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TRANSFER OF TRAINING IN A FAULT DIAGNOSIS TASK

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Two experiments on the learning and transfer of the hypothesis testing strategy of testing easy-to-test hypotheses first were conducted. The first experiment found that this strategy could be discovered and used in a very simple fault diagnosis task but not in a slightly more complicated task. Subjects who learned the strategy in the simple task were able to transfer it to the more complicated task. The second experiment showed far transfer: The learning of this principle of hypothesis testing transferred to a task sharing no surface features with the training task. It is concluded that it is worthwhile to train people on the use of fault diagnosis strategies.

When a complex system fails, there are invariably several possible causes of the system malfunction, and, to locate the source of the problem, one must search through these possible causes until one locates the "bug," or error. During this search, people can be plagued by the biases that typically affect judgment (i.e. recency, availability, etc.). This paper explores the hypothesis that search is often hindered because people look for very complex reasons for system malfunction when the real problem is quite simple.

A computer user, for example, may experience difficulty in printing a document. The user issues the command and nothing happens. Perhaps the user then refers to the manual to make sure he or she used the correct command sequence. The user might then examine the system files on the computer to try to determine why the document will not print. The user contacts the computer company's help desk by telephone. The company consultants retrace the steps in creating and printing the document and find nothing wrong with the sequence of steps that the user followed. Finally, the user notices that the printer is not plugged in.

The research reported here examines how people select hypotheses for testing in a diagnostic task. The emphasis is on developing and training an efficient strategy for selecting hypotheses for testing and on transferring that strategy to different types of diagnostic problems.

The theory of hypothesis testing presented by Levine (1975) provides an excellent framework for understanding troubleshooting and debugging. According to Levine, hypotheses are grouped into *domains*, or subsets, of related hypotheses within the universe of hypotheses. One domain might contain hypotheses about features of the stimuli (size, shape, etc.), whereas a second domain might contain hypotheses about the sequence in which stimuli are presented. An important aspect of Levine's theory is the "infinite-set assumption," which states that a subject sampling from an incorrect domain that is infinitely large will never solve the problem. Fingerman and Levine (1974) showed that the vast majority of subjects who were trained to solve a series of complex position-sequence problems could not solve a simple discrimination problem. Lane, McDaniel, Bleichfeld, and Rabinowitz (1976) extended Levine's theory by finding that subjects are more likely to switch from a simple domain to a more complex one than *vice versa*.

Levine's theory provides an elegant account of the Einstellung phenomenon (Luchins, 1942) as well as examples of fault diagnosis procedures in which the people overlook extremely simple solutions. Levine's theory is also important because it underscores the importance of hypothesis selection strategies.

Ashby and Lane (1988) investigated the efficiency o hypothesis selection using a task in which some hypoth eses could be tested easily whereas others required mor time and effort. Subjects were presented with five alge braic equations of varying complexity (the hypothesis domain) and were told that they were to find the one equation that contained an error. Subjects were told explicitly that each equation had an equal chance of containing the error so as to rule out the possibility that subjects would test the more complex equations first thinking that they were more likely to contain the error. Subjects selected a hypothesis to test and were then shown the values for each variable in the equation. From this they could determine if the equation was correct or incorrect. The most efficient hypothesis selection strategy is to test the easiest-to-test hypotheses first. Interestingly, only one of Lane and Ashby's 16 subjects began the task by using the optimal strategy of testing the easiest hypotheses first, and, although most subjects learned the strategy in 20 trials, almost one-third of the subjects were still not using the optimal strategy by the 20th trial. It is striking that college students would have such a difficult time with such an easy task.

In a second experiment, Ashby and Lane modified the task by adding a second bug or incorrect equation to each group of five. Only one of the nine subjects in this condition started out using the optimal strategy. In this only slightly more complex condition, however, there was still only one subject who was using the optimal strategy after twenty trials (it was the same subject who began by using this strategy). There is no ready explanation why this slight modification in the task would make it so much harder for subjects to find the optimal hypothesis selection strategy.

It is clear, then, that in a very simple task, people can learn to use the optimal strategy for hypothesis selection in a diagnosis task, but in an only slightly more complex task, people fail to learn the optimal strategy. Experiment 1 of the present research first attempted to replicate Ashby and Lane's (1988) findings and then address the question of whether the learning exhibited by subjects in the simple one-bug condition would transfer to the similar but slightly more complex two-bug condition. Experiment 2 examined the transfer of this learning to a new and different task.

EXPERIMENT 1

Method

Subjects. Twenty four Rice University undergraduate students participated for required credit in undergraduate psychology courses. Subjects were randomly assigned to either the Experimental or Control Group with the constraint that there be an equal number of subjects in the two groups.

Equipment. The experiment was programmed in Hypercard and run on an Apple Macintosh LC.

