of alternate solutions, more naturalistic theories of decision making emphasize the role of prior experiences and stories (Jonassen, under review). That is, decision makers often construct story-based scenarios that describe possible outcomes when making decisions, rather than rationally analyzing alternatives.

**Troubleshooting Problems.** Maintaining automobiles, aircraft, or any complex system requires troubleshooting (diagnosis). Debugging computer programs or finding out why a committee cannot work together also requires troubleshooting. When part of a system is not functioning properly, its symptoms have to be diagnosed and matched with the user's knowledge of various fault states (Jonassen & Hung, 2006). The primary goal of troubleshooting is fault state diagnosis and replacement or repair of the faulty part or sub-system. Troubleshooters use symptoms to generate and test hypotheses about different fault states.

**Strategic Performance Problems.** Strategic performance entails real-time, complex activities where the performers apply a number of tactical actions aimed at solving a more complex and ill-structured problem, usually under significant time pressure while maintaining situational awareness. In order to achieve the strategic objective, such as flying a commercial airplane or quarterbacking a professional football offense, the performer applies a set of complex tactical activities that are designed to meet strategic objectives. Solving these types of problems is referred to by Klein (1998) as naturalistic decision making.

**Policy Problems.** Most public problems that are described on the front pages of

newspapers or in news magazines are complex, multi-faceted issues on which multiple positions and perspectives exist. Foreign policy issues at the national level, legal issues at the state levels, and economic and development issues at the local level are examples of policy problems. Should our country invade another? Should we raise taxes? Policy problems are complicated by multiple, conflicting perspectives and underlying complexity.

**Design Problems.** Perhaps one of the most ill-structured kind of problem is design. Whether it be an electronic circuit, a mechanical part, or a new manufacturing system, design requires applying a great deal of domain knowledge with a lot of strategic knowledge resulting in an original design. Despite the apparent goal of finding an optimal solution within determined constraints, design problems usually have vaguely defined or unclear goals with unstated constraints. They possess multiple solutions, with multiple solution paths. Perhaps the most difficult aspect of design problems is that they possess multiple criteria for evaluating solutions, and these criteria are often unknown.

**Dilemmas.** Dilemmas are considered the most ill-structured kind of problem because there typically is no solution that will ever be acceptable to a significant portion of the people affected by the problem. The current dialectic about same-sex marriage is a dilemma. There are many important perspectives on the situation (constitutional, political, social, ethical, evolutionary, and religious), though none is able to offer a generally acceptable solution to the crisis. The situation is so complex and unpredictable, that a single best solution can never be known. Dilemmas are often complex, social situations with conflicting perspectives.

### *Learning to Solve Problems*

The principle assumption of this typology of problems is that solving different kinds of problems calls on different kinds of knowledge and skills (Jonassen & Hung, 2008). In medical education programs, students learn to solve diagnosis-solutions problems. In technician training, learners often learn to solve troubleshooting problems. In mechanical engineering programs, students learn to solve design problems. Given that different problems call on different skills, learning to solve different kinds of problems requires different instructional methods. One of the most basic principles of instructional design is that different learning outcomes necessitate different instructional conditions (Gagne, 1985).

## Problem-Based Learning Environments

The purpose of this paper is to suggest instructional components and cognitive scaffolds that may be combined in different ways to comprise problem-based learning environments (PBLEs). PBLE is a generic term to describe the instructional components necessary for supporting students learning to solve different kinds of problems in a PBL

setting. PBLEs may define different approaches to PBL. PBL is an instructional methodology that is:

- problem focused, in which
  - content and skills to be learned are organized by problems
  - knowledge building is stimulated by the problem and applied back to the problem.
- student centered
- self-directed
- self-reflective, with
  - tutors as facilitators

As an instructional methodology, PBL seldom distinguishes the kind of problem to be solved. Rather, PBL programs tend to treat all problems the same, utilizing similar instructional methods, which prompted Jonassen and Hung (2008) to question the kinds of problems that are amenable to PBL. In medical education programs, students learn to solve moderately ill-structured problems, specifically diagnosis-solution problems. The assumption of PBLEs is that PBL instruction should adapt instructional supports to the nature of the problem being solving. That is, PBL instruction, especially online PBL (Savin-Baden & Wilkie, 2006; Tan & Hung, 2007), often needs to support learners' efforts to develop learning scripts that will enable them to become self-directed, self-regulated learners.

