The Computer and Problem Solving: How Theory Can Support Classroom Practice


Editor’s Note: This article was published in the December/January 1998-99 issue of The Computing Teacher. It can be considered as a companion to Moursund’s editorial published in the same issue. Yates did his doctorate in the area of computers and problem solving; Moursund was his major professor.

Introduction

Human beings, with their powerful brains and spoken language, have tremendous ability to create and solve problems. They are particularly good at developing aids to problem solving and teaching their children to use these aids. Some powerful and widely used aids to problem solving include reading, writing, arithmetic, and computers. Since one of the major goals of education is to help students get better at problem solving, it is natural that computers are of growing importance in education.

For the first time in the history of humankind, we have a machine that can emulate some of our own thought processes and therefore solve certain problems that in the past could only be solved by people. This has led to increased emphasis on teaching students to think about thinking; the field of metacognition is flourishing.

We believe that every teacher should be concerned with the classroom applications of computers as an aid to teaching, learning, and doing problem solving. Teachers should also be attentive to the educational research on computers and problem solving. The results from such research can guide and strengthen effective classroom practices or call into doubt potentially ineffective instructional methods.

Problem Solving: Some Key Ideas

There are a number of general problem solving heuristics or strategies advocated by researchers and educators that, while not applicable across all disciplines, do seem to capture some qualities that make them useful in more than one discipline. The research literature supports the contention that all students and teachers should gain a working understanding of these ideas, since doing so will likely increase their ability to solve problems.

Many of our formal ideas about problem solving can be traced back to Dewey (1910). Some early researchers (cited in Best, 1986) believed four steps were typically used in solving a problem: preparation, incubation, illumination, and verification. More recently, the mathematician George Polya (1968) suggested a series of general problem solving steps: understand the problem, devise a plan, carry out the plan, and look back to analyze the solution.

More specific to primary and secondary education, Moursund (1988) has synthesized much of the literature and has suggested a problem solving approach that combines certain aspects of John Dewey's philosophy and Polya's model of problem solving. He defines formal problems as
having four qualities: givens, guidelines, goal, and ownership. The givens of a problem are what is known about the problem at the beginning. Guidelines are the steps or rules that can be used to work toward the end state or goal. The goal is the desired end result or situation. The last component, ownership, requires that the person working to solve a problem have some personal investment in its solution. As most problems don't come to us with these qualities delineated, Moursund suggests that a key idea in problem solving is developing a clear understanding of the givens, guidelines, and goal.

**Research on Human Problem Solving Characteristics**

There has been substantial research on problem solving. We list here 19 statements about problem solving with implications for the educational use of computers. Each one has relatively strong support in the research literature. While you can probably find counter arguments or contrary positions to each assertion, there is enough evidence to convince many educators to consider these ideas when making educational decisions.

1. To become an expert in a particular area requires both talent and at least a dozen years of hard work (Bloom, 1985). We need to provide a rich intellectual environment, so a student gains the necessary experience with more and more complex problems within the discipline. It seems evident that in many problem-solving areas, some of the needed experience can come through the use of computer simulations, and that sometimes this is a cheaper and safer approach.

2. Problem solvers who talk about the steps they are taking to solve the problem do better than those who do not describe their efforts (Berry, 1983; Carey&Tarr, 1968). Computer labs should not be "Quiet Zones." Students should be encouraged to talk to themselves and others as they work to solve problems.

3. How we think about (or represent) a problem is a better indicator of the problem's difficulty than any quality intrinsic to the logic of the problem (Fischler & Firschein, 1987; Fredericksen, 1984). Students should learn to make use of a variety of different representations for a problem, including computer representations. Database, spreadsheet, and graphing software provide rich opportunity for generating different problem representations and examining the types of problem-solving approaches that can be drawn from a given representation.

4. Problem solving skills used in groups do not necessarily transfer to individual problem solving skills (Bender, 1986). The research literature supporting cooperative learning is strong (Kohn, 1987). The human interactions that come from working in pairs or as a group during a simulation or other computer-use experience are very important. However, instructional time also needs to be devoted to individual acquisition of problem solving skills, especially if the primary goal is individual problem solving skill.

5. Even with well defined problems, people tend to frame small subgoals, and may not be able to explain why they did so (Greeno, 1976). When a problem seems complex and perhaps overwhelming, the idea of systematically
breaking a big problem into smaller pieces becomes very important. The computer can be used to explore different options (subgoals). When the problem context is appropriate, the use of spreadsheets and word processor can be used to allow different options to be generated and examined in a short period of time.

