Research Issues in Problem Solving

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Abstract

Problem solving is the most important learning outcomes in most contexts. My theory of problem solving articulate fundamental differences among different kinds of problems, resulting a typology or problem, including story problems, rule using/rule induction problems, decision making, troubleshooting, diagnosis-solution, strategic performance, policy problems, design problems, and dilemmas. Each kind of problem, calls on different instructional supports. There exist at least seven different kinds of cases (Cases as problems to solve, worked examples, case studies, cases as prior experiences, alternative perspectives, and simulations) that may be used to construct problem-solving learning environments and five different kinds of cognitive scaffolds (Analogical encoding, causal reasoning, questioning, argumentation, and modeling). From these options, a large number of unanswered research questions emerges that may challenge researchers for years to come.

Keywords: problem solving, problem typology, schema theory
1. Introduction

1.1 Importance of Problem Solving

I believe that the most important cognitive goal of education (formal and informal) in every educational context (public schools, universities and corporate training) is problem solving. Therefore, the instructional design and technology community should learn how to design problem-solving instruction. In order to support those efforts, instructional design and technology researchers should conduct high quality research on learning to solve problems that will enhance problem-solving learning experiences or all students. In support of these claims, I present the following warrants.

First, problem solving is the most authentic and therefore the most relevant learning activity that students can engage in. Karl Popper (1999) wrote a book of essays that claimed that “all life is problem solving.” In everyday contexts, including work and personal lives, people solve problems constantly. No one in personal and professional contexts is rewarded solely for memorizing information and completing examinations. Problem solving as an essential “21st century skill,” specifically the ability to solve different kinds of non-familiar problems in both conventional and innovative ways and to identify and ask significant questions that clarify various points of view and lead to better solutions (http://www.21stcenturyskills.org).

Second, research has shown that knowledge constructed in the context of solving problems is better comprehended, retained, and therefore more transferable. When solving problems, students must think more critically. Also, the learning is situated in some authentic context, which makes it more meaningful.

Third, problem solving requires intentional learning. Learners must manifest an intention to understand the system or context in which problems occur in order to solve problems effectively. Meaningful learning cannot occur until and unless learners manifest an intention to learn. All human behavior is goal-driven. The clearer our goals are for learning, the more likely we are to learn meaningfully and mindfully.

Fourth, knowledge that is recalled and not used in some authentic tasks is too quickly forgotten, cannot be effectively applied, and in most disciplines becomes obsolete in a short time. Therefore, the primary purpose of education should be to engage and support learning to solve problems.

2. What is Problem Solving and How Do Problems Vary?

My theory of problem solving diverges from traditional approaches to problem solving that articulate single models or approaches to solving all kinds of problems (e.g., Bransford & Stein, 1994). Problems and problem solving vary in several ways. Foremost among these differences is the continuum between well-structured and ill-structured problems (Jonassen, 1997). Most problems encountered in formal education are well-structured problems. Well-structured problems typically present all elements of the problem; engage a limited number of rules and principles that are organized in a predictive and prescriptive arrangement; possess correct, convergent answers; and have a preferred, prescribed solution process.
Ill-structured problems, on the other hand, are the kinds of problems that are encountered in everyday practice. Ill-structured problems have many alternative solutions to problems; vaguely defined or unclear goals and constraints; multiple solution paths; and multiple criteria for evaluating solutions; so they are more difficult to solve.

Problems also vary in complexity. The complexity of a problem is a function of the breadth of knowledge required to solve the problem, the level of prior knowledge, the intricacy for the problem-solutions procedures, and the relational complexity of the problem (number of relations that need to be processed in parallel during a problem solving process) (Jonassen & Hung, 2008). Ill-structured problems tend to be more complex, however, there are a number of highly complex well-structured problems, such as chess.

Dynamicity may be thought of as another dimension of problem complexity. In dynamic problems, the relationships among variables or factors change over time. Changes in one factor may cause variable changes in other factors that often substantively changes the nature of the problem. The more intricate these interactions, the more difficult it is any solution. Ill-structured problems tend to be more dynamic than well-structured problems that tend to be static.

