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Abstract

This study investigated the effects of science curricula organized around topical (a collection of concepts or descriptions) and causal (superordinate principles directly related to underlying concepts) styles of discourse. The curricula were revised to control for number of concepts and amount of vocabulary, and numerous audiovisual materials (videodisc, films, and slides) were used throughout the study. This research attempted to extend prior work on discourse styles by substantially lengthening the intervention and controlling for students' background knowledge. The intervention involved 6 weeks of earth science materials. 46 eighth graders and 2 teachers participated in the study. All students were taught the same background knowledge for 4 weeks prior to the intervention and were randomly assigned to 1 of the 2 discourse groups. Posttests and maintenance tests indicated that students who were taught with material employing the causal style of discourse had significantly better retention of facts and concepts and were superior in applying this knowledge in problem-solving exercises.

Students in the early stages of learning science, who are essentially new to the subject as a formal discipline, commonly struggle with the ideas presented to them. It would be surprising if this were not the case. For young secondary students, concepts such as mass, buoyancy, condensation, relative humidity, and so forth, are abstract and difficult to understand. Problems arise when these students are presented with many new and complex ideas at one time (Voss, 1978). They exhibit difficulty detecting the most important information in texts (Dee-Lucas & Larkin, 1986, 1988). Retention of details remains fragmented and only vaguely related to higher-level principles, and much of what is studied is forgotten or

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assimilated into shallow schemata (Bereiter & Scardamalia, 1986; Voss, 1987). Consequently, these students perform poorly on problem-solving activities (Mayer, 1985).

A current body of research indicates that success with students at this stage of learning is directly related to the organization of content presented to students. Information that is poorly organized—that requires either domain expertise or substantial effort for comprehension—impedes learning for many students. Yet secondary teachers tend to rely heavily on these poorly organized materials (i.e., commercial texts), which account for as much as 90% of daily instruction (Mullis & Jenkins, 1988; Tyson & Woodward, 1989). The problems with science texts and the need to find more effective instructional materials are receiving increasing attention in the literature.

Organization of Secondary Science Texts

Recent critiques of secondary science texts indicate that as the amount of scientific knowledge has grown over the years, texts have become encyclopedic in the attempt to accommodate the latest information (Tyson & Woodward, 1989; Wivagg, 1987). One result is the use of a *topical* style of discourse for connecting ideas. This organizational form, commonly found in factual writing, links units of knowledge through broad themes. Topics are presented sequentially, and explanations vary considerably in depth. Moreover, there are few explicit links between topics to make the relationship of one to another more comprehensible.

Examples of topical discourse can be found readily in texts for young secondary students. In a brief chapter on "Weather and Climate" from a middle school earth science text (Charles Merrill, 1989), one finds subjects ranging from dew point and relative humidity to air masses, tornadoes, hurricanes, and climatology. Associated with any given topic are a number of concepts (e.g., with air masses one finds cyclones and anticyclones; warm, cold, stationary, and occluded fronts; and various types of clouds). Many of these topics are defined and discussed only briefly, often in one or two paragraphs.

More important, the relationship between these topics is not explicit, nor is there sufficient linkage to the underlying mechanisms or laws that cause these phenomena. White and Mayer (1980) discussed a similar style in their analysis of textbook lessons on Ohm's Law. Rarely is this law explained in terms of functional relationships between variables or concepts. There are few references to underlying mechanisms, and the overriding emphasis is on describing concepts. Thus, conceptual knowledge, which is rich in relationships, is given over to a sequential delineation of information.

