Problem Solving and Prior Learning
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Problem Solving and Prior Learning

by
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Good teachers have long observed that when information is given is just as important as what information is given. The implications of this observation are of real concern to all educators, particularly teachers of mathematics and science. Nonetheless, most specialists in education would be hard pressed to explain the mechanisms involved. A better understanding of these mechanisms is imperative if present developments in instructional technology are to reach their full potential. Still, the number of controlled studies which have dealt with this problem are small. Those which involve reading extended passages of technical materials have been almost nonexistent; yet, this is precisely the way in which most students learn such materials at the high school and college levels. The purpose of this project was to explore various ways in which prior (prerequisite) learning might affect the learning of higher order (criterion) material which builds on this foundation. Major emphasis was given to identifying important variables and assessing their relative strengths. Towards this end, three major experiments and one supplemental experiment were conducted.

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Objectives

The purpose of Experiment One was to determine the effects of practice at the prerequisite and criterion levels on the learning, transfer, and retention of some criterion material, as evidenced by the solving of problems defined at the criterion level. Criterion practice involved the same type of problems used to assess learning. It was hypothesized that unless the prerequisite material was sufficiently well practiced, the learning of higher order material, whose description involved prerequisite terminology would be relatively poor. Since the tests for transfer and retention provided only indirect measures of criterion learning, the effects of the independent variables were expected to be less on these measures.

Experiment Two was designed to determine whether information about problems is necessarily reflected in problem solving performance. It was hypothesized that prerequisite information facilitates algorithm learning only when the information is specifically used to describe the algorithm. Other information about problems reflects itself only to the extent that the algorithm, as a method, is inadequate to solve transfer problems and to the extent that the information provides a basis for additional positive transfer.

The most encompassing experiment (Three) was concerned with the effects
of, and interactions between, three independent variables: (1) amount of prerequisite learning prior to instruction, (2) order of presenting prerequisite learning prior to instruction, and (3) prerequisite practice. Learning was assessed at various levels of familiarity with the criterion materials and problems. It was hypothesized that: (1) criterion learning, as judged by problem solving performance can be manipulated by prerequisite learning—only a non-causal relationship has been demonstrated in previous studies, (2) prerequisite learning facilitates problem solving by increasing the degree of criterion learning and not by facilitating problem solving directly—this hypothesis was tested by varying the order of presenting prerequisite and criterion materials, and (3) prerequisite practice facilitates criterion learning only when the prerequisite material comes before the criterion.

The supplementary experiment was conducted to determine the feasibility of extending the results of the first three experiments to actual subject matter like mathematics. Two variables were manipulated, criterion form and prerequisite practice. The criterion was described using either the prerequisite terminology or already familiar terms. In view of the earlier results, an interaction was predicted between prerequisite practice and criterion form. Practice was assumed to facilitate criterion learning only when the criterion description involved use of the prerequisite terms.

Procedure

In the first three experiments, some artificial material, constructed and published earlier by the author, was used to minimize the contaminating influence of uncontrolled individual differences in related knowledge. Four mathematical topics, unfamiliar to the students involved in these experiments, were used in the supplementary fourth experiment. In each of the experimental and control treatments, one part of the experimental material was designated criterion and the rest, prerequisite. Both the prerequisite and criterion materials were presented in paragraph form. The words, symbols, and/or graphic materials used to denote prerequisite notions were also used in presenting the criterion material (except as specified below). Prerequisites, which were logically determined, refer to those statements of principle which apparently need to be understood before new material, whose description involves reference to these prerequisite principles, can be mastered. Operationally, understanding meant that the principles could be applied. In the first and third experiments the criterion material consisted of a definition of the training problems, an illustrative problem and its solution, and pointing out relationships between the problem and its solution. In the second experiment, the criterion material consisted essentially of an efficient algorithm for solving the training problems. Each criterion topic, used in the fourth study, consisted of a description of a simple mathematical concept, one of which was matrix multiplication. Learning, transfer, and retention test problems were constructed for use in the first two studies. The third experiment involved only learning and transfer problems, while the fourth involved a test based directly on the criterion material.

