EXPOSITORY TEACHING OF HIERARCHICAL SUBJECT MATTERS

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Experiments in which two or more teaching methods are compared as to effectiveness have been notorious for their inconclusiveness. In one study, method A might result in superior learning whereas, in another study, method B might prove to be best. More frequently, there are no significant differences at all.

In conducting a series of exploratory studies in the classroom, each comparing one expository method with one discovery method, Scandura (1964b) was able to identify one of the major reasons why such comparisons have not been definitive. Relatively minor within-method differences seemed to have a greater effect on the experimental outcomes than differences in the methods (i.e., expository and discovery) themselves. Nonetheless, the situation did not appear hopeless. In each of the experiments conducted, the major determining factor appeared to be the timing of the information given. Good teachers, of course, have long observed that when information is given is just as important as what information is given. Nevertheless, most teachers and even college teachers of teachers, would be hard pressed to explain the mechanism involved.

A better understanding of the underlying causes and effects of timing might well help to improve existing methods courses for teachers of mathematics and other hierarchical subject matters and, in turn, teaching in the schools. Still, the number of controlled studies which have dealt with this problem is small indeed. Those which involve reading technical materials have been almost non-existent; yet, this is precisely the way in which the learning of most hierarchical subject matter takes place.²

Although timing may be crucial, it is not always possible to tap and make effective use of learner feedback when teaching by expository methods or in preparing expository material. Not only must the prerequisites to learning be identified, but techniques are needed to help insure the attainment of these prerequisite abilities before higher order information is presented. In effect, timing must be characterized in terms of variables under the direct control of the teacher or writer.

The general purpose of this research was to identify factors affecting the learning of hierarchically arranged expository material and to help determine the relative strengths of these factors. Familiarity with the ideas denoted by the signs (i.e., symbols and icons) used to describe higher order material was given the major emphasis. Towards these ends, four experiments were conducted. All of the instruction took place via carefully prepared text-like passages and practice exercises.

Method

To minimize the contaminating influence of uncontrolled individual differences in related knowledge, an artificial, hierarchically ordered subject matter was used in the first three experiments (Scandura, 1964a). Four levels of this material were identified for experimental purposes. At level one were 12 one-to-one correspondences between certain display properties and the symbols which

¹The research on which this paper is based was supported by the U. S. Office of Education (Project S-097). The four research reports on which this paper is based were published in The Journal of Experimental Education during the summer and fall of 1966 (see Scandura, 1966a, b, c; Scandura & Behr, 1966).

²This statement should not be taken as an endorsement for expository (as opposed to discovery) learning but simply as a matter of fact.
denoted these properties. At level two, 2 display labels were introduced together with a means for
deciding, for each set of symbols, whether it was or was not associated with any given labeled display. Level three consisted of defining the problems (i.e., finding all symbol sets associated with each of the 3 labeled displays comprising a problem) and pointing out some of the relationships between an illustrative problem and its solution. In no case was information given as to how the solution was obtained. Level four consisted of an efficient algorithm for solving those problems defined in the level three materials and used to test for learning. This algorithm was potentially generalizable to other problems.

The words, symbols, and/or graphic materials used to denote the ideas introduced at the lower (prerequisite) levels were, in each case, also used in describing the high order (i.e., higher level) material. In the first three experiments, the criterion test consisted of problems similar, in varying degrees, to those defined in the level three materials.

Experiment One

The purpose of Experiment One was to determine the effects of practice on prerequisite\(^2\) (levels one and two) tasks and practice on problems defined at the criterion level on the solving of additional criterion-type problems and transfer problems. It was hypothesized that unless the prerequisite material was sufficiently well practiced, the learning of the higher order material (whose description involved prerequisite terminology) and, hence, of problem solving would be relatively poor. Since the transfer problems provided only an indirect measure of criterion learning, the effects of the independent variables were expected to be less on these problems.

In effect, two variables were manipulated independently, prerequisite practice and criterion practice. The 80 high school juniors who participated in the experiment were simply instructed to study the material as they would be tested on it. They were allowed to check their answers to the practice tasks. The experiment was run in groups of about 20 and the experimenter allowed specific periods of time for each phase of the experiment.

The results were essentially as predicted. Practice at the prerequisite level, with feedback, significantly improved problem solving performance whereas criterion practice did not. The corresponding effects on the transfer problems were smaller.

Experiment Two

Experiment Two was designed to determine whether information about the nature of problems is necessarily reflected in problem solving performance. It was hypothesized that information facilitates algorithm learning (level four) only where it is logically impossible to perform the algorithm without already having mastered this (prerequisite) information. 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 to such problems. The amount of information given about the problems was varied. One group of 21 high school juniors received no prerequisite material at all; a second, received only that part of the prerequisite material (level one) deemed necessary for learning the algorithm; a third, also received information deemed necessary for promoting transfer (levels one and two). The fourth group received all of this information together with the level three material in which the problems were defined and illustrated. Practice, together with knowledge of results, accompanied each level of material introduced. In other respects, the experiment was similar to experiment one.

