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All Problems are Not Equal: Implications for Problem-Based Learning

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All Problems are not Equal: Implications for Problem-Based Learning

David H. Jonassen and Woei Hung

Abstract

Problem-based learning (PBL) is an instructional model that assumes the centrality of problems to learning. Research on PBL has focused on student learning, student roles, tutor roles, problem design, and technology use (Hung, Jonassen, & Liu, 2008), but little attention in the PBL literature has been paid to the nature of the problems that provide the focus for PBL. In this paper, we articulate a model for evaluating problem difficulty. Problem difficulty is define in terms of complexity, including breadth of knowledge, attainment level, intricacy of procedures, relational complexity, and problem structuredness including intransparency, heterogeneity of interpretations, interdisciplinarity, dynamicity, or competing alternatives. Based on these characteristics, we identify four classes of problems and then describe three different kinds of problems: decision-making, diagnosis-solution, and policy problems. We then examine the amenability of these classes and problem types as foci for PBL curricula. Finally, we challenge PBL researchers and designers to consider the issue of problem difficulty in articulating PBL curricula.

Keywords: problem solving, problem difficulty, problem complexity, problem structuredness

Centrality of Problem Solving

In everyday life and professional workplaces, people expend their greatest intellectual effort solving problems. According to the SCANS Report, problem solving is an essential thinking skill for workers (US Department of Labor, 1991). The Accreditation Board for Engineering and Technology (ABET, 2007) specified the abilities to identify, formulate, and solve engineering problems as essential learning outcomes for any engineering program. The National Council of Supervisors of Mathematics claimed, "Learning to solve problems is the principal reason for studying mathematics" (NCSM, 2000, p. 1). Workers solve problems (e.g., technicians troubleshoot; engineers design products, processes, or systems; physicians diagnose; managers plan). In our everyday lives, we all solve problems (e.g., diagnose the source of a toddler's irritation; decide which health plan is most effective; plan

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home decorations). Because of the centrality of problem solving to work and everyday life, problem solving should also be central to education (Cognition and Technology Group at Vanderbilt, 1990; Middleton, 2002; Schaafstal, Johnston, & Oser, 2001; Vye, Goldman, Voss, Hmelo, & Williams, 1997).

Advocates of problem-based learning (PBL) assume problem solving should be the intellectual focus of curricula (see, for example, Barrows, 1986, 1996; Barrows & Tamblyn, 1980; Dunlap & Grabinger, 1996; Gijbels, Dochy, van den Bossche, & Segers, 2005; Norman & Schmidt, 1992; Savery & Duffy, 1996; Schmidt, 1983). In PBL curricula, as Perrenet, Bouhuijs, and Smits, (2000) suggested, learners solve problems, self-direct their learning by collaboratively assuming responsibility for generating learning issues and processes through self-assessment, and monitor their understanding by learning to adjust strategies for learning. In scrutinizing advocates' claims of the advantages of PBL, Norman and Schmidt (1992) conducted a review of the evidence from PBL research. They found that PBL students consistently retain knowledge, especially more principled knowledge, for longer periods of time than students in a traditional curriculum (see also Shahabudin, 1987); apply basic science knowledge and transfer problem-solving skills in real world professional or personal situations more effectively; and become more self-regulated (see also Vernon & Blake, 1993), lifelong learners.

The primary question that we address in this paper is the amenability of PBL methods to different kinds of problems. The success of PBL has been most commonly demonstrated in medical schools where students learn to solve diagnosis-solution problems, which are moderately ill structured (Jonassen, 2000). The goal of diagnosis is to find the source of the physiological anomaly; however, there are numerous paths that can lead to a diagnosis (Jonassen & Hung, 2006). In the treatment or management part of the process, the problem often becomes more ill structured because of multiple treatment options, patient beliefs and desires, insurance companies, and so on.

PBL has been applied globally in a variety of professional schools (Boud & Feletti, 1991; Gijselaers et al., 1995; Wilkerson & Gijselaers, 1996). Furthermore, the types of the problems being used in PBL vary from one area to another, depending upon the nature of the discipline. For example, PBL students in architecture (Donaldson, 1989; Maitland, 1998), chemical engineering (Woods, 1996), and engineering studies (Cawley, 1989) solve design problems. PBL in nursing (Barnard, Nash, & O'Brien, 2005; Higgins, 1994), social work (Bolzan & Heycox, 1998), and teacher education (Oberlander & Talbert-Johnson, 2004) primarily deals with diagnosis-solution problems. Business administration (Merchand, 1995) and leadership education (Bridges & Hallinger, 1995, 1996; Cunningham & Cordeiro, 2003) focus on decision-making and policy analysis problems. In law schools (Boud & Feletti, 1991; Kurtz, Wylie, & Gold, 1990; Pletinckx & Segers, 2001), PBL students learn to construct arguments, based on evidentiary reasoning, to solve a complex form of rule-using problems.

