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ABSTRACT

Techniques are provided for distinguishing explanative information from other types of information in science prose, including the structural method, the logical method, and the empirical method. Research is then provided concerning techniques which increase the subjects' recall of explanative information, and thus the subject's problem solving performance. These techniques include manipulating the reading strategy and manipulating the text design. Finally, some recommendations are suggested for improving science text design and text processing. (Author/CS)

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SERIES IN LEARNING AND COGNITION

Structural Analysis of Science Prose: Can We Increase Problem Solving Performance?

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Report No. 81-3

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Abstract

This paper explores techniques for analyzing the structure and improving the understandability of science prose. Structure refers to a distinction between idea units that explain the mechanisms underlying a rule (explanative information) and idea units that do not (non-explanative information). Understandability is measured by tests of creative problem solving based on information in the passage. Science prose refers to a passage that contains a functional rule among two or more variables and an explanation of the underlying mechanisms. Three techniques are described for distinguishing explanative and non-explanative information: structural method, logical method, and empirical method. Then, research is provided concerning techniques that increase the subjects' recall of explanative information, and thus the subject's problem solving performance. These techniques include manipulating the reading strategy, such as by encouraging reflective or elaborative processing, and manipulating the text design, such as by organizing the text around key ideas or including a concrete model. Finally, some recommendations are suggested for improving science textbooks, with hopes that such recommendations will stimulate further research.

Outline

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INTRODUCTION

Suppose we asked a student to read a scientific or technical passage--such as an explanation of how radar works, the process of photosynthesis, the concept of Ohm's law, or how to write simple computer programs. Further, suppose that the student has the reading skill to correctly "read every word". If we then gave that student a problem solving test based on information in the passage, which factors would influence the student's performance? In short, which characteristics of the passage and of the learner are related to creative problem solving performance? This question could be called the "creative reading problem", and is the focus of this paper. Thus, this paper is concerned with techniques for increasing students' understanding of scientific prose, where understanding is measured by tests of creative problem solving in the domain of the passage.

The present paper differs from other studies in several ways:

<u>passages</u>--the present paper focuses only on certain types of scientific passages (that we call "explanative") rather than on narratives or collections of facts.

<u>independent and dependent variables</u>--the present paper focuses on how reading strategy or text design manipulations influence problem solving performance, rather than on how structural characteristics of idea units influence recall or retention score.

Each of these points is discussed in turn, below.

<u>Passages</u>

The text materials used in our project are somewhat restricted in comparison to some others in this symposium. Table 1 provides a taxonomy for classifying prose passages. The vertical dimension lists three kinds of information:

episodic--refers to passages that tell a story, including characters, events, states, etc., with units such as: "John thanked Sue, and quietly left the room."

semantic--refers to factual information about the world, such as, "There are three kinds of information: episodic, semantic, procedural."

procedural--refers to instructions about "how to do" something, such as: "First add all of the scores for group 1 and for group 2..."

These three types of information in passages correspond to the "traditional" distinctions among episodic, semantic and procedural knowledge in memory.

The horizontal dimension of Table 1 provides an orthogonal division between two kinds of underlying structures for a text:

descriptive--refers to a text in which the key components of events are related in an arbitrary way, such as a list of facts, a series of events in a story, or a set of steps in an algorithm.

explanative--refers to a passage that expresses a functional relationship among two or more variables, and which provides an explanation for the functional rule by refering to underlying mechanisms, such as explaining the t-test in terms of a sampling distribution, or explaining Ohm's Law in terms of electron flow.

This distinction is elaborated in the next section of this paper, and is described in more detail elsewhere (Bromage & Mayer, in press).

Insert Table 1 About Here

The example passages provided for this symposium can be classified as follows: The "Saint" passage from Miller (1981) fits into slot A since it is a narrative in which there is no logical relation among the key events; the "lion" passage from Voss and Bisanz (1981) fits into slot B because it is a narrative in which the "motives" of animals are related to the key events. The "wagon" passage (Miller, 1981) fits into slot C because it provides a list of facts that seem to be unrelated; the supertanker passage (Meyer, 1981) fits into slot D because it provides facts that are supported by a set of explanative mechanisms such as "supertankers having only one boiler and one propeller", etc. It should be noted that "supertankers" also has some narrative portions concerning histories of previous oil spills. Finally, our own work has focused mainly in slots D and F, with the radar passage falling into the D slot. In this paper, we will limit our discussion to passages in slots A, C, and F., and in particular to the radar, supertankers, and lion passages. These are listed in Appendices A, B and C, respectively.

Independent and Dependent Variables

The second major distinguishing characteristic of the present project is our focus on problem solving as the dependent variable of interest, and strategy or text design modifications as the independent variable of interest. Table 2 provides a summary of the differences between two major research goals:

goal 1--to predict recall and retention performance, with typical independent variables of levels in a hierarchy or prior knowledge of the learner and typical dependent variables of recall or retention score,

goal 2--to predict creative problem solving performance, with typical independent variables of advance organizers or adjunct questions and typical dependent variables of creative problem solving.

As can be seen in Table 2, a typical construct used in predicting recall is a schema--a generalized framework into which the specific content can be placed. However, the construct used in predicting problem solving is an "explanative representation"--this involves an integrated structure consisting of the key mechanisms and the causal relations among them. Thus, creative problem solving depends on the presence of certain "explanative" information in memory. A more complete definition and examples are provided in the next section of this paper.

Insert Table 2 About Here

Framework for Research on Learning from Prose

Table 3 provides a general framework for discussing research on learning from prose. As can be seen, some typical independent variables in prose processing studies are passage characteristics, such as hierarchical structure of each idea unit or level of imagery of the words or use of headings; and learner characteristics, such as prior experience or reading strategy. Some typical dependent variables are recall, such as which ideas are remembered in a free recall test; retention, such as which answers are given on a forced choice test covering the basic content; and problem solving, such as whether students are able to generate creative answers for transfer problems.

Insert Table 3 About Here

In order to provide a theory for relating passage and learner characteristics to test performance, a number of intervening constructs are helpful:

encoding process, learning outcome, retrieval process. The encoding process refers to the process by which information in the passage is selected and integrated with knowledge in memory. Thus, encoding involves (1) various ways of selecting information from the passage, and (2) various ways of combining that information with existing knowledge. For purposes of the present paper, we make a distinction between two kinds of encoding processes:

<u>addition encoding</u>--in which subjects select factual details, and can relate them only in arbitrary ways, and

<u>assimilation encoding</u>--in which subjects select explanative information, and integrate this information.

Table 4 provides an example of the difference between addition and assimilative encoding for the radar passage. As can be seen, addition encoding involves selecting isolated facts and not integrating them; assimilation encoding involves selecting the explanations concerning transmitters, receivers, displays, etc., and relating them to one another.

