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REFLEXIBILITY IN PROBLEM SOLVING: THE SOCIAL CONTEXT OF EXPERTISE

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ABSTRACT

What are the factors that cause a problem solver to become blocked? And what are the factors that allow a person to become unblocked? These are the motivating questions for a set of studies we conducted of individual and joint problem solving. By constructing an isomorph of the classic "water jar" problems (Luchins, 1942) as a dynamic graphic microworld, we were able to identify several factors involved in producing blocked states. By comparing the behavior of individuals tackling the "missionaries and cannibals" problem to pairs of people solving this problem, we have been able to identify ways in which problem solvers operating in a social context are able to overcome problem solving blocks that are difficult for individuals. These studies point to the importance of "reflection" (evaluation of problem solving results) for flexible problem solving. These results may also account for the difficulty in showing learning in "discovery learning" uses of computers, such as the use of Logo, since such uses also often do not encourage students to reflect on the outcome of their problem solving.

When cognitive theorists and educators examine problem solving, the focus is generally on the initial steps in the problem solving process: problem definition, alternative paths possible to the solution, and the possible problems that arise when people "fail" to discover the relatively easy solution because of negative transfer from other problems or domains.

There is, however, an important part of the problem solving process that is less often described in cognitive research and often is missing from instruction in problem solving. This is the reflection or evaluation of the solution that was found. Was it the best possible solution? The only solution? How was it discovered? Could it be repeated? What justification can the problem solver offer for his or her move?

We often solve problems by looking for the most immediate solution with little concern for other ways that we could have solved the problem. If the problem is never likely to reoccur this method may be appropriate. However, for problems that reoccur, skilled problem solvers will be those who have a deeper understanding of the fit between the problem and the problem solution. We will discuss here several experiments in two different problem solving situations which point to the vital role that reflection play in problem solving.

The Missionaries and Cannibals Problem

One way to get problem solvers to reflect on their problem solving strategies is to put them in a social situation in which they must convince one another that a given move or strategy is the best one.

"There are three missionaries and three cannibals on one side of the river and your task is to get them across the river using a two person boat without ever letting the cannibals outnumber the missionaries on a side of the river." This is a commonly used problem that involves a sequence of eleven steps from initial state to conclusion (Ernst & Newell, 1969; Reed, Ernst, & Banerji, 1974; Jeffries, Polson, Razran, & Atwood, 1977; Levin & Hutchins, 1981). The sequence is difficult to see immediately and finding the solution often involves illegal moves and repetition of moves that do not move the problem solver any closer to the solution.

We had subjects solve this problem in two different conditions. The first is the more standard situation in which a single person manipulates objects that represent the problem while "talking aloud" about the steps of problem solving. The verbal protocols often related what the problem solver was doing, but not why. The plans and strategies remained difficult to infer from the verbal reports.

The second condition was to ask two people to work together to solve the problem. When people solve problems in social settings, they often discuss their plans or reflect on the success of previous actions (Miyake 1986; Suchman, 1985; Martin, 1983). The need for coordinated action and division of labor often leads to shifting responsibility for monitoring and evaluating each action taken by the group.

We had 10 individuals and 10 pairs of subjects solve the problem. All sessions were audiotaped with an experimenter taking notes about things that will not be available from the tape. The notes and the audiotape are used to construct a transcript of the verbal interaction and a problem solving transcript. The problem solving transcripts list all moves either made or considered from the initial state through the eleven steps necessary for the solution of the problem. We used this information to compare the individual sessions with that of the pairs.

Comparison of individual and joint problem solving. There is a very different pattern when a pair of subjects solve the missionaries and cannibals problem than when individual subjects work alone. The single subjects on the average took twice as long, (13.30 minutes for single subjects and 7.09 for pairs), and made more moves (27 to 17) with a higher percent of both illegal (1.2% to .08%) and of repeat (40.2% to 22.4%) moves. The pairs were also better at detecting their own illegal moves or errors while with single subjects it was often necessary for the experimenter to indicate that an illegal move was made.

The single subject's approach to solving the problem was to begin by moving the pieces directly with no evaluation of possible moves. Their verbal reports most often described what they were doing with less description of their plans for solving the problem. Single subjects rarely proposed a move, considered it and then carried it out. Instead the planning was done "on the fly", often with the subjects expressing a sense of frustration about solving the problem. When they ran into problems, they were less likely to begin the problem over. Consequently, when they did solve the problem they had no clear memory of the solution path, because of all the incorrect or backward moves along the way.

Pairs of subjects, on the other hand, were able to solve the problem much faster than they were likely to do it alone. The pairs talked about their moves as did the single subjects, but the nature of the talk was different. The pair's talk was concerned with which of a number of contemplated moves should be made. This type of talk (negotiation and planning) seemed to be productive in finding solutions to problems. The need to justify a move often led to reflection on a given move and an analysis on how it was likely to bring the problem solvers closer to the goal state. The second person also served as a monitor (Miyake, 1986), noting illegal moves and the lack of progress of a given approach. In the cases where pairs of subjects found themselves having difficulty at a particular step in the problem, they were more likely to start over from the beginning the whole sequence of steps. This contrasted to the behavior of the single subjects who would continue to look for a move that would lead them to the end. Thus when the pairs found a solution, they executed it from start to finish with few irrelevant moves. The relative ease at which two subjects solved the problem compared to that of the single subjects suggested that the interaction between the subjects was an important resource for problem solving.

Water Jars to Charged Particles in Zapworld

The second set of experiments reported here is based on the Luchins Water Jar Experiment (Luchins, 1942). In this experiment subjects solve a set of problems using one particular procedure, then find it difficult to give up using that procedure on other problems, even when it is less efficient or even ineffective. What role does reflection play in helping subjects flexibly move beyond a conventional solution to find a better solution?

