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AUTHOR	Mayer, Richard E.
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ABSTRACT

Five instructional techniques for increasing the meaningfulness of technical or scientific information are summarized: (1) organization of prose: (2) use of concrete analogy and advance organizers: (3) use of inserted questions in prose: (4) elaboration activities such as note taking: and (5) discovery learning. Research on each technique is reviewed from the viewpoint of the student, with attempts made to describe how these techniques influence information processing events during learning. Examples are presented representative of the research by the author in the field, and conclusions are drawn from his expertise concerning systematic and predictable ways that instructional techniques influence the learning process. (CS)

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Department of Psychology
University of California
Santa Barbara, California 93106

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SERIES IN LEARNING AND COGNITION

What Have We Learned About Increasing the Meaningfulness of Science Prose?

Richard E. Mayer

Report No. 81-4

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Introduction

This paper is concerned with the question of how to increase the meaningfulness of unfamiliar science text for novices. Much of the information in science courses is transmitted to students through the use of text. A great deal of effort has been directed towards determining what the content of textbooks in science should be, i.e., in determining the informtion we would like to present to students. However, simply exposing a student to all relevant content does not insure that the information will be learned. Thus, this paper will be concerned with efforts at determining what the structure or design of textbooks in science should be, i.e., in determining how to present the information so that the desired learning outcome will be achieved. While science educators may be regarded as experts on the issue of "what" content should be presented, this paper is motivated by the hope that there is an increasingly useful psychological literature directed at the question of "how" to organize and present that content.

There is a long and unhappy history concerning the relevance--or lack of relevance--of psychological theories of learning to the demands of educational practice (Berliner & Gage, 1976). Unfortunately, the early optimism represented in Thorndike's merger of experimental and educational psychology failed to take hold, as psychologists have spent much of this century buried in highly controlled paradigms involving rats in mazes or lists of nonsense syllables--developing theories and ideas which seemed unrelated to the real world problems of human school learning. More recently, however, the cognitive revolution in psychology has encouraged the development of theoretical and research tools aimed at anlyzying performance in complex domains. Does the psychologist of today have anything to say about instruction? This paper is an attempt to explore that issue within the context of learning science from text.

Learning by Understanding

Why should a science educator be concerned with the issue of understanding? The concept of learner understanding is a rather vague and difficult idea. Isn't it enough to establish clear behavioral objectives and then to measure performance? As long as students can perform on a set of target behaviors, why should we be concerned with whether or not they understand, or whether or not the material was meaningful for them?

Let me give you an example, a rather traditional one, which conveys some of the argument for emphasis on learning by understanding. The Gestalt psychologists, working in the 1930's and 1940's, provided an early large scale attempt to study the role of understanding in learning (see Werthemimer, 1959; Katona, 1940; Duncker, 1945; Luchins, 1942). For example, Wethemier (1959) provides an example of two ways to teach children how to find the area of parallelogram. The first method--which he called the rote, mechanical method--is to teach children the procedure of dropping a perpendicular, measuring the height, measuring the base, and then multiplying height times base to get area. The formual, Area = Height x Base, is emphasized from the start. A second method--which he calls the meaningful or understanding method--is to allow children to see that you could cut off a triangle from one side and move it to the other in order to change a parallelogram into a rectangle. This realization is called "structural insight" because the learner can see how the structure of a parallelogram can be related to what he already knows concerning a rectangle. Since the learner already knows how to find the area of a rectangle, his structural insights about the parallelogram allow him to find that area also.

What are the advantages of learning by understanding? According to Wertheimer, if you gave performance tests to children in both groups you would find that both groups perform quite well on problems like those used in instruction. However, suppose you give unusual problems such as a tall narrow parallelogram or other peculiar shapes. The rote group children give the familiar refrain known to all teachers, "We haven't had this yet". However, the meaningful group children are able to solve the problem. Thus, according to Wertheimer, and the Gestalt claims in general, when children understand a mathematical or scientific procedure they will be better able to transfer what they have learned to new situations. In other words, the payoff for meaningful instruction is not in immediate retention of the just learned information but rather in creative transfer to novel situations.