PBL is becoming increasingly popular in graduate business programs, where students primarily solve case analysis problems that are fairly ill structured. As PBL continues to migrate to other academic disciplines, research needs to consider the nature of the problems being solved and how efficacious PBL methodologies are for those kinds of problems. When Jacobs, Dolmans, Wolfhagen, and Scherpbier (2003) surveyed medical students with a questionnaire based on Jonassen's (2000) continuum of structuredness and complexity of problems, they found that students weighted the importance of problem structuredness more heavily than problem complexity, suggesting that students preferred some degree of structuredness to identify a solution more easily. While we know that student perceptions of problem difficulty affect their willingness to engage with problems, in this paper we examine what kinds of problems are likely to be most successful in PBL methods. For example, can PBL be adapted to word problems in physics, despite the inauthentic nature of those problems? How successful can engineering design problems, which are one of the most complex and ill-structured kinds of problem (Goel & Pirolli, 1989; Jonassen, 2000; Simon, 1973), be adapted to PBL methods? The overarching question is: What is the range of problem difficulty that allows for effective learning using PBL methods?

Problem Difficulty

Among the issues in PBL research, problem difficulty has received little attention. Most often, teachers or instructional designers use their best judgment to determine an appropriate difficulty level based mainly on their experiences or intuition. Problem difficulty is also obtained ex post facto, based on students' performances solving different problems. For instance, Wood described difficulty as "a gauge of how likely the problem is going to be solved correctly or appropriately" (1985, p. 46). As median performance decreases, problems are perceived as more difficult. So problem difficulty is the probability of it being successfully solved. This probability is a function of a number of factors that constitute a problem-solving process, which can be expressed in forms of mathematical formulae. However, because these formulae were derived using well-structured story problems, they offer little advice to PBL designers on the nature of problems that may be amenable to PBL.

Defining problem difficulty is a complex process. Jonassen (2007a) suggests that several external and internal factors contribute to problem difficulty. Internal factors are those internal to the learners, including level of domain knowledge (Greeno, 1980; Hayes, 1989; Rittle-Johnson & Alibali, 1999); experience in solving problems (Bereiter & Miller, 1989); reasoning skills, especially causal reasoning and analogical reasoning (Jonassen, 2007b); and epistemological development, especially for more complex and ill-structured problems (Dunkle, Schraw, & Bendixen, 1995; Wood, Kitchener & Jensen, 2002). These factors are seldom under the control of the teacher or professor, and so we will not examine their role any further regarding their applicability to PBL.

The difficulty of problem solving is also attributable to external factors, those that are external to the learner and endemic to the nature of the problem, such as abstraction and continuity. Bassok (2003) explained these two important external attributes of problems: *abstraction* refers to the representation of the content and context of a problem that either facilitates or impedes analogical transfer of one problem to another. Most classroom problems are more abstract than most everyday problems, which are embedded in various contexts. *Continuity* of the problem is the degree to which attributes of problems remain the same or change over time (described later as dynamicity). High continuity problems are more easily solved and transferred than low continuity problems.

In this paper, we further describe external factors that affect problem difficulty, which in turn will have some effect on their applicability for PBL. Next, we describe two primary external factors that account for problem difficulty: complexity and structuredness. We describe complexity as a dimension that addresses the known portion of the problem and structuredness as a dimension that deals with the unknown portion of the problem.

Complexity of Problems

Kotovsky, Hays, and Simon (1985) contend that the degree of difficulty of a problem is determined by the size of problem space, which consists of the "number of branches at each node and depth of search to a solution node" (p. 248). The more inherent the nodes and branches of a problem, the more difficult the problem is to solve. Complexity of a problem manifests itself in a number of forms, including the breadth of knowledge required, the difficulty level of comprehending and applying the concepts involved, the skill and knowledge levels required to solve the problem, and the degree of nonlinearity of the relations among the variables within the problem space. These four major parameters should be examined when determining the degree of complexity of a problem.

Breadth of Knowledge Required

Simply stated, how much domain knowledge does the problem solver need in order to solve the problem? This parameter determines the scale of a problem. Kotovsky et al. (1985) contended that the difficulty of problems varies positively with the size of problem space. Generally, the greater the amount of general and domain knowledge required for solving a given problem, the greater the size of the problem space, and therefore, the more complex the problem. This knowledge includes the factual information, concepts, principles, and procedures needed for solving the problem (Sugrue, 1995). For example, designing a football stadium equipped with a retractable roof is much more complex than designing a simple aluminum warehouse because it involves much more advanced architecture, structural engineering, civil engineering, and other related knowledge. From a cognitive perspective, when a problem solver is required to possess and apply a large amount of knowledge, the degree of the complexity of the task will vary with at least three factors: 1) the number of individual pieces of information needed to be processed, 2) the number of interrelationships needed to be understood and processed, and 3) cognitive load (van Merriënboer, 1997) or processing load (Halford, Wilson, & Phillips, 1998). Thus, the greater the number of pieces of knowledge and information involved in the problem solving process, conceivably, the higher degree of complexity of the problem.