6. How conscious we are of our thinking processes while solving a problem is dependent on whether we are using a familiar strategy or developing the strategy as we work (Kellogg, 1982). Careful, conscious thinking about problem solving processes helps to improve one's problem solving skills. One model of how people solve problems is that they look for patterns that seem familiar and then apply standard strategies that they have previously found useful when the patterns occur. The capacity of the computer to allow for quick and varied representations of problems (e.g., graphs) may support this type of problem solving by students.

7. We seem to have a few basic general problem solving strategies for dealing with a variety of problem situations (Simon and Simon, 1962). Without specific instruction, many students will fail to develop some widely useful strategies. If we can help students acquire just a few additional strategies, we may make a major contribution to their overall ability to attack a variety of problems. Using the computer to model an event (e.g., simulations) and then providing them with problem solving strategies to apply in that or similar situations can give them a richer repertoire of problem solving strategies.

8. Precise thinking (processing) is one of the keys to strong problem solving ability (Whimbey, 1984). Precise thinking may be represented orally, in writing, in applications software, or through one of the many computer languages available. The main point is that precise thinking is a necessary part of every academic discipline in which people have ideas and points of view they want to communicate. Practicing such careful communication improves one's ability to solve problems in these disciplines.

9. Changing our perspective on a problem often aids in arriving at a solution (Scheerer, 1983). Computers are a powerful and versatile aid in dynamically representing and re-representing data. Databases, spreadsheets, or graphics software can be used to represent and manipulate data to give students practice in examining a problem from different perspectives. 10. Experts outside of their domain of expertise do no better than novices. Good problem solving ability in one area does not carry over to problems in another area (Hayes, 1981; Royer, 1979). Students need a broad and general education in order to understand and cope with the variety of problems they are apt to encounter. Many problems they encounter will relate to technology, and more specifically to computer technology. All students should acquire basic computer literacy.

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11. We improve as problem solvers with experience, but we seem to have difficulty transferring that knowledge to analogous problems in other domains (Reed et al., 1974). Using databases to examine different trends in varying contexts, such as economics and politics, helps increase transfer skills. More generally, all teachers should teach for transfer. When teaching the use of computer tools, they should give ample examples and time for practice in applications to a variety of disciplines.

12. On certain types of problems, the computer has been shown to be a strong problem solving aid (Pogrow, 1985; Stemberg and Davidson, 1982). It is important that students understand the capabilities and limitations of computers as an aid to problem solving within each domain that students study, as well as in a domain free sense. This means that within each domain, the teacher is responsible for helping students to gain domain specific knowledge of roles of computers in solving the problems of that domain.

13. Groups of 2-4 individuals are better than larger groups or individuals at problem solving activities that use computers (Cox and Berger, 1985). This is a statement consistent with other research about cooperative problem solving in a computer environment. It is a statement that "two heads are better than one" and it is also a suggestion that too many heads interfere with each other's work.

14. The more you know about a particular area or the more knowledge you have about a subject, the better problem solver you tend to be on problems within that subject (Best, 1986). There appears to be no substitute for knowing the subject matter domain of a problem. The research in computer-assisted learning indicates that the computer can do as well and often better than traditional methods in helping students to gain basic knowledge and skills over a broad range of subject areas.

15. No general problem solving heuristic applies equally to all disciplines (Groner et al., 1983; Anderson, 1987). The basic modes of inquiry, thought, and problem solving vary greatly across domains. We know that students will get better at this transfer if they receive specific instruction and practice in it. The use of databases, spreadsheets, word processors, and graphing software can be useful in practicing these skills.

16. A prodigious memory may not enhance problem solving skills; but rather, a set of carefully refined problem solving strategies can be a more significant influence on performance in a given domain of discourse (Simon and Simon, 1962). Information retrieval, with and without the use of computers, is an effective substitution for memorization in many cases. In addition, by modeling events using computer simulations, students can develop, test and
refine strategies specific to that problem area and begin to refine problem solving strategies specific to a given domain of discourse.

17. Students who have a positive attitude toward a problem-solving task do better than those who have a negative attitude (Armstrong and Me Daniel, 1986; Ross, 1983). The computer can be a strong motivational element in the classroom by providing a rich world to explore using Logo and other programming languages, games, and software that allow for the constructive interaction between students, and other software that helps facilitate enjoyable interaction with the computer.

18. Problem solving in computer programming doesn't easily transfer to problem solving in other disciplines (Jansson et al, 1987; Ross, 1983). (Also discussed later in this paper.) The teaching of computer programming is not a panacea to improving problem solving skills. Computer programming is an important discipline in its own right, and it could well be an appropriate topic to include in the general precollege curriculum. But doing so may not contribute substantially to the overall problem solving skills of students.

