A MODEL FOR DESIGNING PROBLEM-SOLVING LEARNING ENVIRONMENTS*

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ABSTRACT

This article is about problem solving and problem-based learning (PBLEs). Building blocks of PBLEs will be identified along with the skills that must be developed and supported in order to learn to solve problems, the forms in which problems are represented to learners, and the tools which learners can use to construct their own models of problems that learners may use to enhance their own conceptual understanding of the problems they are learning to solve. Examples of each of these components will be demonstrated in the second part of the article.

Keywords: Problem solving – Problem-based learning – Cases – Skill development – Modelling

1. Introduction

Problem solving and problem-based learning are receiving increased attention in instructional design literature. While models of problem-based learning, such as Barrows (1992), offer strategies for scaffolding learning to solve medical diagnostic problems, no model identifying the components of problem-based learning environments (PBLEs) exists.

This very brief proposal (that requires a book to fully articulate) identifies the building blocks of PBLEs, the skills which must be developed and supported in order to learn to solve problems, the forms in which problems are represented to learners, and the tools which learners can use to construct their own models of problems which learners may use to enhance their own conceptual understanding of the problems they are learning to solve (Figure 1).

Examples of each of these components will be demonstrated in the following section.

2. Building blocks: Cases

The building blocks of any PBLE are represented by cases. Cases may assume many forms, from a simple word problem in a textbook to an elaborate business case study. More important than the form of the case is its function, that is, the way that the case is used to learn to solve problems.

2.1. Cases as problems to solve

The focus of any PBLE is on the cases which represent problems to be solved. All other kinds of cases support cases-as-problems-to-solve. Examples include anchored instruction, goal-based scenarios, and problem-based learning.

In all of these, a problem is embedded in realistic scenarios which require the learners to articulate the problem to be solved, rather than having the entire problem circumscribed by the instruction.

2.2. Cases as examples

Examples serve as models of ideas being represented abstractly. Their purpose is to help learners to construct schemas for the ideas being presented. A schema for a problem consists of the kind of problem it is, the structural elements of the problem (e.g. acceleration, distance, and velocity in a physics problem), situations in which such problems occur (e.g. inclined planes, automobiles, etc.), and the processing operations required to solve that problem (Jonassen, 2000).

The most common form of cases as exemplars in problem solving is the worked example. When learning to solve problems, cases in the form of worked examples may be provided as a form of instruction. Worked examples should 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., 2001).

2.3. Cases studies

Another form of case as exemplar is the case study. In case studies, students study an account of a problem that was previously experienced. Frequently guided by questions, students analyze the case and evaluate the methods and solutions. Typically, students are responsible for solving the problems, only analyzing how others solved the problems and engaging in what-if thinking.

2.4. Cases as analogues

Comparison of analogical cases can help learners to construct more robust problem schemas. The theory that best describes the required analogical reasoning is the 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,
Fig. 1 Dimensions of PBLEs.
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 in the problem and the analogue, a process known as analogical encoding.

2.5. Cases as prior experiences

Problem solving usually begins by searching memory for the most similar problem solved and reusing or adapting it. 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 the memory and retrieved and reused when needed. Problem solving can be supported by access to case libraries of stories which are made available to learners. The stories in the library are indexed 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.

2.6. Cases as alternative perspectives

Another way that cases may function as analogues to support analogical reasoning is to provide cases as alternative perspectives. In complex problems, the underlying complexity should be signalled to the learner, who considers alternative perspectives to the problem in order to construct a personal meaning for the problem (Spiro et al., 1988). Cognitive flexibility theory prescribes the use of hypertexts to provide random access to multiple perspectives and thematic representations of content enabling students to crisscross the cases which 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 (Jacobson & Spiro, 1995).

2.7. Cases as simulations

Cases may also comprise simulations which enable learners to experiment with alternative solutions. Simulations must identify the essential causal relationships and enable learners to manipulate the elements of those relationships to contrast alternative solutions.

2.8. Student-constructed cases

Learners may construct their own cases as models of problems as well as assessments of conceptual understanding. Jonassen, Strobel and Ionas (2008) conducted a three-year, design-based research study of case-based learning. Beginning with a cognitive flexibility hypertext, student activity shifted from navigation to a student authoring environment, because authoring hypertext requires deeper understanding of the domain, identification of core concepts, cases, themes, and careful selection of new cases to represent the content.