Attainment Level of Domain Knowledge

Kotovsky et al. (1985) stated that problem difficulty is a function of the difficulty of the concepts that must be applied to solve the problem. When the concepts involved in solving one particular problem are difficult for learners to grasp, most likely, the problem is more difficult to solve. Attainment level has different characteristics. First, the level of advancement of the concepts being used will determine problem difficulty. Although small in proportion, many engineering problems require the use of differential calculus or differential equations to solve, while others require only algebra or no mathematics at all. The former kind of problem is deemed more complex because of the sophistication level of the formalism needed to represent it.

Another related aspect is the degree of abstractness of the concepts. For example, legal problems are often complex because of the intangible nature of the legal concepts being applied. Abstract concepts usually have a lower degree of perceptibility, which largely accounts for students' difficulty in learning the concepts (Carey, 2002). Therefore, the more abstract the concepts required for understanding the problem and performing the problem solving process, the more complex and difficult the problem is.

When concepts are difficult for students to grasp, a natural consequence is that students will have difficulty applying the concepts during problem solving. Students can experience difficulty in applying concepts during problem solving even though they have demonstrated basic understanding of the concepts (Hung & Jonassen, 2006). For example, students may understand the concepts of and relationships between angular velocity, radians, and revolutions when given an example of a figure skater spinning; however, they may still have difficulty solving end-of-chapter physics problems that involve the same concepts.

Intricacy of Problem-Solution Procedures

The third parameter for assessing the complexity of a problem is the intricacy of the problem-solution process. This is called solution path length (Hays & Simon, 1974). This parameter includes the number of steps to be executed in a solution path and the extent of complexity of the tasks and procedures in these steps. Frensch and Funke (1995) described these tasks as barriers that the problem solver has to overcome in order to close the gap between the initial and goal states of the problem space. Quesada, Kintsch, and Gomez (2005) referred to this as computational complexity, which is measured by the time needed to solve a problem. For example, the solution tasks and procedures for solving a faulty alternator problem in a car are much more complex and lengthy than a dead battery problem.

Relational Complexity

Halford, Wilson, and Phillips (1998) described relational complexity as the number of relations that need to be processed in parallel during a problem solving process, much like cognitive load. The more complex the relations in a problem, the more processing load is required during problem solving, and as a result, the more complex the problem is. Also, the number of attributes (e.g., A→B, A←B, A←→B) in a given relation affects the degree of complexity. For example, describing the function of systems using bidirectional relations are more complex than using unidirectional, linear relations. At the introductory stage of learning, the ability to solve a problem involving one or two concepts or principles in a linear, sequential order is sufficient. However, as Spiro and his colleagues have argued (Feltovich, Spiro, & Coulson, 1989; Spiro, Coulson, Feltovich, & Anderson, 1988), learning and solving problems at more advanced stages often require an application of a more relationally complex body of knowledge. A higher degree of relational complexity is inherent in the advanced stage of learning in most subject areas, such as science, biology, or engineering. Furthermore, real-life problems rarely possess only one single line and type of relation among their variables, and therefore, there will not be one single, simple, straightforward solution path to the problem.

Structuredness of Problems

The dimension of complexity describes problems in terms of the breadth, attainment level, intricacy, and interrelatedness of the problem space. Structuredness, on the other hand, describes problems in terms of the transparency, stability, and predictability of the problem space. Wood (1983) defined the structuredness of a problem as the degree to which the ideas in the problem are known or knowable to the problem solver. The factors that characterize the structuredness of a problem include known versus vaguely defined or unknown states of the problem (initial state, goal state, and operators), regular versus unconventional uses of rules and principles involved, stated constraints versus hidden constraints, predictable operators versus highly unpredictable and unprescribed operators, a preferred and prescribed solution versus multiple viable solutions, and definite versus vague criteria for evaluating the solutions (Jonassen, 1997). These characteristics can be categorized into four parameters of the structuredness of problems: intransparency, heterogeneity of interpretations, dynamicity, and legitimacy of competing alternatives.

Intransparency

Many researchers agree that unknowns in the problem space is one of the features that make problems ill structured (Frensch & Funke, 1995; Spering, Wagener, & Funke, 2005). The higher the degree of intransparency (that is, the more we do not know about the problem), the more ill structured the problem is. For example, predicting weather is considered an extremely difficult task because it contains a great number of variables about which forecasters are uncertain. In order to solve a problem that contains unknowns in the problem space, the problem solver must solve the problem based on assumptions or guesswork. These assumptions or guesswork inevitably reduce the problem solver's confidence level in successfully solving a problem. For example, in Jonassen's (2000) typology of problem types (see Figure 1), troubleshooting problems are less ill structured than diagnosis-solution problems. The reason for differentiating the degree of structuredness of these two categories of problems is their degree of intransparency. Troubleshooting problems usually refer to pinpointing the fault in a man-made system (machinery, computer system, networking system, refrigeration system, etc.), while diagnosis-solution problems often refer to diagnosing and treating human physical and psychological illnesses. Although the troubleshooting and diagnosis part of diagnosis-solution problems are similar for both categories of problems, the extent of the unknown (intransparency) in the respective problem spaces is different. Diagnosis-solution problems inherently present a more ill structured problem space because there are unknowns in human physiology, the legal and economic, social, ethical, and religious aspects of treatments decreed by insurance companies, the patient's biases and beliefs, and the family's wishes. These unknowns may have significant impact on the treatment regimen recommended by the physician or psychiatrist.