Insert Table 4 About Here

The learning outcome refers to the content and structure of acquired knowledge. The learning outcome for addition encoding will be an arbitrary set of facts or other idea units. For example, the learning outcome for radar may consist of unrelated ideas such as, "radar travels in straight lines", "the display seems like a second hand on a clock", "dropping a pebble in a lake causes ripples", etc. The learning outcome for assimilation encoding will be an integrated explanative representation that consists of all the key components and the causal relations among them. For the radar passage, the components are transmitter, pulse, object, receiver, display; and the relations involve how a pulse bounces off an object and how the time to travel is a measure of distance.

The retrieval process refers to the procedure for searching for information in memory and generating an answer for a question. The present paper will focus mainly on encoding processes.

Different learning outcomes may result in different kinds of test performance; a goal of this research project is to shed some light on this relation as well. In particular, integrated versus arbitrary learning outcomes may produce different patterns of performance on recall, retention, and problem solving tests. For recall tests, subjects who have integrated learning outcomes should perform better on recall of the explanative information, but subjects who have arbitrary learning outcomes should perform better on recall of basic details and facts. For problem solving tests, subjects who have integrated learning outcome should perform better on creative problem solving while those who have arbitrary learning outcomes should excel on solving problems that are nearly identical to those given in the passage.

The remainder of this paper consists of three parts: (1) structural analysis of scientific prose provides techniques for distinguishing between explanative and non-explanative information in a passage, (2) improvement of problem solving performance provides summaries of research on whether techniques that enhance students' learning of explanative information also improve their problem solving performance, and (3) implications for text design and reading strategies gives some concrete examples of how to improve the radar, supertanker and lion passages.

STRUCTURAL ANALYSIS OF SCIENTIFIC PROSE

Unit of Analysis

The first step in analyzing scientific prose is to determine a procedure for segmenting the passage into parts. In our studies we have generally used the "idea unit" as our unit of analysis. An idea unit expresses one action or event or state, and generally corresponds to a single verb clause. For some analyses, separate idea units are established for locations, times, organizational signals (such as "The next idea is..." or "The result of this...") and comments (such as "You should try to remember that..."). Thus, each idea unit consists of a predicate--either a verb or a location or a time marker--and one or more arguments. Unlike propositional analysis (Kintsch, 1974; Turner & Greene, 1977), our units do not give separate status to modifiers, conjunctions, connectives and the like. For example consider the sentence:

"It creates concentric circles of small waves that continue to grow outward."

According to our segmentation procedure, the two main verbs are located: "creates" and "grow". Thus, this sentence is divided into two idea units:

(1) It <u>creates</u> concentric <u>circles</u> of small waves

(2) that continue to <u>grow</u> outward.

For purposes of scoring, the main predicate is underlined as well as any key subjects, objects, etc. For the first idea unit "creates" and its object "circles" are underlined. For the second idea unit, only "grow" is underlined. To score a recall protocol, the information must first be divided into idea units as described above. Then, each idea unit from the passage is compared to each idea unit from the original passage. If an idea unit from the protocol contains the same keyword (e.g., "creates" and "circle") and expresses the same meaning as an idea unit from the original passage, that idea unit is scored as present.

As examples of the segmentation procedure, Appendices A, B and C, respectively show how the radar, supertanker, and lion passage can be broken down into lists of idea units. The main predicate for each idea unit is underlined as well as any key arguments; information in parenthesis refers to signals or comments.

The next step is to distinguish between idea units that provide explanations of the mechanisms underlying the information (explanative information) and idea units that do not provide explanations of mechanisms (non-explanative information). For example, in an analysis of textbook lessons on Ohm's Law, White & Mayer (1980) found relatively few instances of explanative information, such as "Resistance is caused by collisions of electrons with atoms in the wire." For Ohm's Law, explanations involved the "flow of electrons", although several textbooks presented the formula without ever refering to the underlying mechanism.

Thus, explanative prose contains a functional rule that expresses a relationship among two or more variables. For example, in the radar passage, one rule is tht the time for a pulse to return to the source is proportional to the distance of the remote object. In addition, explanative prose contains an explanation of the mechanisms that underlie this functional rule. For example, the explanative information in the radar passage concerns the nature of the bouncing radar pulse, as follows:

transmission--the transmitter sends out a pulse

reflection--the pulse bounces off a remote object

reception--the returning pulse is picked up by a receiver measurement--the direction of the pulse and the time for the pulse to return are measured

conversion--these are displayed as location and distance

These idea units refer to the major components in the radar passage--transmitter, pulse, object, receiver, display--and the relations among them. In Appendix A, an E indicates that the corresponding idea unit is part of the explanation.

For the supertanker passage, the key relation is "supertankers cause environmental damage" and the main explanative chain is:

1. Supertankers are very large, thus difficult to maneuver.
2. Supertankers have only one boiler to provide power and one propeller to provide control.
3. In an emergency, difficulty of maneuvering increases and vulnerability of boiler and propeller increases.
4. If boiler or propeller malfunction, the ship loses power or control.
5. If the ship loses maneuverability, power or control, it can wreck onto sharp rocks.
6. When a supertanker wrecks, a storage area can be ripped open and oil will spill out.
7. When there is an oil spill, environmental damage results.

The main components are the propeller, the boiler, the size of the ship, the emergency, the storage area, the oil, the rocks. These idea units give the causal relations among the components. Note that not all the links are present in the passage. In Appendix B, an E indicates that the idea unit corresponds to one of the seven causal links given above.

For the lion passage, those idea units which describe motives provide a partial explanation for the events in the story. While a complete explanation is not possible, those idea units labeled with E in Appendix C provide a partial explanation of the story. For example, the story makes more sense if the reader is aware that the tiger "wants to be leader of the animals."

The foregoing examples highlight the idea that the crucial link in explanative analysis is to have a procedure for: (1) distinguishing explanative passages, and (2) for dividing an explanative passage into explanative idea units and non-explanative idea units. Unfortunately, the procedures are not yet well algorithmized. Clearly, the procedures for propositional analysis (Kintsh, 1972; Turner & Greene, 1977; Kieras, 1980) are better specified. However, we have been able to provide explanative analyses of approximately 12 passages for research in our lab during the past several years. Thus, although the explanative analysis procedures need to be formalized, we have found them to be useable in our own research. In particular, we have used the following three methods for determining which idea units in a passage explain underlying mechanisms and which do not: structural method, logical method, and empirical method. These are described in the next three sub-sections.