A final dimension of problems and problem solving is domain specificity. In contemporary psychology, there is a common belief that problems within a domain rely on cognitive strategies that are specific to that domain (Mayer, 1992; Smith, 1991; Sternberg & Frensch, 1991). These are often referred to as strong methods, as opposed to domain-general strategies (weak methods). For example, Lehman, Lempert, and Nisbett (1988) concluded that different forms of reasoning are learned in different graduate disciplines. Graduate students in the probabilistic sciences of psychology and medicine perform better on statistical, methodological, and conditional reasoning problems than students in law and chemistry, who do not learn such forms of reasoning. The cognitive operations are learned through the development of pragmatic reasoning schemas rather than exercises in formal logic. Graduates in different domains develop reasoning skills through solving situated, ill-structured problems that require forms of logic that are domain-specific. In the following section, I describe different kinds of problems.

2.1 Kinds of Problems

2.1.1 Story Problems

Most commonly found in mathematics and the sciences, story problems (word problems) usually embed the values needed to solve an algorithm into a brief narrative or situation. Learners are required to select the most appropriate formula for solving the problem, extract the values from the narrative and insert them into the formula, solving for the unknown quantity. Unfortunately, the story covers for the problems are too often uninteresting and irrelevant to students. So when they attempt to transfer story problem skills to other problems, they focus too closely on surface features or recall familiar solutions from previously solved problem. They fail to understand the principles and the conceptual applications underlying the performance, so they are unable to transfer the ability to solve one kind of problem to problems with the same
structure but dissimilar features.

2.1.2 Rule-Using/Rule Induction Problems

Many problems have correct 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 and as complex as completing tax return schedules. Using an online search system to locate a library’s holdings or using a search engine to find relevant information on the World Wide Web are examples of rule-using problems. The purpose is clear: find the most relevant information in the least amount of time. Rule induction problems occur when you attempt to learn how to use a new device or system. How does this work? From operating a new remote control or navigation system to understanding the tax code, rule induction problems require the induction and application of operating rules and principles.

2.1.3 Decision-Making Problems

Decision-making problems are usually constrained to decisions with a limited number of solutions. For instance, do we move in order to accept a promotion? Which health plan do we select? Which school is best for my children? Though these problems have 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. The most common conception of decision making is rational choice, where decision makers identify criteria for the decision and rate weight each option according to those criteria. In our everyday lives, however, people more naturally tend to generate scenarios for the leading options and make their decisions based on the strength of the stories they construct.

2.1.4 Troubleshooting Problems

Troubleshooting is one of the most common forms of everyday problem solving. Maintaining complex communications and avionics equipment requires troubleshooting skills. Debugging computer programs and repairing computer equipment requires troubleshooting. The primary purpose of troubleshooting is fault state diagnosis. That is, some part of a system is not functioning properly, resulting in a set of symptoms, which have to be diagnosed and match with the user’s knowledge of various fault states. Troubleshooters use symptoms to generate and test hypotheses about different fault states.

Troubleshooting skill requires a combination of domain and system knowledge (conceptual models of the system); troubleshooting strategies such as search-and-replace, serial elimination, and space splitting; and experience (represented in case-based reasoning). These skills are integrated and organized by the troubleshooter’s experiences. The conceptual model consists of conceptual, functional, and declarative knowledge, including knowledge of system components and interactions, flow control, fault states (fault characteristics, symptoms, contextual information, and probabilities.
of occurrence), and fault testing procedures. The primary differences between expert and novice troubleshooters are the amount and organization of system knowledge (Johnson, 1988).

### 2.1.5 Diagnosis-Solution Problems

Diagnosis-solution problems are similar to troubleshooting. Most diagnosis-solution problems require identifying a fault state, just like troubleshooting. However, in troubleshooting, the goal is to repair the fault and get the system back online as soon as possible, so the solution strategies are more restrictive. Diagnosis-solution problems usually begin with a fault state similar to troubleshooting (e.g. symptoms of a sick person). The physician examines the patient and considers patient history before making an initial diagnosis. In a spiral of data collection, hypothesis generation, and testing, the physician focuses in a specific etiology and differential diagnosis of the patient’s problem. At that point, the physician must suggest a solution. Frequently, there are multiple solutions and solution paths, so the physician must justify a particular solution. It is this ambiguity in solution paths that distinguishes diagnosis-solution problems from troubleshooting.