Figure 2 illustrates the different instructional components and cognitive scaffolds that may be used to build problem-based learning environments (PBLEs). As expected, the problem to solve is the focus of all learning. Students cannot learn how to solve problems by learning about problem solving. They must engage with problems, make mistakes, conjecture about solutions, and argue for the best solution. In order to support learning how to solve problems, some combination of worked examples, structural analogues, case studies, prior experiences, alternative perspectives, or simulations may be accessed to help learners interpret and solve the problem.

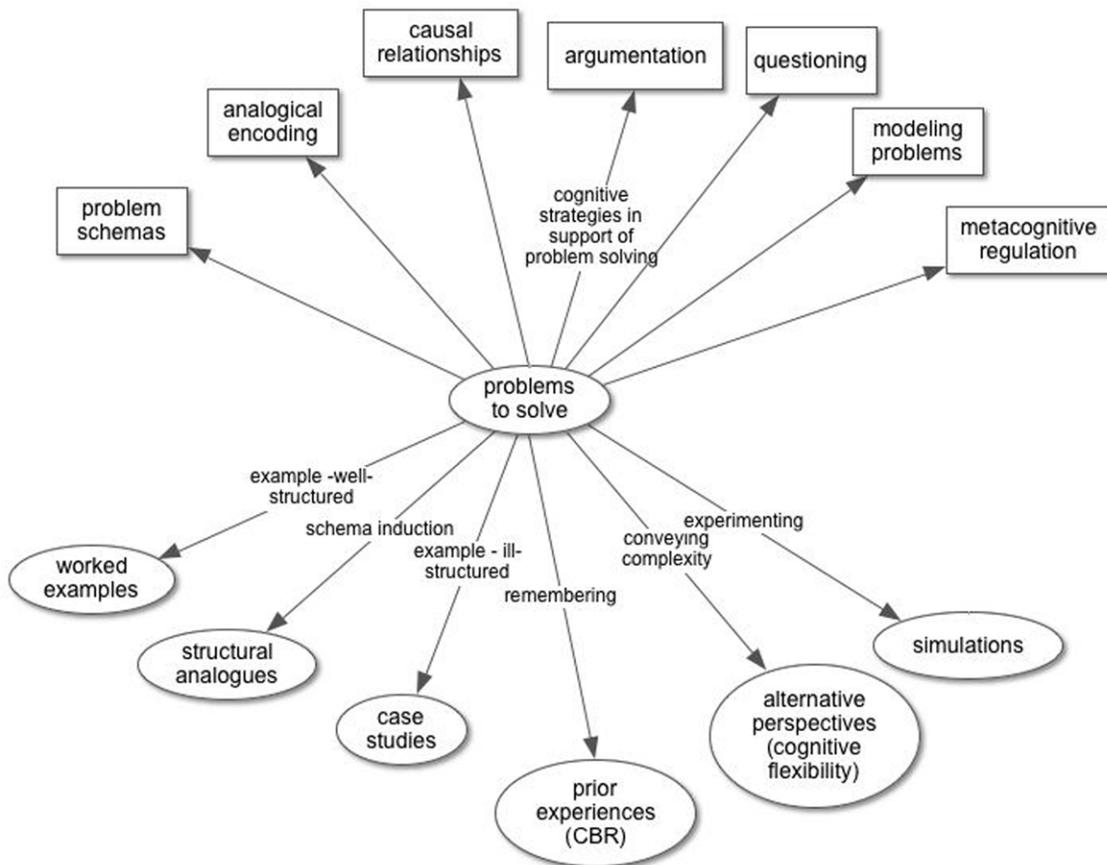
In order to direct student thinking about the problem to be solved and about how the other components of PBLEs relate to the problem to be solved, cognitive scaffolds may be layered over the problem. Scaffolds include strategies for constructing strong problem schemas using analogical encoding, explicating or mapping causal relationships, argumentation, question prompts, problem modeling activities, and metacognitive self-regulation. These components and scaffolds are described next.

### *Components of PBLEs*

The building blocks of problem-based learning environments are cases. The concept "case" has many interpretations. To professionals, a case represents "real world" examples

from their practice, such as a “case of measles” to a physician, or a “case of libel” to an attorney (Shön, 1993). For purposes of building PBLEs, a case is an instance of something that may comprise anything from a sentence level example to a complex, multi-page or video-based case study. As instructional components, most of these cases are provided to help learners make sense of the problem to be solved (see Figure 2).