Structural Method

The first step in structural analysis of a scientific passage is to locate the main functional relationship, or what White & Mayer (1980) call the "rule". A rule is an idea unit that expresses a functional relationship among two or more variables, events, and/or components. Three common kinds of rules are as follows:

> Formal quantitative functions--are formulas that specify a direct or inverse mathematical relationship among two or more variables. An example is the rule for Ohm's Law, "R=V/I", where R stands for resistance, V stands for potential difference, and I

tands for current. Another example, from a study by Linda Cook and I, is "D = M/V" where D stands for density, M for mass, V for volume.

Informal quantitative functions--are statements which describe a direct or inverse quantitative relationship among two or more variables, but do not specify the relation as a formula. An example is radar passage's statement that the time for receiving a reflected pulse is related to the distance of the remote object. A formula rule could be stated, such as $d = (t_r - t_t)/2s$, where d is distance of the object, t_r is the time of reception, t_t is the time of transmission, and s is the speed of the pulse. Another example, from a passage on how to use a 35mm camera (Bromage & Mayer, in press), is the assertion that brightness of a picture depends on how wide open the shutter is.

Informal non-quantitative functions--are statements in which a clear functional (or causal) relation is expressed, but which do not imply a direct or inverse quantitative relationship. For example, the supertanker passage asserts that environmental damage is caused by supertanker travel. Another example is contained in Stevens & Collins' (1977) tutor for teaching the causes of rainfall in the various geographic regions.

In all cases the rule is the most general statement of the observed relationship among variables; the rule does not explain the phenomenon but merely describes the functional relationship observed in the world. Thus, rules are like general behavioral laws in Skinner's (1953) approach to S-R psychology. For example, in the supertankers passage, the main rule gives a relation between the ultimage predicted variable, "environmental damage", and the original predictor variable, "supertanker travel". Other, intervening variables such as "oil spill", "storm", "large size", "single boiler" are not a direct part of the rule--although in another passage they could be part of the rule.

Once the rule has been located, the next setp is to determine the mechanisms that explain the rule, or what White & Mayer (1980) call the "explanation". The explanation gives the underlying components, shows how they relate to one another, and how they can account for the rule. Thus, the explanation is like a cognitive theory for behavioral S-R laws. Each underlying component and the system uniting them must be identified: a component is an event or object that is part of the causal chain underlying the elements in the rule. For example, in the Ohm's Law example, one set of components consists of a battery that generates a potential difference between positive (+) and negative (-) poles, electrons that flow from the positive to the negative pole, a wire that carries them, a bulb that offers resistance by placing many atoms in the way of the flowing electrons, etc. The system for uniting all these components is the circuit. The components in the radar passage consist of the transmitter for sending out pulses, the object for reflecting back some of the pulse, the receiver for picking up the pulse, a display for converting time to distance and representing it on a screen. The system for uniting all these components is the radio wave system. The components in the supertankers passage are features of the ship and the environment such as: the propeller, boiler, and size of the supertanker. As can be seen, some judgment is required for locating the underlying components--electron flowing in circuits for Ohm's Law, pulses bouncing around space for radar, and factors that limit a ship's maneuverability in storms for supertanker.

Third, the causal chain among the components must be spelled out. The causal chain is the functional relationship between the "predicted variable" and the "predictor variable" in the rule, with intervening functional relations included. For example, for the rule "there is less current when resistance is increased", can be explained in a causal chain as "increasing the resistance provides more atoms for the electrons to collide into, more collisions slow down the flow of electrons and thus the current is less". For radar's rule that "the further away the object is, the further away will be the bright spot on the screen from the center", can be explained by the causal chain, "when an object is far away, it takes more time for the pulse to reach it and return, longer time is converted into longer distance on the screen, so that the bright spot will be further away from the center of the screen". For the supertanker rule, "environmental damage is caused by supertankers", an explanation includes the seven statements listed previously. Thus, the explanation involves adding intervening links in the functional relationship between variables in the rule.

The explanative idea units consist of all idea units that describe the components or the relationship with the variables in the rule. In addition, passages may contain analogies such as "echoes" in the radar passage or "water flowing in pipes" in the Ohm's Law passages. Statements about analogies or concrete examples are also explanative idea units if they refer to underlying mechanisms.

As can be seen, the structural method is based on a distinction between "description of functional rules" and "explanation of functional rules". This distinction has been of some interest to historians and philosophers of science (Westfall, 1977; Kearney, 1971; Bronowski, 1978; Cohen, 1960) and its relation to research on learning from science prose has been described elsewhere.

(Bromage & Mayer, in press). To the extent that this distinction can be operationalized, it may be useful in research on prose processing. In addition, it must be noted that a large amount of prose currently in curricular materials cannot be subjected to this analysis because it does not describe a functional rule or an explanation of the rule.

Logical Method

The logical method involves determining the major transfer problem that the subject should be able to solve. Then, using a task analysis approach, the next step is list all of the pieces of information in the passage that are needed in order to solve the problem. Thus, the analysis involves listing all idea units that serve as premises for solving the problem. Solving the problem should involve making inferences from the list of premise idea units. These premise idea units constitute the "explanative information" in the passage.

For example, in the radar problem a creative transfer question is: "How can you increase the area under surveillance for a single radar station?" In order to answer this question, what must a learner know about radar? Some of the crucial idea units are: the transmitter sends out a pulse, the pulse travels in straight lines so the earth's curvature interferes with long range transmission, the pulse can bounce off an object, the reflected pulse can be picked up by a receiver, time and direction can be concerted to measures of distance and location. Some possible answers are: "Use satellites to bounce the pulse on its way to and from the remote object," or "Use relay stations on the ground to bounce the pulse." These answers are possible from making logical inferences from the given information.

For the supertankers passage, a possible transfer question is: "List all of the ways to prevent damage to the environment from oil spills." Answers based solely on the three suggestions given in the passage--better training, back-up boilers and propellers, and ground control stations--are not creative answers. Other answers that rely on the links in the causal chain are, "Don't travel in poor weather", or "Always travel in pairs", or "Use lots of tow boats".

Empirical Method

A third technique, which may be used as a validation technique for the foregoing two methods, is the empirical method. This method involves asking subjects to read a science passage, and then testing the subjects for which idea units are remembered and for creative problem solving.

Based on their performance on the test of creative problem solving, subjects can be ranked or partitioned into groups of good versus poor problem solvers. For each subject, there is a record of which idea units were recalled and of rating on the problem solving test. The recall of the "good" problem solvers is then compared to the recall of the "poor" problem solvers. In particular, the goal is to determine which idea units the good problem solvers remember that the poor problem solvers do not seem to learn from the text. For example, in a passage on how to use a 35mm camera, subjects were asked to recall parts of the passage and to solve transfer problems such as how to set the camera for a pole-vaulter going over the bar on a cloudy day (Bromage & Mayer, in press). The good and poor problem solvers did not differ in recall of the facts (such as what ASA stands for) or the rules (such as "to increase brightness of the picture, increase shutter size"), but they did differ in recall of the underlying explanations (such as, "turning the focus knob moves the film away from the lens"). Thus, good problem solvers tended to differ from poor problem solvers mainly in recall of explanative material.