Procedure. The Experimental Group received 40 sets of algebraic equations with five equations in each set to represent five hypotheses in a specific hypothesis domain. The five equations differed greatly in complexity. Subjects were asked to find the one equation in each set that was incorrect. They were told that each equation had an equal probability of being the incorrect one (indeed, the "bug" was placed randomly in each set by the computer). An equation was selected for testing by clicking the mouse button on the "test" button to the left of each equation. The selected equation was then presented with a set of values for the variables and with a "correct" and "incorrect" button. Subjects clicked on the appropriate button and were either transferred to the next set of five equations (if this was indeed the "bug") or returned to the original set to continue sampling. A check mark was placed by previously-sampled equations (hypotheses) as a bookkeeping aid so that subjects would not feel compelled to test sequentially to avoid retesting any particular hypothesis. After 20 sets, the subjects in the experimental group were given a ten-minute break during which they were encouraged to get a drink, go to the rest room, go outside and relax, etc. At the end of the break they were presented with another 20 sets of five equations each. This time they were told that two incorrect equations were in each set and that the program would only transfer them to the next set after both "bugs" had been found.

The Control Group went through a similar procedure, only both groups of 20 (before and after the break) contained two "bugs" in each set of five equations.

Results

To simplify scoring, each set of 20 problems was divided into five blocks with four problems in each block. A point was given each time the subject used the optimal strategy. There were, therefore, four possible points to be earned in each block. To be considered an optimal strategy, a subject had to test the equations in order from least to most complex until the "bug" was found. The main findings are graphically represented by the box plot in Figure 1.

Ashby and Lane's results were replicated: Subjects in the two-bug condition were much poorer at choosing the optimal strategy than were subjects in the one-bug condition. Further replicating Ashby and Lane, subjects in the two-bug condition showed no signs of learning to use the optimal strategy even over a large number of problems.

Figure 1 also reveals that experimental subjects had no trouble transferring their use of the optimal strategy from the one-bug to the two-bug conditions. The Experimental Group performed significantly better overall than the Control Group, $F(1,22) = 159.44, p < .01$. The interaction between Group (Control vs. Experimental) and task (Training vs. Test) was also significant, $F(1,22) = 4.96, p = .036$.

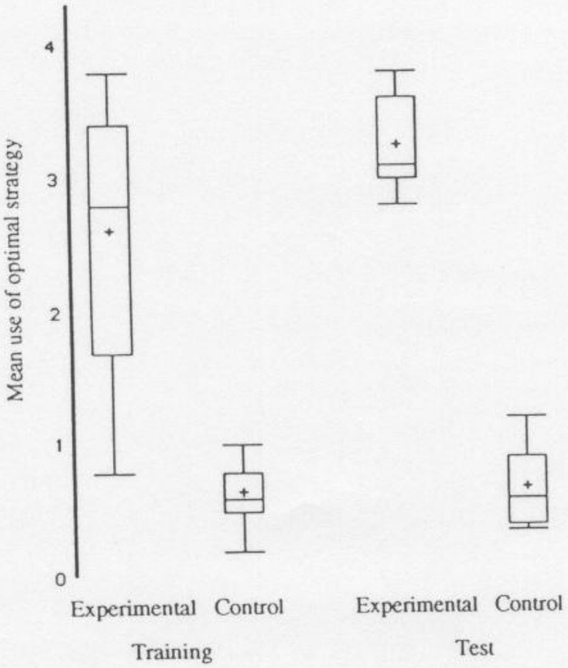

Figure 1. Box plot identifying mean number of times subjects used the optimal strategy (per block of five trials) as a function of condition. (The "+" sign indicates a group's mean and the horizontal bar its median.)

Discussion

As found previously by Ashby and Lane, very bright college students failed to apply the seemingly obvious principle of testing simple hypotheses first in solving a diagnostic problem. When the subjects who learned to apply the principle in the one-bug condition continued to apply it in the two-bug condition, they were exhibiting what Detterman (1993) defines as near transfer. The training task and the test task shared surface features (algebra problems as hypotheses, etc.) and were differentiated only by the fact that the training problems contained only one incorrect equation while the test problems contained two.

It is interesting to note that these findings represent a sort of reverse practice. Reverse practice occurs when practice on Task A produces more improvement in task B than does practice on Task B. In this experiment, practice in the one-bug condition facilitated performance in the two-bug condition whereas practice in the two-bug condition did not improve performance in the two-bug condition.

EXPERIMENT 2

Experiment 2 was designed to determine whether the hypothesis testing strategy learned in the one-bug condition would transfer to a different type of problem. Once again, hypothesis sets consisting of algebraic equations served as a framework for training the "test the easiest-to-test hypothesis first" principle. A simple checkbook balancing task with which almost all adults are familiar served as the transfer task.