**Figure 2.** Components and scaffolds for problem-based learning environments..



**Problem to Solve.** The focus of any PBLE is the problem to solve. The use of problems as the focus of learning is supported by problem-based learning principles (Hung, Jonassen, & Liu, 2008). According to those principles, learning is anchored in an authentic problem to solve. Traditional models of instruction assume that students must master content before applying what they have learned in order to solve a problem. Problem-based learning reverses that order and assumes that students will master content while solving a meaningful problem. The problem to be solved should be engaging, but should also address the curricular issues required by the curriculum. The problem provides the purpose for learning. For example, in an evolutionary biology course, we presented decision-making problems including whether to prescribe anti-nausea medications for pregnant women

experiencing morning sickness, whether to prescribe Tylenol to a child with a fever, or whether to prescribe antibiotics for a minor infection. The issue focused on the evolutionary and protective nature of these different maladies, and the PBLE presented multiple perspectives to focus the decision making. PBLEs most often present the problem to be solved as a story, embedding relevant information in the story context (Jonassen, 2011a).

Most designers assume that the problem to be solved should be complex and authentic. There are two broad conceptions of authenticity: preauthentication and emergent authenticity. Preauthentication refers to analyzing activity systems and attempting to simulate an authentic problem in a learning environment that students solve. Preauthentication is what Barab and Duffy (2000) refer to as a practice field, in which students can practice learning how to function in a disciplinary field by solving what engineering faculty members deem authentic problems. Emergent problems occur during practice within a disciplinary field, where problems are embedded in authentic settings, allowing students to learn a skill by engaging in the activities germane to that field (Barab, Squire, & Dueber, 2000). PBLEs usually engage students in solving pre-authenticated problems, which requires that the designer work with experienced practitioners to articulate the most authentic contexts.

**Worked Examples.** The most common method for supporting schema construction is the worked example. When learning to solve well-structured problems, worked examples of how to solve the problems are typically provided as a primary form of instruction. Worked examples are instructional devices that typically model the process for solving the problem (Atkinson, Derry, Renkl, & Wortham, 2000). Worked examples that focus on problem type and sub-procedures involved in the problem-solving process are cognitively very demanding. Worked examples should break down complex solutions into smaller meaningful solution elements, present multiple examples in multiple modalities for each kind of problem, emphasize the conceptual structure of the problem, vary formats within problem types, and signal the deep structure of the problem (Atkinson et al., 2000). Because research with worked examples has always focused on well-structured problems (usually story problems) with convergent solutions and solution methods (Sweller & Cooper, 1985; Ward & Sweller, 1990), it is doubtful that worked examples are effectively applicable to very ill-structured problems. How can you model a solution that is unknown?

**Structural Analogues.** Learning to solve well-structured problems can also be supported by providing analogous problems for students to compare with the problem to solve. When students compare the problem to solve with structurally similar problems, they gain more robust conceptual knowledge about the problems. There are two theoretical approaches to using cases as analogues: analogical encoding and case-based reasoning (both discussed later). Mapping analogues to problems to be solved is affected by the similarity of objects between the examples and problems being solved, especially story

lines and object correspondences. Learners often fail to recall or reuse examples appropriately because their retrieval is based on a comparison of the surface features of the examples with the target problem, not their structural features. When the target problems emphasize structural features that are shared with the example, generalization improves (Catrambone, & Holyoak, 1989). The theory that best describes the required analogical reasoning is structure mapping theory (Gentner, 1983), where mapping the analogue to the problem requires relating the structure of the analogue to the structure of the problem, independent of the surface objects in either. In order to do so, those surface features (which attract the attention of poor problem solvers) must be discarded. Then the higher-order, structural relations must be compared on a one-to-one basis between the example and the problem, a process known as analogical encoding.

**Case Studies.** The most common application of case-based learning is the case study. In case studies, students study an account (usually narratives from 1 to 30 pages) of a problem that was previously experienced. Frequently guided by questions, students analyze the situation and processes and evaluate the methods and solutions. This analysis is usually *ex post facto*. In most case studies, students are not responsible for solving the problems, only analyzing how others solved the problems and engaging in what-if thinking. Case studies are stimuli for discussions. The goals of the case study method are to embed learning in authentic contexts that require students to apply knowledge rather than acquire it. Case studies are examples of ill-structured problems that may be used to support problem schema construction for more complex and ill-structured problems. That is, students can compare case studies with complex and ill-structured problems to solve in order to construct problem schemas and consider alternative perspective and solutions.