### 2.1.6 Strategic Performance

Strategic performance entails real-time, complex activity structures where the performers apply a number of tactical activities to meet a more complex and ill-structured strategy 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. Meeting that strategy through tactical maneuvers is a tactical performance. Typically there are a finite number of tactical activities that have been designed to accomplish the strategy, however, the mark of an expert tactical performer is his/her ability to improvise or construct new tactics on the spot to meet the strategy. In battlefield situations, officers identify a strategy and may negotiate tactical concerns with the performer, however, both realize that tactics may have to be adjusted. This type of problem is also referred to as recognition-primed decision making (Klein, 1998).

### 2.1.7 Policy Analysis Problems

Policy analysis problems are complex, multi-faceted situations. What makes these problems difficult to solve is that it is not always clear what the problem is. Because defining the problem space is more ambiguous, these problems are more ill-structured. These are the most common types of problem solved in professional contexts. Case problems 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 that any kind of problem considered so far. That is, their solutions rely on an analysis of contextual factors. Solving business problems, including planning production, are common case problems. Classical situated case problems also exist in international relations, such as ".... given low crop productivity
in the Soviet Union, how would the solver go about improving crop productivity if he or she served as Director of the Ministry of Agriculture in the Soviet Union" (Voss and Post, 1988, p. 273). International relations problems involve decision making and solution generation and testing in a political context. Justifying decisions is among the most important processes in solving case problems.

2.1.8 Design Problems

Perhaps the most ill-structured kinds of problems is designing something. Whether it be an electronic circuit, a house, a new entre' for a restaurant, or any other product or system, designing requires applying a great deal of domain knowledge with a lot of strategic knowledge resulting in an original design. Normally the designer is required to conduct a needs assessment and use domain knowledge to generate a design that will work within system constraints. Usually, most design problems have multiple if not infinite solutions. Designing usually involves iterative cycles of decision making where the decisions are impacted by constraints and designer biases. In addition to ill-structured, most design problems are complex, requiring the designer to balance many needs and constraints in the design. The importance of design problems cannot be diminished. Most professionals get paid for designing things (products, systems, etc.).

2.1.9 Dilemmas

Dilemmas or issue-based problems are the most ill-structured and unpredictable, often because there is no solution that will ever be acceptable to a significant portion of the people affected by the problem. The most common dilemmas, where policy decisions never satisfy all of the people. Usually there are many valuable perspectives on the situation (military, political, social, ethical, etc.), none is able to offer a generally acceptable solution to the crisis. The situation is so complex and unpredictable, that no best solution can ever be known. That does not mean that there are not many solutions, which can be attempted with variable degrees of success, however, none will ever meet the needs of the majority of people or escape the prospects of catastrophe. Dilemmas are often complex, social situations with conflicting perspectives, and they are usually the most vexing of problems.

3. Research in Problem Solving

3.1 Limitations of Existing Research

Most of the research on problem solving has examined methods for improving story problem solving. Lesser amounts of research have addressed decision making, troubleshooting, and design problem solving. None of the research, however, has recommended any sort of systematic model for designing instruction for solving different kinds of problems. Research questions have generally been idiosyncratic and not based on any coherent model of problem solving.
3.2 Case Variables in Research

Jonassen (2011) has written a handbook on designing problem-solving learning environments (PSLEs). The handbook provides an architecture for building problem-solving learning environments. That architecture consists of combinations of seven different kinds of cases that may be included in any PSLEs, depending on the kind of problem being learned. Cases constitute the building blocks of problem-based learning environments. Studying cases in relation to the problem to be solved enhances students’ understanding of the problem and their abilities to solve it. In order to help learner to understand and apply cases, Jonassen (2011) also recommends a number of cognitive scaffolds to assist students’ analysis and comparisons of the different kinds of cases. These cognitive scaffolds focus student attention on important relationships among the elements in the problem. These scaffolds help students to better understand the problem.