Framework

The traditional approach to instructional research was to conduct some instructional manipulation (e.g., producing method A and method B) and then to measure the performance of students who learned under each method. Thus, the goal of research was to determine the effects of some observable manipulation on some observable behavior. In general, the results of such studies may be summarized as "method A is better (or worse, or no different) than method B."

One problem with this approach is that it does not provide an understanding of why or how method A is better than method B. We could have a much more powerful and useful psychology of instruction if we understood the general principles or mechanisms which mediate between the instruction and the test performance. This is where the "cognitive point of view" (see Farnham-Diggory, 1976) is relevant. In the cognitive approach to instructional research the goal is to determine how instructional procedures influence internal information processing events and the acquired cognitive structure.

Some of the major variables in instructional research are summarized in Table 1. As you can see, the table includes the two observable variables--the instructional method and the test performance. In addition, I have added some internal varibles--<u>subject characteristics</u> such as what the learner already knows, <u>cognitive learning processes</u> such as paying attention or actively integrating new information with old, and <u>cognitive learning outcomes</u> such as an isolated or an integrated learning outcome.

In this paper I will employ an information processing framework for describing the three "internal" variables in Table 1, with special focus on how people learn scientific information from text. The information processing view of learning and memory proposes that people may be thought of as processors of information (see Farnham-Diggory, 1976). In order to make some general comments about the three "internal" variables in Table 1, allow me to introduce a simple information processing system. The system consists of short term memory, working memory, and long-term memory.

First, students may vary with respect to the cognitive structures (i.e. knowledge) and cognitive strategies that they bring to a learning situation. Some knowledge may be conceptually pre-requisite to the to-be-learned information. In this case, we may evalute learners as to the degree to which they possess conceptual knowledge. Let's call this an evaluation of <u>availability</u>--for meaningful learning one of the conditions that must be met is that the learner has relevant pre-requisite knowledge available in his/her long term memory.

Second, subjects may vary with respect to the cognitive processes they use for meaningful learning. One obvious information processing event concerns whether or not students pay attention to the presented material. In this case, we may evaluate learners as to the degree to which they pay attention to the presented material. Let's call this an evaluation of <u>reception</u>--for meaningful learning one of the conditions that must be met is that the learner receives the presented information and transfers it to working memory.

Another basic information processing event involves the degree to which subjects transfer their pre-requisite knowledge from long term memory to working memory. In other words, students may vary with respect to how actively they search long term memory and consciously think about that existing knowledge during learning. Let's call this <u>activation</u>--for meaningful learning one of the conditions that must be met is that the learner actively transfers relevant knowledge from his long term memory to active consciousness (i.e. working memory).

In short, I have presented three information processing conditions for meaningful learning--(a) reception of the presented material in working memory, (b) availability of pre-requisite knowledge in long term memory, (c) transfer of pre-requisite knowledge from a long term memory to working memory. If all three conditions are met, then, the presented information can be integrated within the context of existing knowledge-- let's call this integrative learning. The outcome of this series of events will be a broad learning outcome, i.e., the acquisition of congnitive structure with many connections to past experience. However, if condition (a) is not met there will be no learning, and if condition (b) or (c) is not met the learning process will involve addition learning. By this I mean that information will be added to memory without making many connections with existing knowledge; the outcome will be an isolated learning outcome, i.e., the acquisition of cognitive structure with few connections. While these three conditions of meaningful learning and the possible learning outcomes represent very general characterizations of the learning process, it is useful to keep them in mind when assessing the impact of various instructional methods.

Techniques for Meaningful Learning

The literature on instructional psychology is replete with grand claims and conflicting results. However, there has been extensive research attention paid to a number of potentially important instructional techniques for influencing meaningful learning. In this paper I will examine five major types of instructional techniques: (1) organization of prose, (2) use of concrete analogy and advance organizers, (3) use of inserted questions in prose, (4) elaboration activities such as note taking, (5) discovery learning.

This paper is not meant to be an extensive review of the literature, but rather to provide the reader with an overview of the state of the field. Further, my goal is to provide you with a perspective--e.g., the information processing framework outlined above--for making sense out of instructional research and claims. For example, I have choosen five instructional techniques which should have an effect on one of the three major processes I listed earlier--

paying attention to the material, possessing a rich set of existing concepts, actively using that knowledge to integrate the incoming information. For each of the instruction techniques, I will try to point out how these information processing events will be involved in determining what is learned.