**Prior Experiences.** Another way of supporting problem solving is by analogy to prior experiences. Prior experiences are stories about how similar problems were solved. When a new problem is encountered, most humans attempt to retrieve cases of previously solved problems from memory in order to reuse the old case. If the solution suggested from the previous case does not work, then the old case must be revised (Jonassen & Hernandez-Serrano, 2002). When either solution is confirmed, the learned case is retained for later use. Case-based reasoning is based on a theory of memory in which episodic or experiential memories, in the form of scripts (Schank & Abelson, 1977), are encoded in memory and retrieved and reused when needed (Schank, 1990; Kolodner, 1993).

In order to help students solve the encountered problem, it is necessary to find the most similar problem (perhaps case study) in an online library of annotated problem cases. The students may reuse the advice from that problem or adapt it. In order to determine the most relevant and similar stories in the library, it is necessary to index them (Jonassen & Hernandez-Serrano, 2002) in order to make them accessible to learners when they encounter a problem. Those indexes may identify common contextual elements, solutions tried, expectations violated, or lessons learned. The indexes answer the question of why

that prior experience was remembered when this problem was encountered.

**Alternative Perspectives.** Ill-structured problems tend to be more complex than well-structured problems. What makes them more complex is the variety of perspectives that are often brought to bear on the problem. For example, in any municipal decision there are almost always multiple perspectives, including the city council, the mayor, citizens, the Better Business Bureau, etc. Those perspectives represent a variety of themes including economic development, conservation, fiscal responsibility, and so on.

In complex knowledge domains or problems, the underlying complexity should be signaled to the learner, who considers alternative perspectives on the problem in order to construct personal meaning for the problem (Spiro, Coulson, Feltovich, & Anderson, 1988). Cognitive flexibility theory prescribes the use of hypertexts to provide random access to multiple perspectives and thematic representations of content. These different perspectives enable students to criss-cross the cases that they are studying through the use of multiple conceptual representations, linking abstract concepts to different cases, highlighting the interrelated nature of knowledge via thematic relations among the cases, and encouraging learners to integrate all the cases, as well as their related information, into a coherent knowledge base. The interlinkage of concrete cases and perspectives with abstract themes allows students to develop a much more complex and coherent knowledge base (Jacobson, Maouri, Mishra, & Kolar, 1995). Most ill-structured problems involve the use of cases as alternative perspectives.

**Simulations.** Problem-based learning is practice based. That is, students must practice solving problems, not learning about problem solving. You cannot effectively teach students about problem solving and expect them to be able to solve problems without practicing and receiving feedback. Simulations are environments where components of a problem are manipulated by learners, who receive feedback about the effects of their manipulations. The manipulations that are available are determined by some underlying model of the system, "the main task of the learner being to infer, through experimentation, characteristics of the model underlying the simulation" (deJong & van Jooligan, 1998, p. 179). When learners interact with the simulation, they can change values of some (input) variables and observe the results on the values of other (output) variables. These exploratory environments afford learners the opportunities to test the causal relationships among factors in the problem. The feedback provided by the system confirms or rejects students' understanding of the relationships as represented by their mental models of the problem.

Simulations vary tremendously in detail, complexity, and discipline. There are hundreds of commercially available and free laboratory simulations in the science disciplines. School students also use urban simulations such as SimCity to create and test social studies problems, and in higher education, numerous business simulations have been used for decades to train strategic decision making. A large number of medical simulations also exist to support medical training. These simulations typically present a patient, using

video, allowing the medical trainee to examine the patient, order tests, make diagnoses, and test those diagnoses (inference making) by treating the simulated patient. Those patients may be presented on a computer screen or in the form of a manipulable dummy. Some medical simulations are so complex that they allow medical personnel to conduct simulated surgery.

In commercial applications, flight simulators are an important part of pilot training. Pilots can sit in simulated cockpits that even physically move based on flight commands. These simulators can present complex and dramatic situations with which the pilots must deal. A number of planeloads of people have survived airline incidents because pilots had addressed the same problems during simulated flight training. Simulations are used extensively in the trucking industry as well, where driver trainees encounter various road conditions and navigate potential accident situations. Of course, the military uses simulations in numerous aspects of its training program, especially urban warfare. Among the obvious advantages of simulation use is the ability to learn through mistakes without harming anyone.