Heterogeneity of Interpretations

The second parameter of structuredness is described by the number of possible interpretations and perspectives for understanding or solving the problem. The more open

Figure 1. *Typology of problem types (Jonassen, 2000).*

the problem is to interpretation, the more ill-structured the problem will be. There are problems, like political or economic problems, that are wide open to interpretation, depending on the point of view of the stakeholders who have unique interests or beliefs. How a problem solver interprets the problem (initial state) will naturally lead to diverse and sometimes conflicting interpretations about the goal state of the problem, the necessary operators, and the constraints that restrict or regulate the operators.

There are two types of interpretations commonly seen in problems. The first type is the vaguely defined problem that is open to multiple interpretations. When the problem is vaguely defined, it is considered highly ill structured. This type of problem is open to interpretation in terms of its initial state (what is the problem?), goal state (what is trying to be achieved?), and constraints (what are the rules or barriers?). For example, the goal state of the Hanoi Tower problem is very clear (moving all three disks to the third peg). Reducing the amount of CO^2 emissions into the atmosphere to decelerate global warming seems definite at first glance. However, the forms of the goal state of reducing CO^2 emissions into the atmosphere are much more vague. For instance, to what level should CO^2 emissions be reduced to be considered having reached the goal state of decelerating global warming? What are the criteria for determining the level? When is the goal reached?

A second type of interpretation relates to viable solutions. For example, during the Cuban missile crisis in the 1960s, the military wanted to annihilate Cuba, which President Kennedy refused to accept as a viable solution. In most design problems (e.g., instructional design problems), given any learning problem, there are an infinite number of solutions. However, only a subset of those solutions is viable, given the constraints that surround the problem.

Both types of interpretation vary with different individuals or interest groups viewing the problem. When there are multiple parties involved in a problem situation, the interpretations of the problem, approaches to the problem, form of the goal state, and nature of the constraints are likely to be interpreted differently by different parties because of different interests, beliefs, standards, or cultures. For example, the issue of stem-cell research can be interpreted and approached from scientific, medical, social justice, or religious points of view, which result in diverse and perhaps conflicting interpretations, arguments, reasoning, logic, ways of approaching the problem, and solutions. A simple principle for assessing a problem's openness regarding multiple perspectives is the more parties involved in the problem situation whose interests are conflicting with others, the more ill-structured the problem; for example, the Israel and Palestine conflict, or the abortion issue.

Interdisciplinarity

The third parameter is interdisciplinarity. The degree of interdisciplinarity affects the level of problem structuredness in two ways. First, it infuses a variable of degree of comprehensiveness. When a problem requires interdisciplinary knowledge or considerations to solve, one critical element to successfully solve the problem is making sure that all facets (disciplines) have been taken into account. It is not always clear, however, what and how many disciplines are involved when the problem is first encountered. Thus this uncertainty introduces some degree of difficulty in constructing a complete problem space. Second, the different disciplines of the problem are closely interconnected and interdependent. Unanticipated issues, which emerge from the operations in an interdisciplinary environment, are not uncommon. Furthermore, because of the interdependency of the various disciplines, changing a subdecision in one area will subsequently affect others. As a result, the task of balancing all aspects of the problem makes solving this type of problem a challenge.

Most everyday and professional problems are interdisciplinary in nature, which makes them lean more toward being ill structured. The front page of any newspaper normally contains stories about local issues, such as whether to build a new water treatment plant. Such a problem has social, political, economic, environmental (biological), historical, and personal implications. Such problems cannot be understood or solved by considering only one disciplinary perspective. Each perspective needs to be addressed and integrated into the problem space and the problem solution. Unfortunately, interdisciplinary approaches are not supported well by formal education institutions that divide and identify problems in terms of strict disciplinary perspectives.

Dynamicity

In searching for an agreeable definition of complex problems, Frensch and Funke (1995) asked a number of contemporary researchers to provide their definitions. Dynamic was one of the defining properties that appeared in many researchers' definitions. The dynamic nature of variables or operators contributes greatly to the ill-structuredness of the problem. This concept is not new. In 1976, Greeno argued that the operators within the problem space and the form of the goal state of the problem will dynamically change with the decision made or action taken by the problem solver, for example "if the goal is '(A and B) or (not-A and C),' then if the problem solver produces C, the feature not-A is required, but if B has been produced, then A is required" (p. 480). In addition to goal state, the dynamic property of ill-structured problems can be seen in various states of operators as well. For example, in chess, a player's available moves at a given time are not determined until after the opponent has made his or her move.