Organization

Problem. This section deals with the role of text organization. In particular, I will address the question of whether it is better to move from the familiar and concrete to the formal and abstract or vice versa. In science and mathematics instruction, the problem often becomes to determine when the "formula" should be presented. Is it better to start out with a formal statement of the to-be-learned rule (i.e., the formula) or is it better to inductively build up to the formula by using concrete examples?

Examples. As an example, suppose you wanted to teach someone the concept of binomial probability. This rule allows one to compute answers to questions such as, "What is the probability of flipping a coin five times and getting heads to come exactly three times?" You could begin by presenting the formula in its abstract form, and then explaining how to use the formula. I call this the formula method. Alternatively, you could begin by presenting familiar, concrete background such as discussing what a trial is, what an outcome is, what a success is, and so on. Examples such as batting averages, probability of rain, and others could be used to demonstrate each of the background concepts. Only when the learner understood the underlying concepts, the instruction would go on to build up to the formula. I call this the general concepts method.

In order to investigate the effects of these two methods, we devised two instructional booklets--formula versus general concepts method--and asked students to read them. On a posttest we found that the formula group performed better than the general concepts group on a straightforward performance test involving problems like those given as examples. Thus, if we had stopped our assessment with a simple performance test we would have concluded that the formula method is best. However, we also included transfer problems. The general concepts group performed much better on unusual problems and on recognizing when the formula did or did not apply. Thus, there was an interaction in which formula subjects performed better on straightforward retention but general concepts performed better on transfer. These results, coupled with an extensive series of follow-up studies lead us to conclude that the groups differed not only in "how much" they learned, but also in the way they structured the information in memory (Mayer & Greeno, 1972; Mayer, Stheil & Greeno, 1975; Mayer, 1974; Mayer, 1975a). In these studies an instructional sequence which moved from concrete underlying concepts to the formula (rather than starting with the formula) lead to better performance particularly for students with poor mathematics and science backgrounds and particularly on transfer questions.

More recently, we have become interested in books which explain how technological devices work. We purchased a number of "how it works" books and popular articles currently available to the general public. Frankly, we were rather disappointed. Often the products of science--that is technological devices--were described in a mechanical way which failed to explain the underlying principles. For example, suppose you wanted to write a short manual to explain how to use a 35mm camera. We produced such a manual by trying to employ the same general information and style as in popular books on the topic. Our text consisted of the following types of information: descriptions of each part of the camera such as the "focus knob" or the "shutter speed dial"; descriptions of how adjusting one of the parts of the camera would affect the final picture such as "adjusting the focus know will affect whether the picture is blurry;" and descriptions of the internal workings of the camera such as the idea that "turning the focus moves the film away or towards the vertex of the image inside the camera". Notice that knowing about the latter category--what we call "internal principles"--are not essential for operating the camera, while the first two types of information are essential.

We asked non-camera users to read our manual, take a cued recall test, and then try some problem solving application items. The problems involved determining how to set the camera for an unusual situation, designing a special camera, etc. As you might expect some of our people performed quite well on the problems while others performed poorly. We compared people who were able to perform well on the transfer problems to those who were not. Good problem solvers did not differ from poor problem solvers in their ability to recall essential facts--i.e., how manipulating one part of the camera influences how the picture turns out--but they did differ greatly in memory for internal principles. Although they seem extraneous, the internal principles seem to be related to good problem solving.

Armed with this new information we designed two versions of the manual--one structured around the internal mechanisms of the camera and one structured around the features of the outcome picture. Both contained the same basic information but differed in organization and emphasis. On a subsequent problem solving application test, the test organized around internal mechanisms resulted in much better performance; however, the groups did not differ on measures of of simple retention of facts. Thus, these results again exemplify the idea that the same content can be structured differently, with drastically different learning outcomes as a result (see Bromage & Mayer, 1980).

There has also been a great deal of research concerning whether deductive or inductive sequencing of information is best. When I last formally reviewed this literature (Mayer, 1972), the results seemed to be confused. However, much of the problem concerns the dependent measure that is used to evaluate learning. When the dependent measure is simple retention, as we have seen above, the positive effects of organizing around concrete concepts does not show up; when the dependent measure is transferred to unusual problems, the effects of this organization are generally strong. If one examines the literature with an eye towards these predictions, the results are far more consistent in supporting the general claims made above.