### *Cognitive Scaffolds in PBLEs*

Studying worked examples, structural analogues, case studies, prior experiences, alternative perspectives, and simulations in relation to the problem to be solved enhances students' understanding of the problem and their abilities to solve it. In order to learn to solve problems, students must learn how to relate various case components to the problem to be solved. Next, I describe different forms of cognitive scaffolds that can assist students during their analyses and comparisons of those building blocks. These cognitive scaffolds focus student attention on important relationships among the elements in the problem as well as between problems.

**Analogical Encoding.** Analogical encoding is the process of mapping structural properties between multiple analogues. Rather than attempting to induce and transfer a schema based on a single example, comprehension, schema inducement, and long term transfer across contexts can be greatly facilitated by analogical encoding, which involves the comparison of two analogues for structural alignment (Gentner, & Markman, 1997, 2005). When learners directly compare two examples, they can identify structural similarities. If presented with just one example, students are far more likely to recall problems that have similar surface features. Analogical encoding fosters learning because analogies promote attention to commonalities, including common principles and schemas. During analogical encoding, students must compare analogous problems for their structural alignment. Problems are structurally aligned when the relationships (arguments) among problem elements match (Gentner & Markman, 1997).

In order to implement analogical encoding in PBLEs, rather than modeling how to

solve a problem, learners are provided with one or more structurally similar problems and are required to identify how the problems are similar. Are they the same kind of problem? Do they contain the same elements? Likewise, providing learners with structurally dissimilar problems and requiring them to identify how the problems are structurally dissimilar will help them to develop stronger problem schemas (mental models of different kinds of problems).

**Causal Reasoning.** When comparing the structures of cases, the designer and the students must examine the underlying causal relationships among the elements in the problem. Understanding the causal relationships among problem elements is essential for comprehension and transfer. Understanding causal relationships means the students can make predictions and inferences involved in a problem. Reasoning from a description of a condition, set of conditions, or states of an event to infer the possible effect(s) that may result from those states is called prediction. Predictions are used for forecasting events (e.g., economic or meteorological forecasts) and testing hypotheses to confirm or disconfirm scientific assumptions (e.g., predicting the effects of a hormone on an animal's growth rate). When an outcome or state exists for which the causal agent is unknown, then an inference is required. A primary function of inferences is diagnosis, as in medicine. Based on symptoms, historical factors, and test results of patients, a physician attempts to infer the cause(s) of that illness state.

In order to understand causal relationships well enough to make predictions and inferences embedded within problems, students must comprehend both the covariational and mechanistic attributes of the relationships (Ahn, Kalish, Medin, & Gelman, 1995). Covariation is the degree or extent to which one element consistently affects another, which is expressed quantitatively in terms of probabilities. The mechanism describes the causal relationship in terms of its qualitative effects. Why does X cause Y?

Helping students to understand the causal relationships among the elements in any problem will help them to develop qualitative understanding of the underlying mechanisms in those relationships (Jonassen & Ionas, 2008). That can be accomplished by providing influence diagrams (causal diagrams) or requiring learners to build causal maps, expert systems, or systems dynamics models of the problems they are solving. It is important to require students to construct these qualitative models before using quantitative models, such as equations (Ploetzner & Spada, 1998).

**Questioning.** Questioning aids problem solving in many ways. Answering deep-reasoning questions articulates causal processes as well as goals, plans, actions, and logical justification (Graesser et al, 1996), all of which are essential processes for solving problems. During problem solving, questions are essential for guiding students' reasoning as they work to comprehend the problem and generate solutions. Question-driven explanatory reasoning predicts that learning improves to the extent that learners generate and answer

questions requiring explanatory reasoning (Graesser et al, 1996). Questions can be included anywhere in PBLEs in the form of inserted questions to support thinking at the moment of need. By embedding questions in learning environments, students can practice and learn to generate their own deep-level questions, which is predictive of problem solving abilities (Ge & Land, 2003). Finally, questions may form the primary interface in the form of an Ask System (Jonassen, 2011b). An Ask System is an interface comprised of a sequence of questions that function as links to different information.