3. Cognitive skills

Cases alone are insufficient to support problem solving. Four important cognitive skills are required to help learners solve problems, including causal reasoning, questioning, argumentation, and modelling.

3.1. Causal reasoning

The ability of learners to transfer problem-solving skills depends on conceptual understanding of the system in which the problem occurs. The most common type of conceptual proposition that underlies all thinking is causal (Carey, 2002). Causal reasoning is required for making predictions, drawing implications and inferences, and explaining phenomena, cognitive processes which are required to solve different problems. Jonassen and Ionas (2008) describe different methods for supporting causal learning, including influence diagrams, simulations, questions, and different causal model-
ling tools, including expert systems, systems dynamics tools, and causal modelling tools.

3.2. Questioning

Questioning is one of the most fundamental cognitive components that guide human reasoning (Graesser et al., 1996). In PBLEs, they are essential for guiding student reasoning as they work to comprehend the problem and generate solutions. Answering deep-reasoning questions articulates causal chains; goals, plans, and actions; and logical justification (Graesser et al., 1996). In PBLEs, questions may be inserted in any kind of case to guide interpretation or inferences from the case, or they may be used to guide an understanding of the inter-relationships between cases. Questions may also form the cognitive model for cases in the form of an Ask system, that models a kind of reflection-in-action (Schon, 1982). Questions may also be student generated. The quality of those questions is predictive of problem-solving ability.

3.3. Argumentation

The ability to construct and evaluate cogent, coherent arguments in support of a solution is essential to problem solving. Being able to generate and support justifications and counterarguments for alternative solutions is probably the most important skill, especially for ill-structured problems. Additionally, argumentation provides the best form of assessment of problem-solving ability. Argumentation may be scaffolded by prompting for argumentative constructs and visualization of arguments.

3.4. Modelling

Developing rich, multi-faceted problem schemas is essential to problem-solving transfer. Problem schemas include not only the processing operations, but also the semantic and situational structure of the problem. That structure included the causal relationships and conceptual associations among the problem elements. Unfortunately, problem solving often fails because students represent problems in only one way, typically quantitative. The more ways that learners are able to represent problems and their relations to domain knowledge, the better able they will be to transfer their skills. Using a variety of tools, such as semantic modelling tools (concept maps), expert systems, systems modelling tools to model the relationships among problem elements will enhance student understanding of the problem (Jonassen, 2000b).

4. Applying the PBLE model

The obvious question is which combinations of these cases and supports are required for learning to solve different problems. Problems vary in terms of context or discipline, structuredness, complexity, and abstractness of problem representation (Jonassen, 2000). Along a continuum ranging from well-structured to ill-structured problems, Jonassen (2000), defined different kinds of problems, including:

- algorithmic problems
- story problems
- rule-using problems
- decision-making problems
- troubleshooting
- diagnosis-solution problems
- strategic performance
- systems analysis problems
- design problems
- dilemmas.

Table 1 proposes the required case components which should be included in problem-solving learning environments for several different kinds of problems. Additionally, Table 1 identifies the cognitive skills which are most important for the solution of each of those kinds of problems. It is important to note that Table 1 proposes recommended components. For example, solving story problems is a ubiquitous activity in P-16 science and mathematics classes. Story problems are normally solved by learners by identifying key concepts and values in a short scenario, selecting the appropriate algorithm, applying the algorithm to generate
a quantitative answer, and hopefully checking their responses. When students use this algorithmic approach to solving problems, they do not develop sufficiently rich problem schemas to support transfer. In order to help them support problem schemas, I would recommend the following instructional components:

- cases as problems to solve (the story problem);
- cases as examples: many scholars would suggest worked examples to facilitate this form of problem solving;
- cases as analogues: structurally analogous problems for learners to compare and contrast;
- questioning to focus their analogical comparison of problem structures;
- causal reasoning: analysing the causal relationships defined by the problem structures is essential to understanding the structure and developing a robust problem schema;
- argumentation: while a strong connection has not been established between argumentation and story problem solving, Nussbaum and Sinatra have shown that argumentation can support problem scheme development in physics.

Although some of the components and skills have been empirically validated, most of the recommendations in Table 1 have not. That is, a great deal of research is needed to validate these recommendations. I am working on some of that research myself. In order to validate the necessity of all the components and skills, many researchers around the world must commit to researching different kinds of problem solving and the case components and cognitive skills which are essential to solving different kinds of problems. That is a challenge that I hope many of you take up.

### REFERENCES