Recommendation. In cases where direct retention and straightforward application of a rule or formula are the instructional goals, there is no need to use a "familiar and concrete to formal and abstract" sequencing. However, when creative transfer and future learning are instructional goals, it becomes more important to develop useful organizations which present familiar and concrete underpinnings before introducing the formula. According to the framework presented earlier, the familiar to formal sequencing may serve to increase transfer of conceptual information from long-term memory to working memory and to encourage active integration of information in working memory.

Analogies

Problem. This section of the paper deals with the role of concrete analogies in learning from science text. In particular, this section investigates instructional situations in which an unfamiliar or technical scientific text is preceded by a description of relevant analogies which are familiar to the learner. Since the early work of Brownell (1935) mathematics instructors have noted the importance of using concrete anaogies; for example, manipulative such as Dienes' blocks have been used to concretize computational algorithms. However, the use of analogies and models in science instruction has not been as well spelled out; consequently, using analogies and concrete models means different things to different people. This section attempts to clarify the role of concrete models in science prose.

<u>Examples</u>. For example, consider the way in which most textbooks present the concept of Ohm's Law. In general, text sections on Ohm's Law include the following: a brief set of historical facts such as the statement that "Ohm's Law was discovered by Ohm"; a formal statement of the rule such as "$R = V/I$"; a statement of the rule of English; definitions of key terms; practical facts such as "The resistance of copper is less than steel"; and computational examples of how to derive numerical values.

What is missing from the above discussion of Ohm's Law? From a purely objective point of view, nothing is missing. All essential information is presented. However, if we take the learner's point of view, there is more to meaningful learning than just being presented with the information. In addition, the learner must attend to the information, and relate it to what he or she already knows. Have we given the learner any help in his information processing task? If you were the learner, what would you conclude is the goal of instruction? Based on the emphasis and relative space given to information in some textbooks, a student would be justified in concluding that the goal was to learn to recite facts, to write formulas, and to compute values using a formula. There is certainly nothing wrong with learning facts and learning a computational procedure; however, many physics instructors also profess to maintain other instructional goals such as productive use of information, transfer to new situation, understanding of general principles. How can we arrange instruction so that learners will process the information in a way compatable with these goals?

In order to help answer these questions, White & Mayer (in press) analyzed the content of several textbooks' treatment of Ohm's Law. Of the 10 books reviewed, two presented concrete analogies to help the learner understand the underlying principle. One related Ohm's Law to a person pushing a cart up an inclined plane; the angle of incline was analogous to resistance; the person's push was analogous to voltage; the actual speed of movement up the hill is analogous to current intensity. Although this analogy provides a familiar context for understanding the formula and there is a one-to-one correspondence between each of the three variables in the formula and in the model, the cart analogy does not possess some crucial properties that exist in the Ohm's Law relationship. Another physical analogy we found related Ohm's Law to a set of bouncing electrons flowing down a congested pipe: the number of particles in the pipe blocking the flow is analogous to resistance; the number of electrons per time unit that would get through without any collisions is analogous to the voltage; the number that do get through per time unit is analogous to current. This analogy is more powerful because it is consistent with more properties of electric flow; for example, it can easily be extended to discuss the role of changes in temperature. (One California undergraduate who learned of this analogy, however, quickly translated it into a freeway with a lot of potholes.)

In these examples, the analogies do not provide directly essential information. In a sense, they give extra information. However, they also provide a familiar system which the learner can use for interpreting and integrating an unfamiliar system of facts about Ohm's Law. Examples such as this one raise the question of whether analogies aid learning, and if so, how. The remainder of this section provides an overview of the literature on this question.