**Argumentation.** Although problems differ, argumentation is an essential skill in learning to solve most, if not all, kinds of problems, as well as a powerful method for assessing problem solving ability for both ill-structured and well-structured problems alike (Jonassen, 2011a). When students answered well-structured physics problems incorrectly and later constructed an argument for the scientifically correct answer, Nussbaum and Sinatra (2003) found that those students showed improved reasoning on the problems. When the students were retested a year later, the quality of their reasoning remained strong. This strategy engages students in refuting misconceptions. As in the case of Nussbaum and Sinatra (2003), students are refuting their own misconceptions.

Argumentation plays a more obvious role in the solution of ill-structured problems. Cho and Jonassen (2003) showed that the production of coherent arguments to justify solutions and actions is a more important skill for solving ill-structured problems than for well-structured problems. Ill-structured problems are the kinds of problems that are encountered in everyday practice. Such problems have alternative solutions; vaguely defined or unclear goals and constraints; multiple solution paths; and multiple criteria for evaluating solutions, so they are more difficult to solve (Jonassen, 2000). Groups that solved ill-structured economics problems produced more extensive arguments. Because ill-structured problems do not have convergent answers or consistent solution criteria, learners must construct arguments to justify their own assumptions, solution paths, and proposed solutions.

When students are learning to solve ill-structured problems that do not necessarily have correct solutions or known solution criteria, the best evidence of problem-solving ability can result from construction of arguments to support the solution that is selected. Students will often propose different solutions, so it is important that student arguments contain not only their preferred solution and reasons to support their solutions, but also identification of counterarguments, reasons that others may provide to support those arguments, and rebuttals to those counterarguments. For example, student arguments should contain:

- What is your solution to this problem?
- Why is it the best solution?
- What evidence supports those reasons?

- What solutions might others recommend?
- What reasons would others provide to support their solutions?
- What evidence did they provide to support their reasons?
- How would you argue against their reasoning?

**Modeling.** “Scientific practice involves the construction, validation, and application of scientific models, so science instruction should be designed to engage students in making and using models” (Hestenes, 1996, p. 1). Mental models are enhanced and confirmed by the construction of external models. Those models may be quantitative (equations) or qualitative. Students in the sciences and engineering often provide only quantitative models of problems by solving equations. If they do not construct qualitative models, such as causal maps or concept maps, they may fail to understand the problem or its lessons. Both are essential to understanding and solving problems. Several types of modeling tools including databases, concept maps, expert systems, systems dynamics tools, and graphic tools may be used to construct external models (Jonassen, 2006). While students are analyzing problems, they should be constructing models of the components and relationships in the problem. Those models will help students to hypothesize and confirm solutions to the problem.

### Which Components and Scaffolds Support Different Kinds of Problem-Solving?

Which components and cognitive scaffolds are necessary to support students learning how to solve different kinds of problems? In this brief section, I make some warranted suggestions, however, most of them, as well as other implications, require empirical testing. The majority of research on problem solving has focused on solving story problems, so little advice is available on how to solve other kinds of problems.

In principle, when students are learning to solve well-structured problems, components should include the problem to solve, such as a typical physics problem, worked examples to model how to solve the problems, and structural analogues to help students understand what kind of problem they are solving—that is, to construct problem schemas. Cognitive scaffolds should include analogical encoding to foster problem comparison, causal reasoning to explicate the elements of the problem and their relationships, and perhaps modeling of the problem and questions to direct student attention.

For ill-structured problems, case studies, prior experiences (based on case-based reasoning), and alternative perspectives (based on cognitive flexibility theory) may be accessed to help learners interpret and solve the problem. Simulations are also useful for trying solutions to all kinds of problems. Cognitive scaffolds should include argumentation, not only as a learning strategy but also as the most effective means for assessing

the ability to solve ill-structured problems. Modeling complex, ill-structured problems may also elicit better understanding. The more complex the problem, the more important self-regulation becomes. Often, self-regulation is focused by questions inserted into instructional materials.

Table 1 provides a list of recommended components for different kinds of problem-based learning environments. Although there exists empirical support for some of the instructional components and scaffolds recommended, many of my recommendations require empirical validation. Rather than positing these recommendations as truths, I present them as hypotheses that will require myriad studies to support. I believe that the field of instructional design should focus more of its research and development efforts on problem solving, because, as stated at the beginning of this article, in everyday life and work, problem solving is a ubiquitous activity.