3.2.1 Cases as Problems to Solve

The focus of any problem-based curriculum is the problem to solve. The use of problems as the focus of learning is supported by problem-based learning principles. 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. When learning becomes problem-focused, learners usually begin learning by addressing simulations of an authentic, ill-structured problem. There are other conceptions of authenticity that focus on students’ engagement in service learning projects. Regardless of the source of the problem, the content and skills to be learned are organized around problems, rather than a hierarchical list of topics, so there is a reciprocal relationship between knowledge and the problem. Students learning processes are stimulated by the problem and applied back to the problem. Most problem-based efforts are student-centered and self-directed, where students individually and collaboratively assume responsibility for (a) generating learning issues and processes through self-assessment and peer assessment and (b) accessing the learning materials they think are necessary in order to help them solve the 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.

3.2.2 Cases as Worked Examples

All models of instructional design insist on the inclusion of examples in instruction. After defining an entity, examples should be presented to learners. The purpose of examples is to serve as models of ideas being represented abstractly. Their purpose is to help learners to induce and 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, 2003).
The most common method for supporting schema construction is the worked example. When learning to solve problems, cases in the form of worked examples are typically provided as a primary form of instruction. Worked examples are instructional devices that typically include the problem statement and a procedure for solving the problem that shows how other problems of a similar nature may be solved (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 are useful examples of well-structured problems, such as story problems. They cannot be effectively used with ill-structured problems.

3.2.3 Case Studies

The most common application of case-based learning is the case study. In case studies, students study an account (usually narratives from one 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. 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 examples of more ill-structured problems that may be used to support problem schema construction for more complex and ill-structured problems.

3.2.4 Cases as Analogues

Learning to solve problems can also be supported by providing analogous problems. When students examine similar problems for their structures, they gain more robust conceptual knowledge about the problems. That is, they construct stronger problem schemas. There are two theoretical approaches to using cases as analogues: analogical encoding and case-based reasoning. 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 (i.e., whether similar objects filled similar roles) (Ross, 1984, 1987). That is, 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.

3.2.5 Cases as Prior Experiences

Another way of using cases to support problem solving is by analogy directly with the source problem without attempting to construct a schema. Problem solving consists of finding the nearest case in an organized library of annotated problem cases and reusing or adapting it. 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). Case-based reasoning is applied to instruction in the form of case libraries of stories that 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.

3.2.6 Cases as Alternative Perspectives

Ill-structured problems tend to be more complex than well-structured problems. 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, enabling 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. Most ill-structured problems demand the use of cases as alternative perspectives.

3.2.7 Cases as Simulations

Students must be able to practice solving problems. 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 system are able to be manipulated by learners. 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 student understanding of the relationships in the learner’s mental model of the problem.

3.3 Cognitive Scaffold Variables in Research

3.3.1 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 (Catrambone & Holyoak, 1989). 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 (Gick & Holyoak, 1983). 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).

### 3.3.2 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 the elements in the problem 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 or set of conditions or states of an event to inferring the possible effect(s) that may result from those states is called prediction. Predictions are used for forecasting an event (e.g., economic or meteorological forecasts) and testing of 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, 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 and covariance. The mechanism describes the causal relationship in terms of its qualitative effects.

### 3.3.3 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 student 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 in problem-based learning environments 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. Finally, questions may form the primary interface in the form of an Ask System. An Ask System is an interface comprised of a sequence of questions that function as links to different information.

3.3.4 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, 2011). 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 pays 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 (Jonassen, 1997).

3.3.5 Modeling

“Scientific practice involves the construction, validations, and application of scientific models, so science instruction should be designed to engage students in making and using models” (Hestenes, 1996, p. 1). The same assumption applies to all disciplines. Throughout this chapter, I have emphasized the construction of mental models of the problem space. Mental models are enhanced and confirmed by the construction of external models. Those models may be quantitative (equations) or qualitative. 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 confirms solutions to the problem.