Again, the results were as hypothesized. 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.\(^4\)

Experiment Three

The most encompassing experiment (Three) in the series was primarily concerned with the effects of, and interactions between, three independent variables. In addition, learning was assessed at various levels of familiarity with the criterion materials and problems. The following hypotheses were made. First, criterion learning, as judged by problem solving performance, can be manipulated by prior prerequisite learning (pretraining)—only a non-causal relationship has been demonstrated in previous studies. Second, prerequisite learning facilitates problem solving by increasing the degree of higher order (criterion) learning and not by facilitating problem solving directly—this hypothesis was tested by varying the order of presenting prerequisite and criterion materials. Superior performance, resulting from the order prerequisite-criterion, was presumed to provide positive support for

\(^2\)The term prerequisite is used in this paper to indicate a logical relationship between subject matters. One subject matter is said to be prerequisite to another if it is logically impossible to learn the second subject matter without already having mastered the first. In this sense, being able to count prerequisite to an ability to determine the number of elements in all but very small sets.

\(^4\)This finding clearly provides support (in a neutral setting) for the widely held belief that children can learn to perform arithmetic computations without knowing what they are doing. More important, it emphasizes the futility of talking about such things as meaning and understanding independently of their operational definition in behavioral terms (see conclusion two).
this hypothesis. Third, prerequisite practice facilitates criterion learning only when the prerequisite material comes before the criterion.

A 2 x 2 x 2 factorial design was used in conjunction with three control treatments. The variables were: (a) amount of prerequisite knowledge (pretraining) prior to the actual experimentation; (b) order of presentation of the prerequisite and criterion materials; and (c) prerequisite practice. In one control group, none of the prerequisite material was learned either before or during the experiment. A second control group learned some, but not all, of the prerequisite material just prior to the experiment. The third control group prelearned all of the prerequisite material prior to the experiment. Each of the 165 elementary school teachers who served as experimental subjects was tested on the training problems both after the criterion had been presented once and six times thereafter, each time interspersed with repeated presentations of the criterion, additional hints, and test problem feedback.

The third experiment was 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. All of the subjects reported for the experiment at the same time. Those subjects receiving pretraining 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.

Many of the results of Experiment Three were also as predicted: (a) pretraining had a highly reliable facilitating effect on problem solving; (b) 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 (c) prerequisite practice improved problem solving only when the prerequisite material came before the criterion but this effect was relatively weak as compared to the former two effects. Perhaps the major result of the entire project, however, was unanticipated. This concerned the long-lasting effect of pretraining on criterion learning in Experiment Three. The repeated reintroduction of the criterion, along with additional hints and practice in problem solving with feedback, failed to diminish the superiority originally evident with the pretrained groups.

Experiment Four

The fourth experiment was conducted to determine the feasibility of extrapolating to mathematics from the results of the first three experiments. Two variables were manipulated, criterion form and prerequisite practice. The criterion was described by 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 the use of the prerequisite terms.

Originally, a 2 x 2 factorial design with repeated measures was planned. This 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 (his students) a homework assignment which was directly relevant to one set of materials (divisibility) and indirectly to another (NIM).

General linear regression methods were required to analyze the uncontaminated data. Although only half of the Experiment Four data were 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 higher order mathematics.

Conclusions and Implications

Four major conclusions may be drawn from this research.

1. Practice on prerequisite tasks significantly improves the learning of higher order material, as judged by criterion test performance, when the prerequisite terminology is used to describe this higher order material (Experiments One and Four). While this conclusion is hardly earth-shattering, one has only to witness what goes on in many classrooms to see that many teachers fail to take this fact into account. Fortunately, elementary school teachers are typically far more inclined to provide ample practice at prerequisite levels than their counterparts at the high school and college levels.

As in the previous experiments, the primary dependent variable was the percentage of correct or partially correct solutions given to the test problems. In addition, learning and test times were recorded. These latter measures, however, did not lend themselves to direct interpretation since they probably reflected both learning and motivation factors (e.g., persistence) in unknown proportion.
2. Knowledge had by a learner affects future learning ONLY when this knowledge is prerequisite to the to-be-learned material (Experiments Two and Four). In Experiment Two, for example, the learners were able to solve problems and even generalize the algorithmic solution procedure to new problems without even knowing what the problem was. This particular finding suggests that understanding is an imprecise term. The educationally relevant question is not understanding versus no understanding, but simply what is learned (see Footnote 4).

3. The possibility that prerequisite learning simply amounts to learning part of the criterion task or that a substantial amount of criterion material can be retained and then correctly interpreted when the prerequisite meanings later become available is untenable (Experiment Three). 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 provides further support. On this basis, it would appear to be poor practice to present higher order concepts first and then shore up deficiencies; rather, the reverse order of presentation seems indicated.

4. Simple exposure to prerequisite information is often not sufficient to insure later learning. Furthermore, spending more time on higher order material and having an opportunity to practice on related criterion problems, cannot normally be expected to overcome prerequisite inadequacies (Experiments One and Three). Since the effects of inadequate prior knowledge are undoubtedly cumulative and since (by conclusion 3) it is inefficient to make up prerequisite deficiencies after students have wasted time trying to learn higher order concepts, the task of salvaging students who would normally fall by the wayside is made doubly difficult. It would appear that there is little room for error. It is urgent that we learn more about both the proper sequencing of materials and how to determine when students have the necessary prerequisites. Clearly, more basic research on these problems is needed.

References