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Perspectives on problem solving and instruction

Jeroen J.G. van Merriënboer

Maastricht University, The Netherlands

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ABSTRACT

Most educators claim that problem solving is important, but they take very different perspective on it and there is little agreement on how it should be taught. This article aims to sort out the different perspectives and discusses problem solving as a goal, a method, and a skill. As a goal, problem solving should not be limited to well-structured problem solving but be extended to real-life problem solving. As a method, problem solving has clear limitations for novice learners; providing ample support to learners is of utmost importance for helping them to develop problem-solving skills. As a skill, problem solving should not be seen as something that only occurs in the early phases of a process of expertise development but as a process that develops in parallel in System 1 and System 2. The four-component instructional design model (4C/ID) is briefly discussed as an approach that is fully consistent with the conceptualization described in this article and as a preliminary answer to the question how problem solving is best taught.

1. Introduction

All life is problem solving (Popper, 1999). In everyday and professional contexts, everyone frequently solves problems. When we wake up, we must decide what clothes to wear. In schools, teachers must deal with management problems in their classroom and students must determine how much time to spend on different types of school work. In professional life, workers are required to organize complex projects, deal with interpersonal conflicts, and develop innovative products. And in the evening, we must decide whether we relax on the couch, play a sport, or visit the theater. What all these situations have in common is that there is an unknown entity (e.g., the clothes to wear) in some situation, that is, a difference between the current state (wearing your pajama) and a desirable goal state (wearing appropriate clothes). Jonassen (2000) makes the important point that finding or solving for the unknown in such real-life problem situations not only has some intellectual value, but also a social or cultural value. Thus, solving problems is not only an integral part of life but also helps people feel valuable.

Whereas most educators regard problem solving as critical for life, there is yet little agreement on how problem solving should be taught in schools, other educational institutions and the workplace. One reason is that problem solving is an extremely complex cognitive process about which little is known. We should more deeply understand the breadth and complexity of problem-solving processes in order to be able to effectively engage and support learners in them. Moreover, the scientific discussion on problem solving in education is a Tower of Babel, making it even more difficult to reach some consensus on how to teach problem solving. For example, some educators reserve the term problem solving for the use of cognitive methods that can be applied in any domain, while others stress the importance of domain knowledge in problem solving. Some focus on the importance of problem solving as an educational goal that can best be reached by teaching known solutions, while others advocate the use of problem solving as an educational method. And some see problem solving as an early phase in the process of expertise development, while others see problem solving as one important aspect of fully developed – reflective – expertise.

The main goal of this article is twofold. First, it aims to sort out the chaos and distinguish the most important perspectives on problem solving. Second, it aims to provide a preliminary answer to the question how real-life problem solving is best taught. What makes this article original is that it not only highlights the various perspectives of problem solving but also critically analyzes how these different perspectives are conceptually interrelated with each other.

The structure of this article is as follows. The first section discusses different perspectives on problem solving as an educational *goal*. A distinction is made between weak problem-solving methods, strong problem-solving methods, knowledge-based problem-solving

E-mail address: j.vanmerrienboer@maastrichtuniversity.nl.

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methods, and a combination of strong and knowledge-based methods in real-life problem solving. The second section discusses different perspectives on problem solving as an educational *method*. It will be argued that problem solving might be a goal but is not an appropriate educational method for novice learners, and that effective educational methods should carefully and gradually help learners move toward this goal. The third section discusses different perspectives on problem solving as a *skill*. A distinction is made between phase models, which typically see problem solving as an early phase in the development of expertise, and System 1/System 2 models, which view problem solving as an important feature of two interacting systems. The fourth section briefly discusses the four-component instructional design model (4C/ID; Van Merriënboer, 1997; Van Merriënboer & Kirschner, 2013) as a preliminary answer to the question how real-life problem solving is best taught. The fifth and final section provides the main conclusions and directions for further research.