3.2. Needed Research on Problem Solving

With nine kinds or problems, seven kinds of cases, and five kinds of cognitive scaffolds, 315 possible research questions are immediately suggested. However, there
exist many more than that. For each kind of problem listed below, Jonassen (2011) suggest the following case components and cognitive scaffolds.

<table>
<thead>
<tr>
<th>Problem type</th>
<th>Case Components</th>
<th>Cognitive scaffolds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story Problems</td>
<td>Problems, worked examples, analogues</td>
<td>Problem schema, analogical, causal, questioning, argumentation, modeling</td>
</tr>
<tr>
<td>Rule Using/ Rule Induction</td>
<td>Problems, worked examples, analogues</td>
<td>Problem schema, analogical, causal, questioning, modeling</td>
</tr>
<tr>
<td>Decision making</td>
<td>Problem, case studies, alternative perspectives</td>
<td>Causal, argumentation, modeling, mental simulation (scenario construction)</td>
</tr>
<tr>
<td>Troubleshooting, Diagnosis solution</td>
<td>Problems, prior experiences, alternative perspectives</td>
<td>Causal, argumentation, modeling</td>
</tr>
<tr>
<td>Strategic performance</td>
<td>Problems, prior experiences, simulations</td>
<td>Problem schema, analogical, causal, mental simulation (scenario construction)</td>
</tr>
<tr>
<td>Policy analysis</td>
<td>Problems, case studies, prior experiences, alternative perspectives</td>
<td>Analogical, causal, questioning, argumentation, modeling</td>
</tr>
<tr>
<td>Design</td>
<td>Problems, prior experiences, alternative perspectives</td>
<td>Causal, argumentation, modeling</td>
</tr>
<tr>
<td>Dilemmas</td>
<td>Problems, alternative perspectives</td>
<td>Argumentation, scenarios</td>
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The following represent a few of the many research questions that need to be examined.

- Which case components are necessary for engaging learning for each kind of problem?
- Which cognitive scaffolds are necessary for supporting learning how to solve each kind of problem?
- When representing problems to solve, which case characteristics (narrative, video, information) are most effective in engaging students in solving the problem?
- What kinds of problems (how well or ill-structured) are worked examples useful for engaging?
- How much cognitive load is required to solve different kinds of problems?
- How many case studies are necessary to support ill-structured problem solving?
- What formats are most effective for representing case studies?
- How do we support transfer of lessons from cases studies to the problem to solve?
- How do we support generalization from analogous problems to the problem to
solve?

- Can analogous cases support ill-structured problem solving?
- How do we insure structural similarity between analogues?
- How dissimilar should surface similarity among analogues be?
- Prior experiences
- How do we support the integration of alternative perspectives by students?
- How many dimensions (personal perspectives, thematic perspectives, canonical perspectives) can students accommodate when solving ill-structured problems?
- How realistic do simulations need to be in order to support problem solving?
- How do we create simulations for complex, ill-structured problems?
- How do we support transfer of problems solutions from, simulations?
- How may analogous problems can be encoded by students?
- How do we support analogical encoding by students?
- How do we support conceptual transfer from analogical encoding?
- What support (simulations, influence diagrams, causal modeling, questioning) will be most effective form articulating causal relationships in problems?
- How do we support modeling of causal relationships in problems?
- Which kinds of questions best support different processes in problem solving: problem identification, alternative solution, metacognition and self-regulation, factual)?
- Which form of questions is most effective for supporting different kinds of problems solving: inserted questions, Ask systems)?
- Which kinds of argumentation support results in the best arguments (directions, discussion, scaffolded argumentation systems)?
- For which kinds of problems is argumentation the most effective? How can we use arguments to assess problems solving?
- Which kinds of model (quantitative or qualitative) are more effective for supporting problem solving?

These represent only a small fraction of the potential number of research questions. Although problem solving is the most important learning outcomes, there is little research on the range of problem solving. These and other questions will hopefully challenge scholars for years to come.

References