The subjects used in the first two experiments were high school juniors taking college preparatory mathematics, 80 in Experiment One and 84 in Experiment Two. The third and fourth experiments were conducted with college students enrolled in a mathematics education course for elementary teachers. There were 165 students in Experiment Three and 32 in Experiment Four. Participation was a class requirement in each case.
The first two experiments were conducted in parallel fashion, each dealing with a separate aspect of the overall problem. In the first experiment, entitled "Problem Solving and Prior Learning," two variables were manipulated independently, practice in applying prerequisite material and practice in solving the problems defined at the criterion level. In each case, feedback was given.

The experiment entitled "Algorithm Learning and Problem Solving" was concerned with the amount of information about problems and its effects on the ability to use and generalize an algorithm for solving similar problems. There were four levels of this variable: no prerequisite material at all, only that part of the prerequisite material deemed necessary for learning the algorithm, information deemed necessary for promoting transfer and, finally, definition of the problems themselves.

The third experiment, entitled "Prior Learning, Presentation Order, and Prerequisite Practice," involved a 2x2x2 factorial design along with three control treatments. The variables were: (1) amount of prerequisite training prior to actual experimentation, (2) order of presentation of the prerequisite and criterion materials, and, (3) prerequisite practice. In one control, none of the prerequisite material was learned either before or during the experiment. In another, some of the prerequisite material was learned just prior to the experiment; the rest was not presented during the experiment. The third control group prelearned all of the prerequisite material prior to the experiment. All of the experimental subjects were tested on the training problems after the criterion had been presented once and six times thereafter, interspersed with repeated presentations of the criterion, additional hints and test problem feedback.

The fourth experiment, entitled "Prerequisite Practice and Criterion Form in Mathematics Learning," involved basically a 2x2 factorial design with repeated measures. The original design, in which each experimental subject received each treatment, involved four mathematical topics which were originally unfamiliar to the subjects (i.e., matrix multiplication, derivative of polynomials, divisibility rules, and the game Nim). Both materials and order of presentation were counterbalanced over treatments. Unfortunately, the basic design was contaminated when the regular instructor gave the subjects a homework assignment which was directly relevant to one set of materials and indirectly to another.

Each experiment was run in groups of between 15 and 40 subjects. The subjects were simply instructed to study the material as they would be tested on it. The first two experiments were experimenter-paced. The third and fourth were self-paced since holding time constant, in Experiments One and Two appeared to serve no useful purpose and since self pacing frequently reduces uncontrolled variance. In the third experiment, those involving pre-training were taught in one room while the others discussed some unrelated mathematics problems in a second classroom. After pretraining, all of the subjects were brought together in a single room for the experiment. Where possible, directions were given by tape recorder for uniformity.

The primary dependent variable in these experiments was the percentage of correct or partially correct solutions given to the test problems. In addition, learning and test time, along with the amount of work shown on the papers, was recorded, where appropriate. These latter measures were not particularly helpful, however, since they probably reflected both learning and motivation (persistence factors).
Standard analysis of variance procedures provided the basis for most of the inferences. Nonetheless, other measures and techniques were used where they seemed appropriate. For example, correlational measures were used to estimate test reliabilities (which were about .90). In addition, the contamination problem noted in Experiment Four made it necessary to use more general linear regression methods to analyze the data.

Results

The results of Experiments One and Two were essentially as predicted. Practice at the prerequisite level, with feedback, facilitated problem solving performance whereas criterion practice did not (Experiment One). The corresponding effects on the transfer tests, however, were smaller. In Experiment Two, exposure to information about problems reliably improved problem solving performance, via an efficient algorithm, but only when the information was either specifically used to describe the algorithm or clearly provided a basis for modifying the algorithm taught so as to make solution of the transfer problems possible. Other information about the problems, and particularly definition of the problems, did not facilitate problem solving in any case. The results of Experiment Three were also as predicted: (1) prelearning the prerequisite material had a highly reliable facilitating effect on problem solving, (2) problem solving performance was better when the prerequisite material was presented first and the criterion second than when the order was reversed—the effect disappeared after repeated reintroduction of the criterion, and (3) prerequisite practice improved problem solving only when the prerequisite material came before the criterion—the practice effect was relatively weak and transitory. Finally, although only half of the Experiment Four data was usable, the results were in the predicted direction (at the .10 level). Prerequisite practice facilitated criterion learning only when prerequisite terminology was used in describing the mathematical criteria.