19. Short term, active memory is quite limited in capacity, and is estimated to hold 7 ± 2 "chunks" (Miller, 1957). Computers add a new dimension to the idea of chunking. If we teach students what types of problems are readily solved by computers (e.g., data management tasks of sorting and searching), then we provide them with "chunks" of expertise useful for solving other problems. If we can break a large problem into component problems of the sort that a computer can solve, then we can more efficiently solve a larger problem. In a broad sense, we can consider an artificially intelligent expert system to be a chunk. Increasing availability of such massive and powerful chunks will gradually have a major impact on education.

In summary, these research findings taken as a group suggest that the computer can support and augment the human problem solver. The skillful use of computers in an instructional setting can give the student exposure to problem solving methodologies and a good environment to practice these skills.

**Specific Literature and Ideas on Computers as Aids to Problem Solving**

While the general literature on problem solving is quite extensive, the specific literature on roles of computers in problem solving is rather limited. This section gives the flavor of such research. It provides an indication of some of the things we are beginning to understand about computers and problem solving. However, it is clear that much more research is needed.

Taylor (1980) divides instructional uses of computers into the categories tutor, tool, tutee. In each of these categories, computers are a significant aid to problem solving.

**The Computer as Tool**

One study using spreadsheets examined the role of productive thinking and problem solving. Productive thinking is defined as thinking based on a good comprehension of the problem rather than on rote memorization of facts and figures. Students reported that they experienced greater learning with integrative work using the computer than with repetitive non-integrated assignments involving drill and practice (Borthick and Clark, 1986).
A study by Steinberg et al. (1986), using problems requiring the storage of large amounts of information while applying problem solving strategies, indicated that the computer was a helpful aid to problem solving.

The results of a study by Dubitsky (1986), using an electronic spreadsheet to solve algebra problems, indicated the students were able to understand the workings of the spreadsheet and devised systematic problem solving methodologies and were able to transfer these skills from problem to problem.

Each of the studies cited give support to the proposition that computerized data management systems like spreadsheets and databases should be a strong problem solving teaching tool. One study looking at databases confirms this notion. Students using a computer database can find relevant information, determine if it is sufficient to solve the problem, and sort the information in a way likely to produce a solution better than students using traditional paper and pencil methods (White, 1987).

The Computer as Tutor: Simulations

Simulations that use guided discovery seem to be the best use of a computer simulation as measured by tests of scientific thinking and critical thinking (Rivers and Vockell, 1987).

Studies involving computer simulation in chemistry classes have indicated that the science skills learned using a simulation are as effective as more traditional noncomputer methods and often take less time (Choi, 1987). In a summary article on computer lab simulations, Wells (1985/86), concluded that computer simulations of lab experiments can be as effective as other instructional methods involving labs and paper and pencil exercises.

McClurg (1985) and Yates (1988) studied the use of problem solving software to help improve spatial visualization skills of students. Both studies provide support for use of software involving spatial visualization activities.

The Computer as Tutee: Programming

A 1985 study done by Clements indicated that the Logo group did significantly better than the CAI and control groups on the ability to decide the appropriate domain in which to solve a problem and on solution processes (cited in Massialas & Papagiannis, 1987; for related work see Clements, 1988/89). Another study by Rieber (1987) examined students' abilities to problem solve after being exposed to Logo in a guided discovery educational environment. The results indicate that the Logo group performed better on the problem solving measures than the control group. However, other studies have not shown positive results (Rieber, 1987).

Rose (1983) examined the effect of teaching BASIC programming on tests of logic and problem solving. The results indicate that hypothesis testing was significantly better for the experimental group but no other logic or problem-solving effects were observed.

A study conducted by Jansson et al. (1987) tested the hypothesis that computer programming would improve performance on conditional reasoning tasks. Three separate experiments were carried out using Logo, BASIC, and Pascal. No significant results were found.

Their investigation appears to place the burden of proof on the shoulders of the advocates of computer programming as a means of developing certain thinking skills.
Summary

The computer as a tool is a strong problem solving aid. Teachers using databases can teach important information processing and problem solving skills to students. Word processors and spreadsheets are also important problem solving tools.

Simulations placed in an environment where guided discovery is fostered and metacognitive activities are encouraged show strong indication of fostering problem-solving skills.

The Logo environment is consistent with much of the literature on human problem solving, but other programming environments have little research support that indicates they foster general problem solving skills in students.

[Billy C. Yates, Teachers College, Emporia State University, Emporia, KS 66801; Dave Moursund. ICCE, University of Oregon, 1787 Agate St., Eugene, OR 97403.]

References

This includes only sources cited in the body of the paper. Readers interested in a complete list of references used in researching this paper may contact Bill Yates at the address above.


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