Another variation of this method is to use regression analysis, with the independent variables being recall of each type of information and the dependent variable being score on the problem solving test. In the camera study (Bromage & Mayer, in press), creative problem solving correlated well with recall of explanations but not with recall of other information. Thus, the explanative information is defined as the idea units that are related to good problem solving but not related to poor problem solving.

IMPROVEMENT OF PROBLEM SOLVING PERFORMANCE

Predictions

The assimilation framework outlined in Table 3 suggests some basic predictions concerning the relation between recall of explanative information and problem solving performance. In particular, students who are able to focus on the explanative information in science prose should be more likely to build integrated learning outcomes and hence to excel on tests of creative transfer. Two kinds of predictions may be offered:

- within subjects prediction--subjects who recall the explanative idea units are more likely to excel on problem solving, while subjects who do not recall explanative idea units are less likely to excel on problem solving. The previously cited camera study (Bromage & Mayer, in press) provides support for this prediction.
- between subjects prediction--techniques or factors that increase recall of explanative information should also increase performance on problem solving tests.

The goal of the present section is to explore techniques for increasing recall of explanative material and problem solving, i.e., to investigate the above prediction.

Although experimenters (or teachers) may be able to distinguish between the explanative and non-explanative information in a passage, there is no guarante that a reader will be sensitive to this distinction. In fact, a reader may be presented with an explanative passage--one that contains underlying explanations of mechanisms--and may read it as a descriptive passage. Since most early reading exercises involve descriptive-narratives or descriptive-semantic passages, subjects may develop expectations that are inefficient for science prose. It seems likely that many readers lack skills for dealing with science prose, i.e. for selecting explanative information. Thus, research on techniques for influencing how students read science is particularly needed.

Unit of Analysis

This section explores techniques that influence students' ability to use text information for creative problem solving. In particular, the focus of this section is on how to improve the students' problem solving performance for tests based on prose information. The target behavior is transfer--the ability to use the information from the text in novel ways, going beyond what was presented in the passage. Examples of transfer questions were given in the subsection on "logical methods".

For example, a transfer question for the radar passage might be: "What can you do to increase the area under surveillance by a radar station?" Some possible answers are: to bounce the radar pulse off of satellites, to bounce the radar pulse off of ground stations that circle the source, by using multiple radar stations and integrating the information by computer, etc. In order to answer these kinds of questions, a student needs to know the basic explanative information concerning transmission, reflection, reception, measurement and conversion. In addition, the learner must be able to put this information together in a new way. Thus, learning of the explanative information is a necessary but not a sufficient condition for creative problem solving.

The traditional unit of analysis for performance tests is score on a retention or recognition test, and the traditional unit of analysis for recall tests is number of idea units recalled. However, in the present studies, the unit of analysis for performance tests is score of a test of creative transfer, and the unit of analysis for recall is score on recall of explanative information.

In particular, the following subsections explore two basic kinds of techniques for influencing students' understanding of prose: (1) processing strategies--providing instruction or training in how to find the main explanative information in the passage, and (2) text design--organizing the text in a way that emphasizes or signals the main explanative information. These techniques are based on the idea that "what is learned" from the passage is related to creative problem solving performance; specifically, when students are able to focus on the explanative information they should be better able to perform well on tests of creative problem solving.

Processing Strategy

"What is learned" from prose depends both on the passage itself and on how the learner processes the passage. In our lab we have been examining the effects of processing strategy on "what is learned" and on the ability to solve problems.

One set of studies (Mayer & Cook, 1981) compared a verbatim strategy to a reflective strategy for processing the radar passage (see appendix A). Subjects listened to a tape recording of the radar passage that was presented at a moderately slow rate of 70 words per minute. The passage contained pauses at natural boundaries, occurring at about every 4 to 7 words. Some subjects (verbatim processing group) were asked to shadow the passage; that is, during each pause, they were asked to repeat the words they had just heard. Other subjects (reflecting processing group) were asked to listen to the passage and try to understand it; since the passage was presented at a slow rate, subjects had time to mentally connect segments of the passage during each pause.

In one experiment, all subjects took a verbatim recognition test, a retention test, and a transfer test. The retention test consisted of true-false questions covering the basic content of the passage, and revealed no differences between the two groups. Thus, if we had used only a standard measure of retention we would have concluded that processing strategy had no effect on "what is learned" in this study. However, as previously stated, a reflective processing strategy should encourage subjects to focus on the underlying theme, i.e., the explanative information, and result in superior transfer performance. Transfer was measured by asking subjects to answer essay questions that required using the presented information in a new way, such as the example question above. Similarly, a verbatim processing strategy should encourage subjects to focus on the details within each segment of the passage. Recognition tests asked subjects to choose which of a pair of sentences actually came verbatim from the passage, with the distractor having a synonym that replaced one of the original words. As predicted, there was a significant interaction in which the verbatim processing group performed better on transfer. One implication is that when the goal of instruction is creative problem solving, reflective strategies are better than "learning every word".

The foregoing differences in problem solving performance were attributed to differences in what verbatim and reflective subjects learned from the passage. In order to test this idea more directly, an additional study was conducted.

As in the previous study, one group engaged in verbatim processing and one in reflective processing of the radar tape. However, the test was to write down all that could be remembered from the passage. If we examine overall recall, we find that there is little difference between the two groups, and might conclude that "what is learned" is the same for the two processing groups. However, the problem solving results suggest that the reflective processing group will recall more of the explanative information while the verbatim group will recall more minor details. To score the recall protocols, the passage was broken down into idea units (as shown in Appendix A). As can be seen in Appendix A, some idea units were labeled as "explanative" and all others were not. Examination of the recall protocols revealed that the reflective group recalled much more of the explanative information than the verbatim group, but the groups did not differ on recall of other content information. Finally, a propositional analysis of the passage was performed based on Kintsch's system (Kintsch, 1974; Turner & Greene, 1977). Each idea unit was classified as either major (i.e. those with verbs, locations, times, causes, etc.) or minor (i.e. those giving modifiers, conjunctions, etc.). As predicted, the verbatim group performed better on recall of minor propositions than the reflective group, while the reflective group recalled more of the major propositions than the verbatim group. Thus, there is consistent evidence that the reflective group is able to focus on the explanative information and thus perform better on creative problem solving, while the verbatim group focuses on details within each word sequence and thus performs well mainly on verbatim recognition. This result is consistent with Morris, Bransford & Franks' (1977) theory of transfer appropriate processing, in which different encoding strategies support performance on different kinds of memory tests. In addition, however, the present studies extend the notion of transfer appropriate processing to tests of problem solving, and specifically focuses on processes strategies that distinguish good problem solving performance form poor performance.