One major research battleground concerns the role of advance organizers in learning from prose. This area of research is of particular interest because most of the studies involve science text as the materials. Ausubel (1960) is responsible for much of the early work on advance organizers. For example, in a typical study subjects read a 2500 word passage on the metallurgical properties of plain carbon steel after reading either a 500 word historical introduction or a 500 word summary of relevant general principles. Retention scores for the main passage were slightly but significantly higher for the advance organizer group. Ausubel attributed the superior performance to the fact that subjects were able to assimilate the ideas to an "ideational scaffolding" provided by the principles in the advance organizer. Subsequent studies by Ausubel (see Ausubel, 1968) and more recent reviews (Mayer, 1979a; 1979b) have provided continuing evidence for assimilation theory.

More recently, new studies have been conducted in which the advance organizers involved concrete, specific models rather than the abstract principles suggested by Ausubel. For example, Royer & Cable (1975, 1976) asked subjects to read an abstract passage on the flow of heat through metals or the conduction of electricity after reading a passage which either presented relevant physical analogies or which presented only relevant abstract principles. Results showed that pre-exposure to the concrete analogies significantly facilitated learning and memory of the second passage.

Similarly, we have conducted a series of studies in which subjects are asked to read a 10 page manual on computer programming (Mayer, 1975b, 1976, 1978, 1979a; Mayer & Bromage, in press). A concrete model of the computer was presented either before or after reading the passage. The model represented input as a ticket window, memory as an eraseable scoreboard, executive control as a shopping list, output as a message pad. Subjects in the advance organizer group excelled on creative use of the presented information in problem solving; subjects in the post-organizer group performed as well or better than the advance organizer group on test items involving simple retention of the presented information. In addition, subjects in the advance organizer tended to recall more of the conceptual information in the passage while subjects in the post-organizer group tended to recall more of the technical facts. These results are consistent with the idea that advance organizers provide an assimilative context to which new information may be systematically integrated.

There has been a great deal of additional research in this area. For example, in a recent review, I analyzed about 50 advance organizer studies (Mayer, 1979b). In general, advance organizers tend to have their strongest effects when the material is unfamiliar--so that the learner does not already posses his/her own model--or when the subject is a novice--again, so that the learner is unlikely to possess his/her own model--and when the dependent measure is creative problem solving. Some reviews which did not pay attention to these factors such as Barnes & Clowson's (1977) recent review conclude that the support for advance organizers is thin. However, when one pays attention to the conditions listed above, the case for advance organizers in science learner becomes much stronger (Mayer, 1979b).

<u>Recommendation</u>. When the text presents information that is unfamiliar or technical and when the learner is not likely to possess or use his existing relevant analogies for comprehending the material, it is useful to carefully construct relevant analogies and to carefully show the learner how elements in the text map into elements in the model. There is still no foolproof system for constructing an analogy or for conducting the mapping process; however, I have previously suggested the following guidelines:

(1) The analogy should allow one to generate all or some of the logical relationships in the to-be-learned material.

(2) The analogy should provide a means of relating ach unfamiliar element to each element in the analogical model.

(3) The analogy should be easy to learn and remember.

(4) The analogy will be useful if the learner would not normally think of using it or an equally useful one.

Since the domain of physics is particularly ameanable to the use of concrete analogies, and since students often complain of not understanding science formulas, it seems especially important to consider how to make effect use of analogies in science instruction.

Inserted Questions

Problem. Another technique which has been suggested to influence meaningful learning is the use of adjunct or inserted questions. Rothkopf (1970) called question answering a "mathemagenic activity" because it is an activity which gives birth to learning. In general, summaries of the inserted question literature (Frase, 1968; Mayer, 1977), show that when questions are inserted in a passage performance on a final test which covers the same material is improved.

There have been two basic theories to account for this inserted question effect—a backwards theory and a forwards theory. The backwards theory states that students use the question as a chance to review the specific material in the question; thus students have an extra exposure to the material that is involved in the question. The forwards theory states that the questions serve to direct the readers' attention on subsequent portions of the passage; based on previous questions, students develop expectations concerning which type of information is important in the text.

Example. Suppose you wanted to teach students about set theory and the laws of probability. In order to accomplish this task, I developed eight sequential lessons. Each lesson had the same general form in that it presented a formula with definitions of each variable, it presented an example of how to compute a value using the formula, and it presented a concrete example of the principle underlying the formula. I then constructed three sets of the questions for each lesson--questions on definitions, questions on computing an answer, and questions about the concrete model. Students read each of the first six lessons in order, with questions as part of each lesson; on each of the first six lessons a student received soley definition questions, soley computation questions, soley model questions, all three or none.