Perhaps the major result of the entire project, however, was unanticipated. This concerned the long-lasting effect of prerequisite prelearning on criterion learning in Experiment Three. The repeated reintroduction of the criterion, along with additional hints and practice in solving the training problems with feedback, failed to diminish the superiority originally evident with the pretrained groups.

Conclusions

Although there were a variety of peripheral results, four fundamental conclusions may be drawn from this project.

1. Practice in applying prerequisite terminology significantly improves the learning of higher order material, as judged by criterion test performance, when the description of the criterion material involves prerequisite terminology (Experiments One and Four). This conclusion implies that teachers, particularly of mathematics and probably of science, should be careful to make provision for practice with newly introduced prerequisite terms before using these terms to describe higher order materials. This is not always done in high school and college classrooms.

2. The effects of prerequisite practice obtain only when the criterion description involves use of prerequisite terminology (Experiments Two and Four). In effect, there are often alternative means available for achieving a desired objective and these should be considered in those cases where the teacher is primarily interested in promoting acceptable criterion performance with the least expenditure of time. This possibility was demonstrated in Experiment Two.
by the use of an efficient algorithm and in Experiment Four by the use of alternative criterion descriptions in familiar, as opposed to prerequisite, terms. An incidental implication of this conclusion, rather glaringly evident in Experiment Two, is that it is possible to solve problems and even generalize solution procedures to new problems without even knowing what the problem is. This finding suggests that understanding is an imprecise term. The educationally relevant question is not understanding versus no understanding, but simply what is learned.

3. Learning prerequisite material, via practice or otherwise, does not affect criterion test performance directly, but indirectly by increasing criterion learning. This conclusion may be drawn from the Experiment Three result in which the order prerequisite-criterion was superior to the order criterion-prerequisite. The interaction between prerequisite practice and presentation order (Experiment Three) provides further support. This conclusion makes it possible to discard the possibility that prerequisite learning simply amounts to learning part of the task or that a substantial amount of criterion material can be retained and then correctly interpreted when the prerequisite meanings later become available. Insofar as possible, prerequisites should be taught first and not after the criterion to insure efficient learning.

4. The most far-reaching conclusion to be drawn from this project is that learning ability is far from innate; it depends fundamentally on the amount of prerequisite learning already available. Furthermore, it may be concluded that spending more time on criteria and having an opportunity to practice on related problems, cannot be expected to diminish the advantage of prior prerequisite knowledge. Presumably, the only way this can be done is by going back and teaching the prerequisites to the lacking students.

The practical implications of this conclusion seem clear. Just because a student from one of our top high schools, for example, does a better job in college calculus than a student from an underprivileged background, is no reason to believe that this same outcome would obtain if the underprivileged student had had the opportunity of equivalent prior training. Since the effects of such pretraining are probably cumulative, we need to devise ways of salvaging those students who would normally fall by the wayside, probably by individualizing instruction. Although developmental activities are needed now, it should be emphasized that we know precious little about the fundamental bases on which individualized instruction rests. Clearly, more basic research on this problem is needed.

There are 29 different references listed in the final report.

All four experiments, conducted during the course of this project, have been accepted for publication in the Journal of Experimental Education. The will appear simultaneously, some time during 1966, under the titles:

(1) Problem Solving and Prior Learning,
(2) Algorithm Learning and Problem Solving,
(3) Prior Learning, Presentation Order, and Prerequisite Practice in Problem Solving, and
(4) Supplement: Prerequisite Practice and Criterion Form in Mathematics Learning.