In another set of experiments (Mayer, 1980) subjects read an eight page booklet that described a simple computer programming language. Some subjects (elaboration processing group) were asked to answer questions after each page of the booklet; the questions required subjects to compare information in one part of the booklet to another or to describe information from the booklet in the context of a familiar situation. Other subjects (normal processing group) were asked to read the booklet as they normally read any textbook and to be preapred for a test.

To test problem solving performance, subjects were asked to write and interpret programs that were either very similar to those in the booklet (near transfer problems) or which required putting several statements together in a new way to form a loop (far transfer). If we looked at overall performance, combining near and far transfer, there would be no strong evidence of differences between the two processing groups. However, if elaborative processing leads to focusing on the explanative information, then the elaborative group should excel only on far transfer. The results revealed an interaction in which the elaborative processing group excelled on far transfer while the normal processing group excelled on near transfer or performed at the same level on near transfer as the elaborative processing group. Thus, there is replicatory evidence that processing strategies that encourage active integration of the information result in superior performance on tests of creative problem solving but not on tests of retention of specific content.

An implication of the foregoing result is that the elaborative processing encourages the learner to focus on explanative information, such as descriptions of the internal changes in the computer, while normal processing encourages the learners to focus more on surface details and symbols, such as the format for specific computer commands. In a separate series of experiments, subjects read the booklet under either elaborative processing or normal processing conditions, and then were asked to recall all they could about several portions of the booklet. In order to analyze the recall protocols, the text was broken into idea units with some being labeled as "explanative"--namely, those dealing with changes in the computer's memory, program list, output, or input stack. When overall recall was examined there was no clear superiority for the elaborative processing group, and hence no support for the idea that there were differences in "what is learned" between the two treatment groups. However, a closer investigation revealed an interesting pattern in which elaborative subjects excelled in recall of "explanative" information while the normal group excelled in recall of technical details. Thus, again, there is evidence that elaborative processing leads to subjects' learning more of the explanative information and hence to superior problem solving.

In another set of studies (Peper & Mayer, 1978; Peper, 1979), subjects viewed videotaped lecturess on topics such as statistics, computer programming, or how a car engine works. Some subjects were asked to take notes on the key ideas in the lecture (notes group) while others only watched the lecture (no notes). Results indicated no overall differences in retention tests or recall tests for the two groups, and hence would have led one to conclude that there were no differences in "what is learned". However, a closer examination revealed a pattern in which note takers, especially low ability subjects, tended to excell on tests of creative problem solving and recall of explanative information while non-note takers excelled on near transfer tests and recall of technical details. Thus, as in the foregoing studies, when subjects are asked to engage in an activity that encourages active integration of the incoming information, they are more likely to remember the explanative information and perform well on creative transfer tests.

Another set of studies investigated the effects of repetition on learning from a scientific passage. For example, when a technical or scientific passage does not make much sense, a typical approach is to read it again. What happens to the learning outcome when a passage is read over several times? In particular, does repetition have mainly a quantitative effect--in which the learner acquires more and more information--or does it also involve a qualitative effect--in which different kinds of information are acquired and the structure of the learning outcome changes?

In our lab, Bromage (1981) has conducted a study in which a passage on how to use an exposure meter was presented either one, two or three times. Recall of all kinds of information, including explanative information, increased with repetition. There was also a pattern in which the first exposure encouraged the subjects to focus on the first sentence in each paragraph, technical symbols and numbers (as in learning a list of nonsense syllables); while, by the third exposure subjects seemed to focus on other material related to the explanation. In addition, when an advance organizer was provided, the repitition effects were drastically reduced. Apparently, when the reader already knows what to look for, repetition is not as useful.

In addition, a similar set of follow-up studies was recently conducted in our lab. Subjects listened to either a passage on Ohm's Law or radar for either one, two or three presentations. The recall protocols after the first presentation emphasized symbols, numbers, and statements of definitions. Recall after the third presentation emphasized explanative information. Thus, there is some evidnece that reading strategy changes with repeated exposure to a scientific passage. However, far more analysis is required before a change in processing strategy can be confirmed.

Another way to influence reading strategy may be through the use of behavioral objectives and adjunct questions. For example, objectives or adjunct questions that focus on explanative information should result in the student's ability to perform well on creative problem solving, while objectives and questions that focus on non-explanative information such as rote facts should restrict problem solving performance. In a typical study (Mayer, 1975a) subjects read eight short lessons on set theory. After each of the first six lessons, subjects received questions that focused on non-explanative information such as formal definitions in verbatim form or questions that focused on explanative information such as a concrete model for representing the rules. An example of a concrete model is to describe combinatorial analysis in terms of R people sitting at N places at a table. On passages 7 and 8 all subjects received all kinds of problems. Subjects who expected non-explanative questions performed well on questions involving recall of details and simple retention of the formula. Subjects who expected explanative questions performed well on all kinds of problems including the transfer problems. The same effects were noted when the questions were given before each passage as an "instructional objective". Thus, there is consistent evidence that adjunct questions can serve to guide the learner's attention towards or away from explanative information in the passage.

Finally, Linda Cook and I are currently studying the idea that subjects with prerequisite knowledge are able to process scientific knowledge differently than those without such knowledge. In particular, subjects were asked to read a three page passage concerning the concept of density, including the formula, density = mass/volume. Some subjects were given a brief introduction to the concepts of mass and volume prior to reading the passage (prior knowledge group) while other subjects were not given any prior knowledge (no prior knowledge group), and all subjects had little or no background in science. When subjects without prior knowledge were asked to recall the passage, they emphasized the formula in symbol format and produced many symbols in their protocols. When asked to solve creative problems based on the passage, subjects with no prior knowledge performed poorly. Subjects with prior knowledge tended to recall the formula in English rather than symbols and retained more of the explanative information in the passage; in problem solving, there was a trend in which subjects with prior knowledge performed better on certain questions but the differences have not yet been thoroughly tested. Apparently, when subjects read the density passage without an understanding of the concepts of mass and volume, they use a reading strategy that focuses on symbols, equations, and computing a numerical answer; however, when subjects who understand mass and volume read the density passage they tend to focus on the explanative prose rather than the symbols. Apparently, subjects are not always aware that their reading strategy is not efficient for problem solving, since many of the no prior knowledge subjects complained, "But I read every word."