**Table 1.** Case and scaffold requirements by problem type..

<b>Problem type</b>	<b>Case Components</b>	<b>Cognitive Scaffolds</b>
Story	Problems, Examples, Analogues	Analogical, causal, questioning, argumentation, modeling
Rule-using/induction	Examples, problems, analogues	Analogical, causal, questioning
Decision making	Problem, case studies, prior experiences, alternative perspectives	Causal, argumentation, modeling (scenario construction)
Troubleshooting	Problems, prior experiences	Causal, argumentation, modeling
Policy analysis	Case studies, problems, prior experiences, alternative perspectives	Analogical, questioning, argumentation, modeling
Design	Problems, prior experiences, alternative perspectives	Causal, argumentation, modeling
Dilemmas	Case studies, alternative perspectives	Argumentation

### Summary

This paper has outlined an evolving theory of problem solving, which is the focus of problem-based learning. Problem-based learning is an instructional methodology that is too often uniformly applied to all kinds of problems, regardless of the nature. Most PBL

research has focused on learning how to solve moderately ill-structured problems, such as diagnosis-solution problems in medicine. My assumption is that there are different kinds of problems. Perhaps the most fundamental principle of instructional design is that different learning outcomes require different instructional conditions. In this paper, I have described a variety of instructional conditions that affect learning to solve problems and have suggested which of those conditions may be most effective for supporting different kinds of problems. Validating these recommendations would require hundreds, if not thousands, of empirical studies. It is my hope that researchers will find those challenges sufficiently compelling to research.

**Note:** The model of problem solving described in this brief paper is described more completely in Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments*. New York: Routledge.

## References

- Ahn, W., Kalish, C. W., Medin, D. L., & Gelman, S. (1995). The role of covariation versus mechanism information in causal attribution. *Cognition, 54*, 299-352.
- Armarego, J. (2002). Advanced software design: A case in problem-based learning. IEEE Computer Society: Proceedings of the 15th Annual Conference on Software Engineering Education and Training.
- Atkinson, R., Derry, S. J., Renkl, A. & Wortham, D. (2001). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research, 70*, 181-215.
- Barab, S. A., & Duffy, T. M. (2000). From practice fields to communities of practice. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 25-55). Mahwah, NJ: Lawrence Erlbaum Associates.
- Barab, S. A., Squire, K. D., & Dueber, W. (2000). A co-evolutionary model for supporting the emergence of authenticity. *Educational Technology Research & Development, 48*(2), 37-62.
- Catrambone, R; Holyoak, K.J. (1989). Overcoming contextual limitations on problem-solving transfer. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(6), 1147-1156.
- Cho, K.L., & Jonassen, D.H. (2003). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research & Development, 50*(3), 5-22.
- Cline, M.J., & Powers, G. J. (1997). Problem based learning in a chemical engineering undergraduate laboratory. *IEEE Frontiers in Education, 350*-354.
- DeJong, T., & van Joolingen, W.R. (1998). Scientific discovery learning with computers simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.
- Dunlap, J. C. (2005). Problem-based learning and self-efficacy: How a capstone course prepares students for a profession. *Educational Technology Research and Development, 53*(1), 65-85.