Dynamic variables are often emergent. There are emergent properties in some cases that only appear in response to the changes of other related variables or states of the problem or certain actions taken by the problem solver. In cases of emergent variability, certain constraints or properties will not emerge until certain operators have been chosen and executed (Capra, 1996). For example, in the 1950s, gray wolves in Yellowstone National Park were systematically killed to extinction to solve the farmers' problem of keeping livestock from becoming prey to the wolves. However, the extinction of gray wolves in Yellowstone caused a missing link in the area's ecological system, which consequently created an imbalanced ecological system and introduced different problems (e.g., the extermination of gray wolves in Yellowstone caused a behavioral change in elks in the area, which consequently caused streamside vegetation to sharply declined. The ripple effect continued throughout the entire ecosystem, such as streamside soil erosion, warmer water changing the fish habitat, cycling nutrients through the food web, and so forth).

Legitimacy of Competing Alternatives

This parameter refers to the extent to which the number of conceivable options for executing operators in various states and solution paths exist within the problem space. On the continuum of structuredness of problems (Jonassen, 1997), extremely well-structured problems possess one single, prescribed solution path, while extremely ill-structured problems possess an indefinite number of solution paths. This parameter contributes to the difficulty of a problem in two ways. First, it increases the uncertainty of confidence in selecting the best solution to the problem. Second, it increases the amount of tasks and time needed for validating and evaluating the options or alternatives for selecting the most viable solution paths.

In summary, problem difficulty can be analyzed and evaluated in terms of its nature and level by examining its complexity and structuredness dimensions. The dimension of complexity comprises four parameters: breadth of knowledge required to solve the problem, attainment level of domain knowledge, intricacy of problem-solution procedures, and relational complexity. The dimension of structuredness consists of five parameters: intransparency, heterogeneity of interpretations, interdisciplinarity, dynamicity, and legitimacy of competing alternatives.

Appropriateness for Problem-Based Learning

PBL is an instructional methodology, and like all instructional methodologies, is not universally applicable to different learning problems. The primary goal of PBL is to enhance students' application of knowledge, problem solving, and self-directed learning skills by requiring them to actively articulate, understand, and solve problems. PBL is problem focused, where learners begin learning by addressing simulations of an authentic problem. The subject matter content and skills to be learned are organized around problems, rather than as a hierarchical list of topics, so there is a reciprocal relationship between knowledge and the problem. Learning is stimulated by the problem and applied back to the problem. PBL is also student centered, requiring learners to self-direct their learning in order to determine what they know and do not know about the problem.

To achieve these educational goals of PBL, researchers (Duch, 2001; Dolmans, & Snellen-Balendong, 1997; Hung, 2006; Jacobs, Dolmans, Wolfhagen, & Scherpbier, 2003;

Majoor, Schmidt, Snellen-Balendong, Moust, & Stalenhoef-Halling, 1990; Neame, 1981; Schmidt, 1983; Sibley, 1989; Thomas, 1992) have suggested a number of general principles for designing good PBL problems. The general principles can be summarized as follows.

PBL problems should be

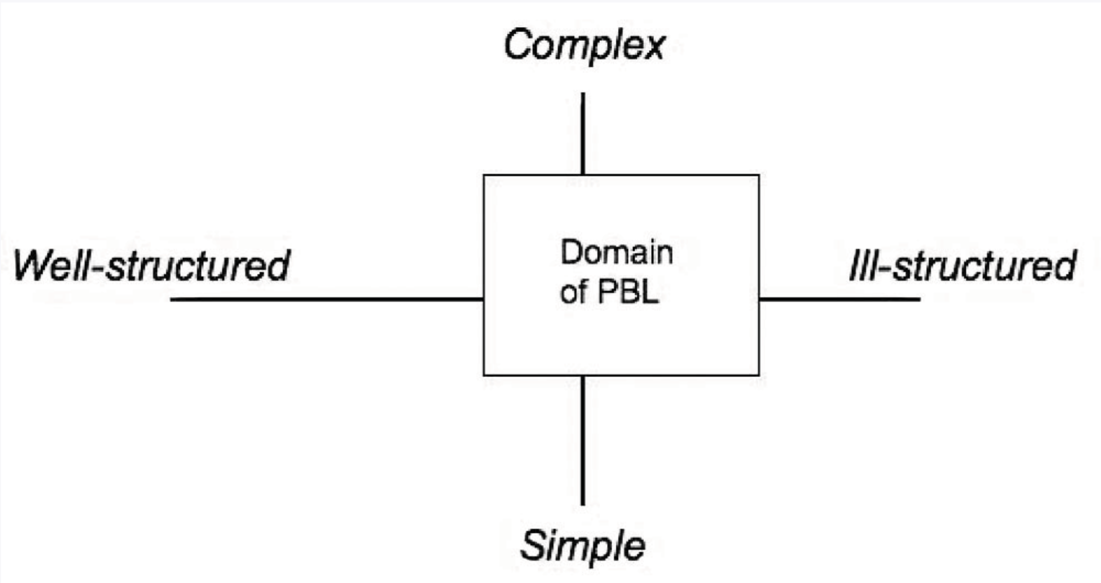
- open ended, ill structured, however,
  - with a moderate degree of structuredness;
- complex, however, the degree of complexity should
  - be challenging and motivating, engaging students' interests;
  - provide opportunities for students to examine the problem from multiple perspectives or disciplines;
  - adapted to students' prior knowledge;
  - adapted to students' cognitive development and readiness;
- authentic[1]
  - contextualized as to students' future or potential workplaces.