Text Design

Another way to influence "what is learned" from a scientific passage, is to design the passage in a way that focuses attention on the explanative information and that encourages the reader to integrate the information. The major idea explored in this section is that certain text organizations are more likely to lead to subjects' learning the explanative information and thus to creative problem solving.

The major research effort on text design carried out in our lab has involved the study of how advance organizers influence learning from scientific prose. In particular, we have used advance organizers that provide a visual or concrete model of the main components in the text--i.e. the components used in providing an explanation. For example, in the radar passage a concrete model would present a picture of the transmitter, object, receiver, display and pulse as shown in the bottom right corner of Table 4. For Ohm's Law an advance organizer might show an electric circuit with electrons colliding into atoms in the high resistance portion of the circuit. In our research on teaching various computer programming languages, we used an advance organizer that showed the functional units of the computer--memory scoreboard, input window, output pad, and program list. We have reported elsewhere the summary of over a dozen advance organizer experiments (Mayer, 1979). In general the results are consistent with predictions cited above: there is clear evidence that advance organizers increase recall of explanative idea units (but not non-explanative idea units) and increase performance on creative problem solving (but not on simple retention).

In an earlier series of studies carried out in Jim Greeno's lab at the University of Michigan, we compared two ways of organizing mathematical prose. For example, in teaching the concept of binomial probability, a passage may begin with the formula and then tie general information to the formula later in the passage (formula-to-concrete organization) or the passage may begin with a discussion of concrete examples such as batting averages and probabilities of rainy days before moving on to the formula (concrete-to-formula).

The results of a long series of over a dozen experiments on this issue have been reported elsewhere (Mayer, 1975). However, the main results are consistent with the predictions cited above: for the formula-to-concrete organization, recall focused on symbols and formulas and creative problem solving was not present; for the general-to-formula organization, recall focused on general explanative concepts and subjects excelled on creative problem solving.

In a recent study (Bromage & Mayer, in press) we organized a passage on how to use a 35mm camera in two ways: one version organized the text around the major rules such as "to make the picture brighter, open the shutter" (rule organization), while the other version organized the text around the underlying components (explanation organization) such as "the particles on the film are influenced by how much light strikes them". In a previously cited study, subjects who excelled on problem solving tended to also recall more explanative information. Thus, a logical extension is to design a text that is organized so that it emphasizes the explanative information--i.e. the explanative organization version. As expected, subjects who read the explanation organization text recalled more of the explanative information and performed better on the tests of creative problem solving than the subjects who read the rule organization text. Apparently, text can be organized so that it signals the reader's attention to explanative information.

IMPLICATIONS FOR INSTRUCTION

The present paper has provided techniques for distinguishing explanative information from other types of information in science prose, and has suggested techniques for improving how readers understand science prose. In this section, we offer some speculations concerning how to improve text design and text processing.

There have numerous popular publications professing to teach authors how to write and students how to read. Most of the recommendations involve how to read or write narratives or reports, with little attention paid specifically to a focus of this paper--scientific writing. Furthermore, most recommendations are at the level of sentence structure, grammar, punctuation, paragraph structure and the like, with little attention paid to a focus of this paper--higher level organization that leads to problem solving skill. Finally, most recommendations are based on the traditional rules of English composition or on modeling the writings of "good authors", with little attention paid to a goal of this paper--basing recommendations on empirical research. Thus, the present recommendations represent a supplement to the existing popular literature, because the present recommendations are focused primarily on science prose, on fostering problem solving, and being compatable with research.

Within the past few years, research on prose processing has allowed several researchers to offer suggestions for how to design prose. For example, Wetmore (1980) listed seven principles for improving the "comprehensibility of text", including: "(1) Write unimportant ideas as breifly as possible, avoiding the use of vivid examples. (2) Tighten the relationship between examples and important concepts. (3) Turn negative statements of important principles into positive ones. (4) Enumerate important points. (5) Attach semantic labels to important concepts. (6) Underline technical terms. (7) Indicate straw men." In order to test these principles, Wetmore rewrote a passage on "biological taxonomies" so that it contained the same basic meaning as the original but was based on the seven recommendations. Results indicated that rewriting the passage increased recall of "important" idea units but not "unimportant" idea units, as compared to the original version.

Meyer (1975) has shown how "signalling" can improve recall of structurally important information. For example, use of the signals like "First...second... third..." or "The problem is...the solution is..." or "An example is..." can be used to improve recall of signalled information. In another study, Kieras (1978) found that paragraphs beginning with a topic sentence were easier to read than paragraphs that violated the "topic sentence first" convention.

Below are added some suggestions for how to increase the understandability of science text. These are offered as "good guesses" based on a general interpretation of our research, which should be subjected to additional testing. The suggestions are limited to improving understandability (as measured by tests of creative problem solving) for science prose (i.e., prose containing explanations of functional rules). The suggestions all are based on the idea that we should encourage the reader to select the explanative information in the passage and actively integrate that information with existing knowledge

1. Early in the passage, present a concrete model that includes the major explanative components underlying the rule. (For example, in the radar passage, provide a diagram that shows the transmitter sending a pulse, an object that reflects that pulse, a receiver that picks up that pulse, and a display that converts time to a measure of distance.)

2. Signal the major explanative ideas in the text such as using numbers. (For example, "First, a pulse is sent out. Second, it strikes a remote object. Third, some of the energy returns...")

3. Label the major explanative ideas. (For example, "The five steps of radar are: transmission, reflection, reception, measurement, conversion."

4. Use headings and indentations to indicate the major ideas. (For example, each idea is present on its own line.)

5. Use high imagery, familiar examples and analogies for the explanative ideas. (For example, radar is like an echo.)

6. Show the mapping between examples (or analogies) and the major explanative ideas. (For example, "shouting is like transmission of a pulse").

7. Organize the text around major ideas, and signal the organization through headings and introductory comments. (For example, the sections of the radar passage can be labeled: "Definition", "Devises", "Early Display Systems", "Modern Display Systems".

8. Shorten sentences about unimportant information, and avoid concrete examples or analogies for unimportant information. (For example, the "pebble in the pond" analogy may serve to distract from the overall theme.)

9. Provide definitions and examples of any prerequisite information. (For example, the reader should understand the concepts of a radio wave.)

10. To encourage active processing, include questions in the text that focus attention on explanative information. (For example, after each section questions could be inserted.)

11. To direct the reader's attention, include objectives that state creative problem solving as the goal of instruction. (For example, before the passage some creative transfer questions may be given as examples.)

12. Provide summaries that emphasize the key ideas so that the reader can compare his notes with the author's.

13. Underline technical terms and provide a glossary for all technical terms, so that unfamiliar words will not make smooth reading impossible.

14. Include repetition of important ideas in various wordings; build redundancy into the passage so that the reader has several opportunities to get exposed to the main points.