Imagine yourself as the learner in this task. For each six lessons you are asked the same type of question. How would this influence your information processing strategy on the seventh and eighth lesson? Would you pay more attention to that part of the text that contained the type of information you expected to be tested on? Students in our study tended to behave as if previous tests influenced how they studied new material. In our study, we gave all three types of questions after lesson seven and after lesson eight. Students who had expected only definition questions performed well on definition questions but poorly on the other questions; students who expected computation questions performed well on computation questions but poorly on the other questions; students who expected model questions performed quite well on model questions and also performed well on the other questions. A particularly interesting aspect of the result is that we obtained the same pattern when the questions were given before each of the first six lessons (without students having to solve them) as when they were given after each of the first six lessons (with students actually having to solve them).

These results are consistent with the idea that previous test questions influence processing of new material. Thus, inserted questions have a "forward effect" of drawing students' attention to particular parts of the material. Related studies by Watts & Anderson (1971) and by McConkie, Rayner & Wilson (1973) have provided complimentary evidence that the type of question you ask influences the information processing strategy of students on subsequent reading.

Recommendation. Inserted questions can have both desirable and undesirable effects. For example, telling a student in advance of learning that he or she should be able to answer a given set of questions may have the effect of encouraging the student to ignore incidental material. Further, giving students questions which emphasize computation may limit the students' learning strategy. Questions may serve as road signs telling the learner what to pay attention to and what to ignore. If the goal of instruction is the acquisition of a well defined set of responses to a well defined set of questions then explicit emphasis on these questions before and during the text is appropriate. However, if the goal of instruction is the production of students who will be able to creatively solve novel problems and who will be able to build new learning on old, then more consideration must be paid to using a balanced set of questions--questions which will not serve as blinders.

Elaboration

Problem. Another class of techniques that have been suggested as a way of increasing meaningful learning are elaboration strategies such as note taking. Rothkopf (1970) has used the term "mathemegenic activity" to refer to an overt behavior which influences learning. In addition, Wittrock (1974) has suggested that activities such as writing summaries and paraphrases of prose material are "generative activities" that serve to broaden learning.

This generative hypothesis may be summarized within the context of our information processing framework presented earlier in this paper; note taking may encourage the learner to search long-term memory for relevant underlying concepts and the act of writing down notes encourages an active integration of presented information with existing concepts. An alternative conception is that note taking forces that the learner pay more attention, and thus should result in better learning overall.

Example. Suppose we asked our students to watch and listen to a short video-taped lecture on statistics or on how to use a computer. Some subjects are allowed to take notes as they watch the screen while others are not. Then, we give our students a test consisting of retention questions and problems which require creative transfer. Will there be any differences in how note takers and non-note takers perform?

According to the generative theory, students who take notes are actively integrating the newly presented material with their own past experience; this should result in broader learning outcome which will support creative problem solving. According to the attention theory students who take notes simply pay more attention overall and thus should show better performance on all measures. In a recent series of experiments (Peper & Mayer, 1978), subjects who took notes performed better on far transfer test items but non-note takers performed better on near transfer or retention items. This pattern was particularly strong for low ability subjects, thus suggesting that high ability subjects have learned strategies for integrating the material even when note taking is not allowed.

These results suggest that note taking can result in a broader learning outcome. In order to get a better description of what is learned by note takers and non-note takers, another study was conducted in which students were asked to take a recall test rather than a problem solving test. Note takers tended to produce more conceptual ideas and more intrusions from other information while non-note takers produced more technical facts in their recall protocols. This pattern is consistent with the earlier results since it seems likely that creative problem solving is best supported by the conceptual ideas in the passage.

Past research on note-taking has been far from unanimous. However, in general the goal of previous research has been to determine whether or not note taking helped overall retention. If we had limited our analysis simply to retention of presented information we also would have concluded, as many other studies, that note taking does not affect learning. However, basing our description of note taking on an information processing model, we were able to predict that note taking should have its strongest effects on transfer problems, and that the effects should be strongest for subjects who do not possess the natural strategy of trying to integrate new information.