We implemented an isomorph of the water jar experiments in InterLISP on a Xerox 1108 computer. In this version, which we called "Zapworld", the subject is shown a number of moving objects each with a certain amount of "charge." The goal is to accumulate a specified amount of charge by gaining charge from charged objects (by touching them with a mouse-driven pointer and pushing a button) and by losing charge to uncharged objects.

The problem set contains a sequence of 12 problems. The first 2 are example problems and the next five problems can all be solved by using a particular lengthy procedure. The next two problems (called critical 1 and 2) can be solved by the same lengthy procedure or by a shorter "direct-method" procedure. The 10th or "direct-method problem" can only be solved by the shorter procedure. Then two more problems (critical 3 and 4) were given in which either the long or direct method procedure could be used.

In the classic experiments by Luchins, only 19% of the subjects saw and utilized the direct method for solving the first set of critical problems. His subjects took much longer to solve the direct method problem and only 39% made the shift to the direct method of solution for the last two critical problems.

When subjects worked these same problems in Zapworld we found a surprising result. The subjects did not get blocked on the "critical problems" in the same way as the findings of Luchins would predict. When faced with the first set of critical problems, 63% shifted to the direct method immediately. After the "direct-method" problem 85% shifted to the direct method for the last two critical problems.

We began to use alternate problem isomorphs to understand this result. We used computer printouts of the problem to create a pencil and paper version of the task. Subjects were blocked in this format in a way that was similar to that found by Luchins although the finding was not quite as strong as he reported. When they reached the first set of critical problems 41% shifted to the direct method and 55% shifted to the direct method for the last two problems.

We also compared the strategies that were used by the subjects on paper and on the computer as they worked the first 7 problems.

Solving the problem on paper requires the subject to carry out the arithmetic involved in the problem (which is done automatically in the computer version). So subjects developed and applied a lengthy problem solving procedure that worked for the initial problems. Once this procedure was developed, they continued to use it until they found that it did not work. They were more likely to use the longer procedure over the direct method even after a problem that indicated that the procedure might not work in all cases. The paper and pencil subjects seemed to approach the problem in exactly the way one would predict from the original Luchins data.

The computer implementation of the problems weakened the learning and the automatic application of previously successful strategies. The implementation of the problem on the computer with the mouse pointer enabled the students to play with the problem and not necessarily attend to the computations that are the only strategy available to the person working with paper. The behavior of the subjects was similar to that we had seen in the single subjects' approach to the missionaries and cannibals problem. They could try things out by interacting with the problem, using visual cues to suggest the next action. It was more like what is frequently called the "discovery learning" approach to problem solving. The students tried a number of different strategies with each problem and one subject even discovered a new and original solution to the "direct-method" problem when working on the computer. Another subject was about to use the strategy that had been successful in the past but he made an error in discharging to the wrong particle. The new state created on the computer by this error suggested the direct method of solving the problem.

Since the work with missionaries and cannibals had pointed to the role of evaluation or reflection in problem solving, we decided to try a change in the procedure that would encourage the subjects to reflect on their problem solving approach. The Zapworld procedures were modified so that after each solved problem, the subject had to record how they had solved the problem. Once subjects were asked to record how they had solved the problems, they did appear to develop the same procedure as the subjects who worked on paper and this was confirmed by their performance on the the first 2 critical problems. On this problems, 70% of the subjects continued to use the long procedure. After the "direct-method" problem, we found another surprise. Almost all the subjects, (90%) shifted to the short method for the "direct-method" problem and the critical problems that followed it.

This finding suggests that reflection on the problem solving strategies resulted in a clearer development of a problem solving procedure that is applied for efficiency. But once that strategy becomes less effective, the subjects were able to shift to the direct method with no difficulty.

We were able to constrain the computer environment somewhat by making it a requirement that the subject record the steps that he or she took to find the solution after solving the problem. When forced to record the steps to solution, the problem solvers began to search for the mathematical procedure that could be used to describe the solution. The performance on the first two critical problems indicates that the subjects were more likely to experience the initial problem of being blocked but as soon as a problem required a direct approach, they were the most likely to try this new direct approach on the next set of critical problems.

Implications for Computer-Based Problem Solving Instruction

In both these problem domains we found that reflection on the moves that were necessary for finding the solution led to better problem solving. In the Missionaries and Cannibals, the subjects who worked cooperatively were placed in a situation in which they had to negotiate their moves. The cooperative condition made is necessary for the subjects to explain why a given move was likely to bring them closer to the solution of the problem.

In the Water Jars isomorph, Zapworld, we made it a condition of the task that the subjects stop and explain how they had arrived at the solution of a problem. This reflection on the solution helped focus the attention of the subjects on a productive strategy. Unlike the subjects in the classic Luchins experiments or the subjects that did the same task on paper, the subjects who reflected on the problem solution were able to shift to a new "direct-method" solution procedure with no difficulties.

These findings suggest why problem solving environments on the computer often allow students to do what looks like sophisticated problem solving, but these same students then fail to transfer these problem solving skills to problems in other domains. Research on the effect of Logo on students' problem solving skills has shown little transfer (Papert, Watt, diSessa & Weir, 1979; Pea & Kurland, 1984). If we could arrange for students to reflect on what they have accomplished in these domains, then we might see more flexibility in their application of these skills to other problem domains. Our results suggest that interaction with the computer in such settings might be more effective if there is a reflective stage in which students review what they have done on the computer and why. It may be that some of this takes place naturally when subjects work together on a problem.

This research has focussed on the important step of reflection on problem solving. It suggests that teaching students to analyze what they have done will help them develop flexibility in using a new approach when blocked.

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