In general, these recommendations allow the author to tell the reader which ideas are the explanative ones. Examples of rewritten versions of the radar and supertanker passages are given in Appendices D and E respectively. Although they do not include all the recommendations, many are incorporated into the revision. It seems unlikely that any one of these recommendations is always "right"; however, the attempt to study them and revise them may provide the basis for a theory of science prose learning.

In conclusion, this paper has shown (1) that it is possible to locate "explanative" information in a science passage, (2) that there are techniques for influencing whether readers build learning outcomes that are based on this explanative information, and (3) that techniques that encourage explanative processing also tend to increase problem solving performance for material in the passage. Thus, in response to the question, "Can we increase problem solving performance?" this paper offers some reason to suppose the answer is "yes". It is hoped that this summary of our preliminary ideas, and findings, and even our speculative recommendations, will foster additional research on how to improve the understandability of science textbooks.

Footnotes

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[1]The term "scientific prose" or "science passage" refers to cell D or F in Table 1. Thus, science passage means a passage that contains an explanation for a functional relationship. Certainly, not all passages in science textbooks fit this description; thus, this paper uses the term in a more restricted sense than is generally used.

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Table 1

Six Types of Passages

	Descriptive	Explanative
Episodic	A Saint	B Lion
Semantic	C Wagon	D Radar Supertanker
Procedural	E	F

Table 2

Two Kinds of Research Goals

Typical Independent Variables	Typical Constructs	Typical Dependent Variables
GOAL 1: TO PREDICT RECALL OR RETENTION PERFORMANCE		
Passage Characteristics Level in text base Level in outline structure Level in story grammar Learner Characteristics Perspective of reader Prior knowledge of reader Prior experience of reader	Schema	Recall or Retention Performance
GOAL 2: TO PREDICT PROBLEM SOLVING PERFORMANCE		
Passage Characteristics Headings for each section Advance organizer Signals for key ideas Learner Characteristics Elaborative or reflective processing Question answering Note taking Prior knowledge of reader	Explanative Representation	Problem Solving Performance

Table 3

General Framework for Research on Learning from Prose

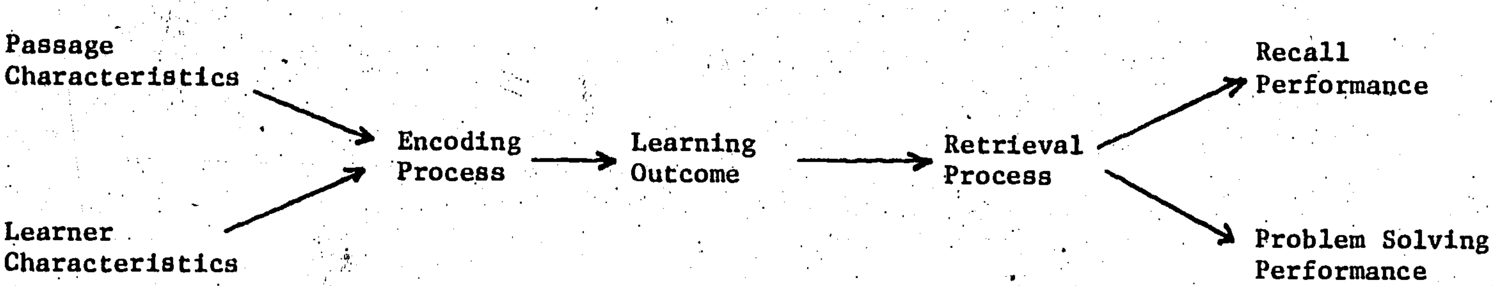

Table 4

Examples of Addition Encoding and Assimilation Encoding for Radar Passage

	Selection of details	Arbitrary, isolated relationships
Addition Encoding	travels in straight lines uses radio waves like dropping a pebble into a pond display has sweeping second hand earliest models in 1930	
	Selection of explanations	**Integrated, unified relationship**
Assimilation Encoding	Transmitter sends out a pulse object reflects back some energy picked up by antenna makes bright spot on screen	

Appendix A.

The Radar Passage

1. Radar means the detection and location of remote objects.
2. by the reflection of radio waves.
3. The phenomena of acoustic echoes is familiar:
4. sound waves reflected from a building or a cliff
5. are received back at the observer
6. after a lapse of a short interval.
7. The effect is similar to you shouting in a canyon
8. and seconds later
9. hearing a nearly exact replication of your voice.
10. Radar uses exactly the same principle
11. except that the waves involved are radio waves, not sound waves.
12. These travel very much faster than sound waves,
13. 186,000 miles persecond,
14. and can cover much longer distances

E 15. Thus radar involves simply measuring the time

E 16. between transmission of the waves

E 17. and their subsequent return or echo

E 18. and then converting that to a distance measure.

19. To send out the radio waves
20. a radio transmitter is connected to a directional antenna
21. which sends out a stream of short pulses of radio waves.
22. This radio pulse that is first transmitted looks very much like the effect
23. of tossing a pebble into a quiet lake.

24. It creates concentric circles of small waves

25. that continue to grow outward.

26. Usually both a transmitter and a receiver are employed separately

27. but it is possible to use only one antenna

28. in which pulse transmission is momentarily suppressed

29. in order to receive echo pulses.

30. (One thing to remember though)

31. is that radar waves travel in fundamentally straight lines

32. and that the curvature of the earth eventually interferes with long range transmission.

33. (When you think about)

34. the reception of the returning pulses or echoes

35. (you should remember)

E 36. that any object in the path of the transmitted beam reflects some of the energy back to the radio receiver.

37. (The problem then becomes) transmitting the pulses

38. picked up by the receiver

39. to a display mechanism for visual readout.

40. One mechanism in large use is the cathode-ray tube

41. A familiar item in airport control towers

42. which looks somewhat like a television screen.

43. (It is easiest to understand how radar is displayed)

44. if you begin with one of the earliest models

45. used around the 1930's.

46. These types of display systems were able to focus the broad radar pulse into a single beam of light

47. which proceeded from the left of the screen to the right.

E 48. When no object impedes the traveling radar pulse

E 49. it continues its travel

50. until lost from the screen on the right.

E 51. When there is an object present

E 52. the pulse would strike it

E 53. and begin to travel back to the receiver.

54. When the object is struck by the radar pulse

55. it creates a bright spot on the face of the screen

E 56. and the distance of the object can be measured by the length of the trace

E 57. coming from the object back to the receiver.

58. (With this model however)

59. you are only able to measure the distance of an object

60. and not it's absolute location

61. since the beam of light on the screen actually represents the entire width of the broader radar pulse.