Based on these general principles, we hypothesize that the problems that are likely to be most successfully implemented in PBL programs are those that are moderately ill structured (near the median) and slightly above average in complexity (see Figure 2).

Problem Types Amenable to Problem-Based Learning

Which kind of problem falls into this difficulty range and therefore, is most amenable to PBL? Previous research could perhaps provide us with some indications. In PBL literature, the most consistent success of PBL has been demonstrated in medical fields (Gijbels et al.,

Figure 2. *Domain of PBL*



2005; Hung, Jonassen, & Liu, 2008) where diagnosis-solution problems are the dominant type of problem. In terms of the nine dimensions of problem difficulty discussed earlier, diagnosis-solution problems fall approximately in the range of moderately ill structured and fairly complex. Following this line of reasoning, it may be safe to speculate that the characteristics of diagnosis-solution problems could be the benchmark for identifying other types of problems that are also amenable to PBL. Within Jonassen's (2000) typology of problem types, decision-making problems and situated cases/policy problems share fairly similar characteristics with diagnosis-solution problems. Also, design problems possess similar characteristics but are somewhat more ill structured in nature than diagnosis-solution problems. Hence, we conjecture that these four types of problems likely may be more amenable to PBL than other types of problems in the typology. In the following sections, we will discuss the diagnosis-solution problem and analyze its difficulty level in terms of the complexity and structuredness dimensions. Then, we will discuss the nature of decision-making, situated case/policy problem, and design problems, and their similarity in complexity and structuredness to the diagnosis-solution problems.

Diagnosis-Solution Problems

Diagnosis-solution problems involve troubleshooting and treatment (patient management). Diagnosis-solution problems usually begin with symptoms of a sick person or a system (e.g., intense pain on the patient's shoulders and neck and also experiencing chest discomfort with lightheadedness). These types of problem also have a fairly clear goal state (patient reaches a reasonably healthy state). However, they have a relatively high level of intransparency and heterogeneity of interpretations (e.g., multiple possibilities of causes of the symptoms). Also, the high level of intransparency could elevate the legitimacy level of each competing interpretation before the hypotheses can be tested. The physician examines the patient and considers patient history before making an initial diagnosis. In a spiral of data collection, hypothesis generation, and testing (e.g., running blood tests, EKG, and physical examination, etc.), the physician focuses on a specific etiology and differential diagnosis of the patient's problem. Human physiology is incredibly complex, and physicians' knowledge must be fairly deep in order to make inferences about disease states, which increases the level of breadth of knowledge required, attainment level of domain knowledge, and the relational complexity of the problem. After diagnosing an illness (e.g., heart attack), the physician must suggest a treatment plan. Based on this analysis, on the scale of problem difficulty, diagnosis-solution problems would be considered moderately ill structured and fairly complex.

Decision-Making Problems

Decision-making problems require a decision that needs to be selected from a number of competing alternatives. For example, what kind of radiation detector should be used to determine radiation levels in different contexts? Which products are most likely to sell in a specific market? What kind of polymer will provide sufficient strength and flexibility for an aviation part? Decision problems are similar to diagnosis problems in the difficulty profile (moderately ill structured and fairly complex). Also, most of the time, they are a continuation of the diagnosis problems. Diagnosis problems focus on identifying the causes of the problem, while decision problems concentrate more on identifying the most viable solution to the problem under the circumstances in which the problem occurs.

Using the example of the diagnosis problem of a heart attack, after the cause of the patient's symptoms has been diagnosed, the physician needs to make a decision about the treatment. Frequently, there could be several treatment options and a fairly large number of factors to be considered in the decision-making process. The treatment options usually have a variety of interpretations (e.g., surgical, internal, holistic) that require interdisciplinary thinking, and each option may have an equal level of legitimacy because of the patient's personal and external factors. The personal factors may include, for example, economic (insurance plan, personal financial situation), temporal (age, history of the disease, time allowed for absence from work for recovery, etc.), or other conditions. The external factors may include issues such as ethical considerations (e.g., new treatment that is still in experimental stage). These factors could contradict one another, so the physician must be able to justify a particular solution based on multiple factors. Making informed decisions requires deep knowledge about each competing alternative in order to make predictions and understand implications of those decisions. It also requires conceptual understanding of the interrelationships among the factors involved in order to make the best choice. Decisions are often made difficult because of the interacting variables, which increase the level of complexity. Furthermore, difficult decisions have relatively high intransparency and may have many interpretations from interdisciplinary perspectives, each of which has some legitimacy. Also, making preliminary decisions may affect later decisions, indicating a certain level of dynamism.