- Gagne, R.M. (1985). *The conditions of learning and theory of instruction*. Fort Worth, TX: Holt, Rinehart, & Winston.
- Ge, X., & S.M. Land. 2003. Scaffolding students' problem-solving processes in an ill-structured task using question prompts and peer interactions. *Educational Technology Research and Development* 51(1), 21–38.
- Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 77, 155-170.
- Gentner, D., & Markman, A.B. (1997). Structure mapping in analogy and similarity. *American Psychologist*, 52(1), 45-56.
- Henry, H., Jonassen, D.H., Winholtz, R.A., & Khana, S.K. (2010, November). Introducing problem-based learning in a materials science course in the undergraduate engineering curriculum. Proceedings of the ASME International Conference IMECE2010, Vancouver, Canada of Cognitive Science, 6, 1-20.
- Hestenes, D. (1996). Modeling methodology for physics teachers. Proceedings of the International Conference on Undergraduate Physics Education, College Park, MD.
- Hung, W., Jonassen, D.H., & Liu, R. (2008). Problem-based learning. In J.M. Spector, J. G. van Merriënboer, M.D., Merrill, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology, 3rd Ed.* (pp. 485-506). New York: Lawrence Erlbaum Associates.
- Jacobson, M. J., Maouri, C., Mishra, P., & Kolar, C. (1995). Learning with hypertext learning environments: theory, design, and research. *Journal of Educational Multimedia and Hypermedia*, 4, 321-364.
- Jonassen, D.H. (2000). Toward a design theory of problem solving. *Educational Technology: Research & Development*, 48 (4), 63-85.
- Jonassen, D.H. (2006). *Modeling with technology: Mindtools for conceptual change*. Upper Saddle River, NJ: Prentice-Hall.
- Jonassen, D.H. (2007). What makes scientific problems difficult? In D.H. Jonassen (Ed.), *Learning to solve complex, scientific problems* (pp. 3-23). Mahwah, NJ: Lawrence Erlbaum Associates.
- Jonassen, D.H. (2011a). *Learning to solve problems: A handbook for designing problem-solving learning environments*. New York: Routledge.
- Jonassen, D.H. (2011b). Ask systems: Interrogative access to multiple ways of thinking. *Educational Technology: Research and Development*, 59, 159-175.
- Jonassen, D. H. (under review). Designing for decision making. *Educational Technology Research and Development*.
- Jonassen, D.H. & Hernandez-Serrano, J. (2002). Case-based reasoning and instructional design: Using stories to support problem solving. *Educational Technology: Research and Development*, 50(2), 65-77.
- Jonassen, D.H., & Hung, W. (2006). Learning to troubleshoot: A new theory-based design architecture. *Educational Psychology Review*, 18, 77-114.
- Jonassen, D.H., & Hung, W. (2008,). All problems are not equal: Implications for PBL. *Interdisciplinary Journal of Problem-Based Learning*, 2(2), 6-28.
- Jonassen, D.H. & Ionas, I.G. (2008). Designing effective supports for causal reasoning. *Educa-*

- tional Technology Research & Development*, 56, 287-308.
- Klein, G. (1998). *Sources of power*. Cambridge, MA: MIT Press.
- Kolodner, J. (1993). *Case-based reasoning*. New York: Morgan Kaufman.
- LaPlaca, M C. Newstetter, W C. Yoganathan, A P. (2001). Problem-based learning in biomedical engineering curricula. Proceedings - Frontiers in Education Conference. 2, F3E/16-F3E/21 (IEEE cat n 01CH37193).
- Mitchell G.G., & Delaney, J. D. (2004). An assessment strategy to determine learning outcomes in a software engineering Problem-based learning course. *International Journal of Engineering Education*, 20, 494- 502
- Nussbaum, E.M., & Sinatra, G.M. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology*, 28, 384-395.
- Ploetzner, R., & Spada, H. (1998). Constructing quantitative problem representations on the basis of qualitative reasoning. *Interactive Learning Environments*, 5, 95-107.
- Savin-Baden, M., & Wilkie, K. (2006). *Problem-based learning online*. Milton-Keynes, UK: Open University Press.
- Schank, R. C. (1990). *Tell me a story: Narrative and intelligence*. Evanston, IL: Northwestern University Press.
- Schank, R. & Abelson, R. (1977). *Scripts, plans, goals, and understanding: An inquiry into human knowledge structures*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sherrill, J. M. (1983). Solving textbook mathematical word problems. *Alberta Journal of Educational Research* 29(2), 140–152.
- Shön, D. A. (1993). *The reflective practitioner: How professionals think in action*. New York: Basic Books.
- Spiro, R., Coulson, R., Feltovitch, P., & Anderson, D. (1988). *Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains*. Paper presented at the Tenth Annual Conference of the Cognitive Science Society, Hillsdale, NJ.
- Sweller, J., & Cooper, G. A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction*, 2, 59-89.
- Tan, O. S., & Hung, D. (2007). *Problem-based learning in e-learning breakthroughs*. Singapore: Thomson Learning.
- Van Kampen, P., Nanahan, C., Kelly, M., McLoughlin, E., & O'Leary, E. (2004). Teaching a single physics module through problem based learning in a lecture-based curriculum. *American Journal of Physics*, 72(6), 829-834.
- Ward, M., & Sweller, J. (1990). Structuring effective worked examples. *Cognition and Instruction*, 7(1), 1-39.

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