62. Models employed today use two simple techniques

63. which make location of objects much easier

64. (First,) the transmitter now operates muck like the search light used in airports.

65. It emits a single beam of radar pulses

66. that make continuous circular sweeps around the area under surveillance.

67. (Secondly,) the display screen is adjusted

68. so that its center corresponds to the point where the radar pulses begin.

69. The radar pulse seen on the screen

70. operates like the second hand of a clock

71. which continually moves.

72. When an object is present

73. it leaves a bright spot on the face of the screen.

74. (An additional feature is)

75. that the face of the screen actually shows a map-like picture of the area around the radar

76. giving distance and of course location.

77. Thus it is very easy now to determine the location of objects

78. by noting their location on the screens map.

Appendix B

The Supertanker Passage

1. (A problem is)

2. prevention of oil spills from supertankers.

3. (Attributes of a typical supertanker include)

4. carrying capacity of a half-million tons of oil

5. size of five football fields

6. and cargo areas easily accommodating the Empire State Building.

7. (The trouble is that)

E 8. a wrecked supertanker spills oil in the ocean.

9. (As a result of spillage)

E 10. the environment is damaged.

11. (An example)

12. took place in 1970 near Spain

13. when an oil spill from a wrecked tanker exploded into fire.

14. the fire caused hurricane-force winds

15. which whipped the oil into a mist

16. and pulled all of it high into the air.

17. (Several days later)18. black rain resulting from this oil spill

19. destroyed crops and livestock in the neighboring villages.

20. (Another example of damage,)

21. occurred in 1967

22. when the tanker, Torrey Canyon, crashed off the coast of Cornwall

23. and resulted in the washing ashore of 200,000 dead seabirds.

E 24. Oil spills also kill microscopic plant life

E 25. which provide food for sea life

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Appendix C

The Lion Passage (Selected Portions)

1. (Once upon a time)
2. Lion, King of the animals
3. was walking through the forest
4. when he became caught in a hunter's trap.
5. The trap pulled Lion up, up,
6. until he was hanging upside-down high in a tree.
7. The other animals, hearing the noise,
8. rushed to see what had happened.
9. Lion looked down at the animals
10. and said:
11. "Friends, I have been a good leader for many years.
12. Now you must help me."

E. 13. The tiger, who wanted to be King of the animals himself,

14. shouted up:
15. "Why should we risk our lives helping you?
16. Each animal should look out for himself in times of danger.
17. Any animal who cannot help himself is not fit to live.
18. This is the way of our animal kingdom."
19. Then the tiger turned to the other animals and said:
20. "What do you say my friends?"

...

E 21. The horse, who was too proud of his good looks to care about anyone but himself

22. said to the animals:
23. "The tiger is right.

24. If Lion can't help himself,

25. Lion should stay in the trap."

...

26. Only the mouse hadn't spoken.

E 27. The mouse was terribly afraid of the tiger

28. so when it was his turn

E 29. just to make the tiger happy

30. he said very quickly:

31. "I agree with tiger.

32. Lion should not be helped."

...

Appendix D

A Revised Version of the Radar Passage

Definition

Radar involves five basic steps. Once you understand these five steps, you will have a basic knowledge of how radar works. The five steps are:

(1) Transmission--A radio pulse is sent out.

(2) Reflection--The pulse strikes and bounces off a remote object.

(3) Reception--The reflected pulse returns to the source.

(4) Measurement--The amount of time between transmission and reception is measured.

(5) Conversion--This information can be translated into a measure of distance, if we assume the pulse travels at a constant speed.

Thus, radar involves the detection and location of remote objects by reflection of radio waves.

Echo Example

In order to see how these five steps of radar relate to one another, lets consider an example. The example is a familiar phenomenon, an acoustic echo.

(1) First, you shout in a canyon. This is like transmission of a pulse.

(2) Second, the sound waves are reflected from a cliff. This is like reflection of a pulse off a remote object.

(3) Third, a nearly exact replication of your voice is received back at the observer. This is like reception of a radar pulse.

(4) Fourth, there is a short lapse between shouting and hearing an echo. This corresponds to measurement of time.

(5) Fifth, you notice that the further away a cliff is, the longer it takes to receive back an echo. This corresponds to conversion of time to a measure of distance of remote objects.

The same principle is used in radar, except that the waves involved are radio waves, not sound waves. These travel very much faster than sound waves, 186,000 miles per second, and can cover much longer distances.

Devices

Lets consider the actual devices that are used for the five steps of radar.

Transmission--To send out the radio waves, a radio transmitter is connected to a directional antenna which sends out a stream of short pulses of radio waves. As an example of how the antenna sends out radio waves, think of tossing a pebble into a quiet lake. The pebble creates concentric circles of small waves that continue to grow outward.

Reflection--Any object in the path of the transmitted beam reflects some of the energy back to the radio receiver.

Reception--Usually a transmitter and a receiver are employed separately, but it is possible to use only one antenna. In this case, pulse transmission is momentarily suppressed in order to receive echo pulses. One thing to remember about the reception of returning pulses or echoes is that radar waves travel in fundamentally straight lines, and that the curvature of the earth eventually interferes with long range transmission.

Measurement and Conversion--The problem then becomes transmitting the pulses picked up by the receiver to a display for visual readout. One mechanism in large use is the cathode-ray tube, a familiar item in airport control towers which looks somewhat like a television screen.

Early Display System

The earliest display system, used around the 1930's, dealt with the five steps of radar as follows:

To represent transmission, the display system focused the broad radar pulse into a single beam of light, which proceeded from left of the screen to right. When no object impedes the traveling radar pulse, it continues to travel until lost from the screen on the right.

To represent reflection, a bright spot is created on the face of the screen when an object is struck. Thus, when an object is present, the pulse would strike it and begin to travel back to the receiver.

To represent reception, there is a trace on the screen coming from the object back to the receiver.

To represent measurement and conversion, the distance of the object can be measured by the length of the trace. With this system, however, you are only able to measure the distance of object and not its absolute location.

Modern Display Systems

Display models employed today use different techniques for representing the five steps of radar, and thus make location of objects much easier.

For transmission, the transmitter emits a single beam of radar pulses that make continuous circular sweeps around the area under surveillance. Thus, an example is to think of the transmitter as being like the search light used at airports. In addition, the display screen is adjusted so that its center corresponds to the point where the radar pulse begins. As an example, the radar pulse seen on the screen operates like the second hand of a clock which continually moves.

For reflection, when an object is present it leaves a bright spot on the face of the screen.

For reception, there is a trace coming back from the bright spot to the center of the screen.

For measurement and conversion, the face of the screen actually shows a map-like picture of the area around the radar, giving distance and of course location. Thus, it is very easy now to determine the location of objects by noting their location on the screen's map.

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