The two tasks share no common surface structure or identical elements which, according to Detterman's (1993) definition is a requirement for far transfer. Neither were any hints (explicit or otherwise) given as has been the case in many studies which claim to find transfer (Detterman, 1993). Subjects were not told of any relationship between the two problems.

Method

Subjects. The subjects were forty students enrolled in an introductory psychology course at a Houston area community college who volunteered in order to learn more about experimental design and technique.

Equipment. The computer portion of the experiment used the same Hypercard program as in Experiment 1. The checkbook balancing portion of the experiment consisted of simulated checks and checking account statements printed with an Apple Laserwriter. For the checkbook portion, subjects were given a simple calculator with large keys suitable for basic mathematical functions.

Procedure. Subjects were randomly assigned to either a Control or Experimental Condition. In the Control Condition, subjects were given the same two-bug problems as in Experiment 1 (in which the optimal strategy was never learned) and then were presented with five checkbook balancing problems which included one of two possible types of bugs. The first type of bug consisted of a clerical mistake that could be quickly and easily tested for by comparing the amounts on the checks with those listed in the bank statement. The second type of bug was a logical problem (i.e., a deposit was subtracted rather than added, a service charge was overlooked, etc.) which was a great deal more difficult to test.

In the Experimental Condition, subjects were give the same one-bug problems as in Experiment 1 (in which the optimal strategy was learned) and then presented with five checkbook type problems. Location of the bug was random both in the algebra problems and in the checkbook problems.

The independent variable, then, was training condition in the algebra problems (one-bug vs. two-bug) and the dependent variable was performance on the bug location task in the checkbook problems. Both the type of hypothesis tested first (easy to test or hard to test) and time to solve the problems were measured.

The Experimental but not the Control Group was expected to learn the optimal strategy with the algebraic equations. Transfer would therefore be indicated by superior performance by the Experimental Group on the checkbook problems.

Results and Discussion

As in Experiment 1, subjects working on the one-bug problems (the Experimental Group) learned the optimal strategy whereas subjects working on the two-bug problems did not. The most important finding from this experiment is that subjects in the Experimental Group carried this learning over to the checkbook problems, where they tested the easier-to test-hypotheses more often ($\overline{X} = 8.4$) than did the Control Group ($\overline{X} = 6.6$), $F(1,38) = 28.239$, $p < .001$.

The time to complete a particular bank task was significantly lower in the Experimental Group than in the Control Group, $F(1,38) = 11.794$, $p = .0015$. This underscores the simple to complex method of hypothesis testing as the most efficient strategy.

Finally, evidence that subjects who performed well in the training (algebra) task were the same subjects who performed well on the transfer (bank statement) task is provided by a correlation coefficient of .646, $t(18) = 3.59$, $p<.01$ for the Experimental Group. The correlation of .112, $t(18) = .479$, $p=.638$ for the Control Group was not significant.

GENERAL DISCUSSION

This research suggests that the principle that one should test easy-to-test hypotheses first can be learned and applied to other tasks that are similar (near transfer) and to tasks that are dissimilar (far transfer). Although this strategy might seem obvious, it is clear that few people apply it spontaneously even in simple diagnostic problems.

Successful transfer of a general principle from one type of task to another is the exception in the transfer of training literature (Detterman, 1993; Singley & Anderson, 1989). Detterman (1993) made a vehement argument against the existence far transfer citing the fact that many studies of problem solving (Gick & Holyoak, 1980; Weisberg, DiCamillo, & Phillips, 1978) find transfer only in the presence of explicit information given to ensure that the solver connects the training problem with the test problem. In some experiments in which transfer was obtained, the training task and transfer task shared identical elements, supporting the idea that high fidelity between tasks is a requirement for transfer. In others, hints given to subjects were required to generate transfer of an abstract principle from a training task to target task

Experiment 2 indicates that the training task does not have to be similar to the transfer task for the learning of the principle "test the easy-to-test hypotheses first" to transfer. At a minimum, this general problem solving skill can be taught at a rather fundamental level without concern for fidelity between training and transfer tasks.

Much more needs to be learned about the role of hypothesis selection strategies in "real-world" fault diagnosis. Despite the fact that debugging costs constitute a major portion of software costs (Brooks, 1972), debugging strategies are not normally emphasized in computer science classes. There is much anecdotal evidence of people spending countless hours testing complex hypotheses when the bug is actually very simple error. Of great interest is whether this waste of important time and resources could be lessened by training people in strategies for fault diagnosis.

The identification of a particular component of diagnostic problem solving and, more importantly, the exhibition of transfer in the training of this skill, lends hope to the possibility of training of fault diagnosis. Although many questions about fault diagnosis and the best way to train diagnostic skill remain unanswered, the present findings provide a strong indication that principles of fault diagnosis can be trained.

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