Situated Cases/Policy Problems

Situated case/policy problems are typically complex, multi-faceted situations. What makes these problems difficult to solve is that it is not always clear what the problem is. Because the initial state of the problem is vague, defining the problem space is more ambiguous and highly intransparent. These types of problems are also commonly solved in professional contexts, such as international relations (Voss, Wolfe, Lawrence, & Engle, 1991), managerial problem solving (Wagner, 1991), business (e.g., planning production; Jonassen, Privish, Christy, & Stavrulaki, 1999), and medicine (Shanley, 2007; Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007). Using the case of the heart attack patient discussed previously, the problem solver has to go through an almost identical process as when solving diagnosis-solution and decision-making problems. The difference between the case problem and diagnosis and decision problems is that case problems may have a known worked (or failed) reasoning path and solution, while the other two do not. However, the known worked or failed reasoning paths and solutions to case problems do not prevent them from being complex or less ill structured than diagnosis problems. The known solutions are just the ones that have been implemented. Therefore, this type of problem has a similar problem difficulty profile to that of diagnosis and decision problems.

Policy problems tend to be fairly ill structured and may be very complex. They require the solver to articulate the nature of the problem and the different perspectives that impact the problem before suggesting solutions (Jonassen, 1997). They are more contextually bound than any kind of problem considered so far (Jonassen, 2000). Solving international relations problems, for instance, always involves heterogeneous perspectives that their owners take very seriously. These problems are necessarily interdisciplinary, with economic, political, religious, social, and anthropological factors that must be accommodated. International problems are always changing. Policy problems could have two conditions: making policy or complying with policy.

The purpose of policy-making problems is to create a set of rules to regulate situations that may involve multiple parties with conflicting interests. In order to solve these problems successfully, a deep level of understanding of all of these perspectives and variables must be addressed in some way in order to balance the perspectives of all parties involved. In complying with policy problems, on the other hand, the solver will focus on interpreting the policy from his or her perspective while still requiring a fairly deep level of knowledge outside of his or her own domain in order to present the argument. Also, solving policy problems often involves a group of people with different interests, perspective, backgrounds, and so on. Therefore, the heterogeneity of interpretations and the interdisciplinary nature, dynamicity, and legitimacy of competing alternatives in these types of problems are at a moderate to high level. For example, to devise a policy for regulating heart transplants or experimental drugs for treating heart disease patients, the problem solving process would have to take into account the perspectives of all parties involved, for example, patient, patient's family, physicians, hospital administration, medical equipment suppliers, pharmaceutical companies, and so on. More importantly, the policy-making process needs also to consider issues such as morality, social justice, religion, or sometimes, politics. The solutions to situated case/policy problems rely heavily on an analysis of contextual factors. These requirements make these problems the most complex and ill structured of the problem types that we have described here. Justifying decisions is among the most important processes in solving case/policy problems.

What about Design Problems?

Design problems are usually the most complex and ill structured of all problems (Jonassen, 2000), and they are the most common type of problem solved by engineers. Design problems possess all the common attributes of ill-structured problems, such as vaguely defined goals, multiple solutions, multiple solution paths, and unstated constraints. However, as Jonassen (2007a) contended, one attribute that makes design problems even more ill structured than other types of problems is the multiple criteria for evaluating solutions, which are highly subjective, change over time, or are unknown until the end of design process (e.g., interior design, product design, or architecture design). Thus, the degrees of intransparency, dynamicity, heterogeneity of interpretations, and legitimacy of competing alternatives of design problems tend to be at an extremely high level, which makes them highly ill structured. Also, design problems are very domain specific. They require high degrees of breadth of knowledge and attainment level of domain knowledge. Very often, the degree of relational complexity is also at a high level in design problems because of its high degree of dynamicity.

Table 1. *Problem difficulty of different problems.*

	Diagnosis-Solution (base-line)	**Decision Making**	**Situated case /Policy**
Breadth of Knowledge	broad	fairly broad	broad
Attainment Level	high	moderate	high
Intricacy of Procedures	very intricate	Moderately to very intricate depending on decision model	Moderately intricate
Relational Complexity	very complex	complex	complex
Intransparency	may be very transparent	Moderately transparent	Moderately transparent
Heterogeneity of Interpretations	Reasonably homogenous	Homogenous	very heterogeneous
Interdisciplinarity	Moderately interdisciplinary	depends on decision model	very interdisciplinary
Dynamicity	Very dynamic	Moderately dynamic	Moderately dynamic
Competing Alternatives	may be several	may be several	often binary