In addition, other types of elaboration techniques have received wide study. For example, in learning paired associates such as foreign language vocabulary, students must for associations between two words such as, "letter--carta." Elaboration techniques such as generating a keyword, forming an image, or making a sentence tend to improve memory (Bower, 1972; Jensen & Rohwer, 1963; Lynch & Rohwer, 1976; Levin, 1976; Pressley, 1977). More recently, elaboration techniques have been applied to prose learning in science curriculum construction (Dansereau, 1978; Weinstein, 1978).

In order to bridge the gap between laboratory studies with word pairs and large scale development effects involving elaboration techniques, we recently conducted a series of studies (Mayer, in press). Subjects read a manual about computer programming either with elaboration activities after each unit or no elaboration activities. Elaboration activities consisted of telling how two ideas in the manual were alike and how they were different, or in telling how an idea in the manual related to a concrete example. Elaboration students performed much better than the other students particularly on transfer tests and on recall of major concepts, thus giving a pattern of results similar to note taking and advance organizers. Apparently, the elaboration activity served to encourage students to integrate the information in the booklet with other knowledge.

In another study (Mayer & Cook, 1980) we used a technique which could interfer with the process of integrating new incoming information with existing knoweldge. We asked students to listen to a 10-minute lecture on how radar works; half the subjects were asked to repeat back each phrase during short pauses in the tape while the other half were asked simply to listen carefully. According to our information processing model, the group that was forced to repeat the phrases would put more time into the attention process (reception of the material) but would have less time for finding available pre-requisite concepts and actively integrating the new material with those concepts. Thus, by forcing our students to repeat what we say, we were discouraging them from understanding the information.

The main principles in the passage was that a pulse is transmitted, it strikes remote object and is reflected back, and the time between transmission and return can be converted into a measure of distance. This principle was stated in several contexts in the text, as well as much technical and historical information. On a subsequent test, both groups performed equally well on retention of facts (as measured in true-false test) but the listen only group performed much better than the repeat group on problem requiring creative problem solving. In addition, in another study we asked subjects to recall all they could remember. Subjects, in the two groups performed equally well on recall of technical and historical facts but the listen only group recalled twice as much information about the underlying principles as described above. These results suggest that when students cannot give their full interest to a passage--either due to a distraction as in this study or due to anxiety or speed pressure--they are less likely to find the underlying principles.

Recommendation. It is important that students be encouraged to actively process prose material. Exercises such as putting the information in one's own words, as in note taking, encourage an active learning process in which new information is integrated with existing knowledge. However, action per se, such as a lab exercise where a student blindly follows a "receipe", will not normally result in meaningful learning. Instruction should involve activities which encourage the learner to actively search for relevant past experience and to integrate the presented information with that past experience.

Discovery

Problem. During the 1960's there was flurry of excitement concerning the role of discovery techniques especially in science and mathematics (Bruner, 1961). By allowing students to discover important scientific and mathematical principles on their own--rather than by forcing students to memorize formulas--we were promised students who would be motivated, creative, and ready for the challanges of the future. However, later reviews of the scientific support for this enthusiasm revealed an appauling lack of evidence that discovery "works" (Shulman & Keisler, 1966).

A few years ago I conducted my own review of the discovery learning literature with special focus on mathematical and scientific tasks (Mayer, 1972). Sometimes learning by discovery resulted in splendid performance and sometimes it seemed to fail miserably. Why is this so, and when are discovery techniques most likely to succeed? According to the information processing model framework earlier in this paper, meaningful learning requires that the to-be-learned material be received by the learner, that the learner possess a set of relevant pre-requisite concepts, and that the learner actively use that past experience for comprehending the new information.

One problem, then, with pure discovery methods is that they often fail to ensure that the first condition is met--i.e., they fail to make sure that the student ever discover the key principle that is being taught. Thus, in spite of the fact that the subject is very actively using his/her past experience (i.e., satisfying the second and third conditions listed above), no learning is taking place. However, in guided discovery procedures, more hints and direction are given so that the learner does find the to-be-learned rule; in addition, the amount of direction is kept to a necessary minimum so that the learner must actively search and use prior experience. A systematic review of the discovery literature shows that guided discovery is generally more effective than either pure discovery or pure expository--a finding that is consistent with our information processing framework.