2. Problem solving as an educational goal

Educational researchers and practitioners greatly differ in their definition of problem solving. A first definition refers to the use of *weak methods*, which can be used to solve unfamiliar, new problems in *any* domain. There are many of them, such as hill-climbing, means-ends analysis, generate-and-test, heuristic search, subgoal decomposition, hypothesize-and-match, constraint satisfaction, and pure forward search (e.g., Newell & Simon, 1972). An example of one of a number of domain-general methods for the weak method of hill-climbing is: If the goal is to transform the current state into a goal state, then set as subgoals to (i) find the largest difference between the current state and the goal state, (ii) find an operator to eliminate that difference, and (iii) convert the state that results from the application of this operator to the goal state. Thus, this domain-general method tries to reach a goal state by looking for available operators that may eliminate the difference between the current state and the desired goal state. When you are traveling in a foreign country, this method may help you identify the means of transportation (e.g., bus, train, aircraft) that best helps you move from your current to your final destination. Although weak methods allow one to solve problems in any unfamiliar domain, it is highly questionable whether the teaching of such methods should be a primary goal of education. First, weak methods will only be effective if the information they operate upon is correct. They are not able to generate acceptable behavior if they operate on incorrect information from the outside world or from the problem solver's memory. Second, the costs related to the use of weak methods are extremely high. The problem-solving process is slow, will often be unsuccessful, and the load on working memory is exceptionally high. The latter is true because the interpretation of declarative information requires continuous retrieval of this information from memory or the outside world, and this information must be held active in working memory. Third, the general assumption is that weak methods are innate (Anderson, 1993) and that it may be impossible to teach them because they are 'wired in' the human cognitive architecture. Indeed, attempts to teach domain-general problem solving have typically been unsuccessful (Sweller, Clark, & Kirschner, 2010).

A second definition of problem solving refers to *strong methods*, which can be used to solve specific problems in a particular domain. Strong methods are typically described as highly-domain specific *if-then* rules that generate a solution to well-structured problems, that is, problems that present all elements of the problem to the learner, require the application of a limited number of rules or procedures, and have knowable, comprehensible solutions (Frederiksen, 1984; Jonassen, 1997). Many typical school tasks are well-structured problems that can be solved by strong methods: Procedures for addition, subtraction, division and multiplication in arithmetic; formulas for doing computations in physics and science; grammatical rules for the conjugation of verbs, and so forth. When people can recognize problems as belonging to a particular class and have the applicable rules available, they can use their specific knowledge to solve these problems (i.e., *same* use of the same knowledge). Moreover, strong methods are algorithmic, meaning that their correct application under appropriate conditions guarantees that the problem is solved: Correctly applying the procedure for doing addition, for example, will always yield the correct answer independent of the numbers that are added. After extensive amounts of practice, the application of rules or procedures may become fully automatic so that learners respond to the problem "what is the sum of 14 and 3?" with the answer 17, without the need to consciously apply the procedure anymore. Thus, strong methods may eventually be applied very fast and with low demands on working memory, but they are highly inflexible because they are only applicable to specific problems. Although most educators will agree that strong methods should be taught in education, many of them would not classify the application of strong methods as problem solving but rather as "just performing a routine". But it is equally justified to call it the most extreme, efficient type of problem solving one can think of.

A third definition of problem solving refers to *knowledge-based methods*, which can be situated between weak and strong methods. They may help to find an acceptable solution for ill-structured problems, that is, problems that contain unknown elements, have multiple acceptable solutions (or no solution at all), possess multiple criteria for evaluating solutions, and often require learners to make judgments. A very important contribution of David Jonassen (e.g., 1997) is that he was one of the first educational researchers to stress the importance of using ill-structured problems in education and training and much of his work investigated instructional methods for teaching ill-structured problem solving. This definition of problem solving refers to the interpretation of domain knowledge and/or previously encountered cases to come up with possible solution steps. It stresses the importance of deep understanding of a domain in order to effectively solve problems in it. If problem solvers have a good understanding of how things are named and interrelated in a domain (i.e., *conceptual* models), how things work and affect each other in a domain (i.e., *causal* models), and how things are built or organized in a domain (i.e., *structural* models), they may use this general knowledge to restructure a given problem situation and to infer tentative solutions for the problem. Alternatively, they can use their memories of previously encountered cases as an analogy to come up with possible solutions (analogical problem solving; Gick & Holyoak, 1980; Jonassen, 2002). In addition, they may also use domain-specific cognitive strategies that help them approach problems in a systematic fashion and apply rules-of-thumb that help them to successfully complete each phase in a systematic problem-solving process. Knowledge-based methods thus allow one to solve problems in a particular domain of learning but do not guarantee that an acceptable solution is reached: They are heuristic rather than algorithmic. Although knowledge-based methods are much more efficient than weak methods, they are yet slow, error-prone and effort-demanding in comparison with strong methods. The reason is that they refer to the *different* use of the same knowledge, which requires conscious interpretation by the problem solver. This makes knowledge-based problem-solving methods much more flexible than strong methods, which refer to the *same* use of the same knowledge. Most educationalists will argue that knowledge-based methods should be taught in education and, indeed, knowledge is typically taught in the hope that learners will eventually use it to solve problems.

A fourth and final definition combines the perspectives on well-structured and ill-structured problem solving and pertains to *real-life problem solving* (Van Merriënboer, 1997). Whereas the distinction between ill-structured and well-structured problem solving is valid from