Many inquiry-based and project-based curricula focus on design problems, including a concerted effort by Kolodner and colleagues, using a method known as Learning by Design ™ (Kolodner, 2002; Kolodner et al., 2003). Kolodner's work has focused on middle-school inquiry, using design problems "to help children acquire a deeper, more systemic understanding of such complex systems" (Hmelo, Holton, & Kolodner, 2000, p. 247). These investigations are highly scaffolded environments for learning about systems such as the respiratory system. Yet they are not intended to teach learners to become designers and do not include many of the attributes or requirements of traditional PBL programs. In a series of studies, Atman et al. (2007) have shown that experienced designers approach design problems in fundamentally different ways, spending more time scoping the problem and gathering information than students. These tasks are required for effectively and successfully solving a design problem by reducing its intransparency and actively responding to the dynamicity, heterogeneity of interpretations, and legitimacy of competing alternatives. Hence, design problems fall into the highly ill-structured and moderate to highly complex quadrant. Although their moderate to highly complex nature will not exclude design problems from being used in PBL, the extremely high level of ill-structuredness may present challenges or even negative effects on students' learning in PBL environments. Thus, when the intended learning outcomes include professional design skills, we do not yet know how successful a PBL program can be.

Summary

Based on the positive results of PBL implementation in medical education where diagnosis-solution problems are the dominate type of problems employed, we used this type of problem as a baseline to identify other types of problems that also may be amenable to PBL. In analyzing the similarities and differences among the problem difficulty profiles of diagnosis-solution, decision-making, and situated case/policy problems led us to hypothesize that decision-making problems should be used as the problem focus of PBL. Policy problems are somewhat more ill structured than either decision-making or diagnosis-solution problems, so it is somewhat more speculative to hypothesize that they will be equally effective in PBL environments. Table 1 offers a perspective on the question of problem types by examining diagnosis-solution, decision-making, and policy problems in terms of the nine dimensions of problem difficulty.

Conclusion

Problem difficulty plays a role in the effectiveness of students' learning outcomes in all types of instructional methods that use problems. A problem with an appropriate difficulty level is within learners' cognitive readiness and therefore solvable, while an inappropriate difficulty level of problem may exceed the learners' readiness and result in failure. The purpose of assessing problem difficulty is to help researchers identify the problem types that are most effectively used in PBL environments. The problem difficulty assessment method serves as a tool to enable designers and teachers to map out the degree and the nature of difficulty of a given problem in order to match the nature of the subject area, supporting the intended instructional purpose and function of the problem, and ensuring appropriate difficulty level for the intended level of the course. Our purpose was to explore the design issue of problem difficulty, which has not been adequately considered in the design of PBL courses.

Questions that might focus this debate include:

- Is design problem solving too difficult to support using PBL, so that studio approaches, rather than PBL may be required?
- Does PBL have serious implications for story problems found in science textbooks, or will the goals of science learning have to be adapted in order to make the most effective use of PBL?
- Which of the components of problem difficulty (breadth of knowledge, attainment level, intricacy of procedures, relational complexity, intransparency, heterogeneity of interpretations, interdisciplinarity, dynamicity, or competing alternatives) has the greatest impact on PBL methods and outcomes?
- How might the PBL process be adapted in order to support these different components of problem difficulty?

Because the majority of research on PBL has focused on diagnosis-solution problems faced by medical practitioners, little data on how PBL transfers to other kinds of problems are available. No direct comparison of problem types has been attempted. We believe that a better way to resolve these questions is to directly compare the effectiveness of PBL by problem type, rather than problem discipline, which represents a new research agenda for PBL researchers. This means that very well-structured problems, like story problems, may not be appropriate for PBL. Likewise, very ill-structured and complex problems, like design problems, may be too difficult to learn in a PBL setting. However, without adequate support from research data, we cannot conclusively eliminate these problem types from PBL consideration. Another difficulty in answering these questions is the diverse use of the term PBL to describe a variety of learning activities that often bear little resemblance to each other (formats ranging from student-directed full problem simulation to teacher directed complete case, [see Barrows, 1986]). These questions must be answered complementarily.

Our goal in this paper was to initiate a dialogue on the kinds of problems most amenable to PBL and how the PBL process may have to be adapted in order to support different kinds of problem solving with varying levels of problem difficulty. We hope that the research questions proposed here will engage researchers for some time to come.

Note

1. There are two broad conceptions of authenticity, pre-authentication and emergent authenticity. The authenticity used in this paper refers to pre-authentication because this paper addresses the curriculum design in regular educational settings, which abides within constraints that prevent true authentication. The details of the distinctions between these two conceptions of authenticity are beyond the scope of this paper. For more details about pre-authentication and emergent authenticity, please see Barab & Duffy, 2000; Barab, Squire, & Dueber, 2000; Nicaise, Gibney, & Crane, 2000; Radinsky, Buillion, Lento, & Gomez, 2001.

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