Another problem with research on discoovery is that the dependent measure is often simple retention of the facts. Since guided discovery procedures should have strongest effects on measures of transfer to novel problems, it is important to concentrate on studies which involve transfer measures. When we do focus on such studies, there is clear and consistent evidence for the superiority of guided discovery procedures.

A third implication of the information processing framework is that discovery techniques will result in broader learning outcomes only if students already posses a rich set of relevent experiences. Discovery techniques which try to encourage a learner to actively search and use his/her existing long term memory will not produce much of an effect if the learner lacks relevant prerequisite information in long term memory. Thus, we can predict that discovery procedures favor the prepared mind.

Example. As an example to test this idea, consider an instructional sequence for learning statistical concepts by discovery. (Mayer, Stheil & Greeno, 1975). Students are given probability problems to solve, and then feedback is given after each step in the process. This is essentially a guided discovery procedure--students must generate answers but each part of the answer is immediately corrected if it is incorrect. Will our subjects be able to transfer the procedure they have learned to new types of problems or will they only be proficient on problems like those given in training?

The answer to this question depends on the pretraining that we give to our students. Half the students wre given a short introduction to general formula, with each variable given a name. The other half of the studens were given a short introduction to the basic concrete concepts underlying probability theory; for example, combinatorial analysis was compared to determining how to seat R people at N spaces at a dinner table. Subjects given the conceptual pre-training showed superior transfer performance after learning by discovery but students given the mechanical pretaining excelled only on problems like those given during training. Thus, discovery procedures are more likely to result in broader learning outcomes, if we make sure that students already possess the required assimilative context for the new material.

Recommendation. Discovery techniques will be effective for certain learners, when carried out in certain ways, and for certain instructional objectives. To be more specific, discovery techniques require prepared learners--i.e., learners who already possess the specifically relevant prerequisite concepts. Also, discovery techniques will not succeed if the learner does not discover the to-be-learned rule; some guidance may thus be necessary. Finally, if the objective is straightforward application of a formula or rule discovery techniques should not be used; if the objective of instruction is to produce good transfer then a suitable guided discovery procedure may be established. As Ausubel (1968) has clearly pointed out, it is possible to incorporate guided discovery procedures into expository prose. Thus, not all expository prose is rote and not all laboratory exercises are discovery.

Conclusion

In this paper I have attempted to summarize five instructional techniques for increasing the meaningfulness of technical or scientific information. Each technique has received much research attention, with less than perfectly consistent results. However, when we take the point of view of our students, and try to describe how these techniques influence information processing events during learning, we are better able to make sense out of the literature. The examples I have presented are representative of much of my own research in this field. Based on this work it seems clear to me that instructional techniques influence the learning process in systematic and predictable ways.

The goal of research on the psychology of learning and instruction must be to continue to develop precise descriptions of the mechanisms involved. I hope that this paper has encouraged you that such work will have increasing relevance not only for cognitive theory but also for the difficult task of developing instructional procedures in science.

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Table 1

Some Variables in Instructional Research on Meaningful Learning

(Internal) Subject Characteristics	(External) Instructional Method	(Internal) Cognitive Learning Processes	(Internal) Cognitive Learning Outcomes	(External) Performance Outcomes
Amount and type of pre-requisite knowledge and strategies.	Organization Advance Organizers Inserted Questions Elaboration Discovery	Reception of Presented information in working memory. Availability of knowledge in long term memory. Activation of knowledge.	Broad, integrated Narrow, isolated	Retention Transfer

Footnote

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About the Author

Richard E. Mayer received his Ph.D. in Psychology from the University of Michigan in 1973. He served on the faculty of Indiana University from 1973 to 1975, and since then has been on the faculty of the University of California, Santa Barbara. His research interests are in human learning and cognition, with special interest in mathematical and scientific problem solving. He is member of the editorial board of the Journal of Educational Psychology, and has written several books including Thinking and Problem Solving (Glenview, Illinois: Scott, Foresman & Co., 1977), Foundations of Learning and Memory (Glenview, Illinois: Scott, Foresman & Co., 1978, with Roger Tarpy), and Human Reasoning (Washington, D.C.: Winston, 1979, with Russell Revlin).

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