Related to the topical style of science texts is the amount of unfamiliar vocabulary, much of which is used in an ancillary manner. The new vocabulary introduced in texts climbs from about 300 words (approximately one word per page) in the sixth grade (Armbruster & Valencia, 1989) to over 3,000 terms and symbols in the tenth grade (Hurd, 1986). Quite often the vocabulary in a 1-week science unit is greater than that of a similar unit in a foreign language course (Eylon & Linn, 1988). Other evaluations of science texts indicate even higher rates for new vocabulary (e.g., Pauling, 1983; Yager, 1983). Past research (Dee-Lucas & Larkin, 1986; Eylon & Linn, 1988) suggests that, given the extensive number of concepts and vocabulary found in most commercial science texts, readers are likely to spend more time engaged in lower-level cognitive processes (e.g., decoding) at the expense of effective comprehension.

Improving Science Instruction through Revised Materials

Research over the last decade has supported various methods for improving student comprehension of science materials. One alternative is to leave the core reading material unaltered and to sensitize students to discourse styles or text structures through graphic organizers (Berkowitz, 1986; Idol, 1987), idea networks (Brooks & Dansereau, 1983), frames (Armbruster, Anderson, & Ostertag, 1987), outlines (Slater, Graves, & Piché, 1985), or "think sheets" (Raphael, Englert, & Kirschner, 1986).

A second alternative for improving science instruction is through a substantive revision of the materials. With the growing availability of technology and software programs, some researchers (e.g., Dickson, 1985; Kozma, 1991; Salomon, Perkins, & Globerson, 1991) have argued that, when contemporary forms of media are coupled with effective methods of curriculum design, student comprehension improves.

Visual systems such as television and videotape are often semantically richer than text-based systems. Potentially, they contain more information and have more associations with knowledge already in long-term memory (Baggett, 1989). The use of visual and auditory symbol systems in concert (e.g., instructional television, videodiscs) can help students construct mental models and strengthen recall and understanding (Kozma, 1991; Mayer, 1989). These systems are likely to be particularly beneficial to poor readers as well as students who have a fragmented knowledge of a discipline. These students can watch and listen to explanations of conduction or buoyancy rather than struggle to abstract and visualize these concepts while reading traditional texts. Audiovisual materials were used for a substantial portion of the instruction in the study reported here.

Recent research in science also suggests that an optimal method of organizing curricula is hierarchically (i.e., knowledge that is organized with successively greater levels of supporting detail). Material that is organized in this manner enables precise elaboration of declarative knowledge that is to be recalled in long-term memory (Gagné, 1985). Hierarchical organization has led to improved retention and superior performance on complex tasks in earth science and physics (Brooks & Dansereau, 1983; Eylon & Reif, 1984).

However, recent research suggests that hierarchical organization often reflects only the most general features of a knowledge structure. Although in some instances the relations between superordinate and subordinate concepts are important, on other occasions this organizational scheme is incidental (Voss & Bisanz, 1985). How connections are made between the different levels of a conceptual hierarchy is often critical (Meyer, 1984; Meyer & Freedle, 1984; Voss, 1978).

Meyer, Young, and Bartlett (1989) pointed out that the retrieval of information in a hierarchy is guided by a particular discourse style. Meyer's earlier research (Meyer & Freedle, 1984) indicated that a collection of descriptions, or what has been referred to as a *topical* style of discourse, is a less effective vehicle for retention than causal discourse. Meyer and Freedle argued that the causal discourse style facilitates encoding and economical storage because there is more overlapping information, and, hence, there are more retrieval cues (or a richer form of elaboration). Applying this discourse style to secondary science materials, where the relations between many concepts may not be apparent to the novice reader, could lead to better comprehension.

Purpose of the Study

The study reported here addressed the effects of two discourse styles on the study of earth science concepts. Extensive audiovisual materials were presented throughout the study to convey the concepts. Videodiscs containing archival footage, narration, and computer graphics were used in conjunction with short films. These audiovisual materials were used in both experimental and comparison conditions as a way of controlling for the effects of media. This issue has been a confounded variable in past studies (e.g., Kelly, Gersten, & Carnine, 1990; Moore & Carnine, 1989) that contrasted audiovisual materials containing specific curriculum design principles with modified print materials.

I hypothesized that the materials organized according to a causal style that explicitly linked high-level physical science principles to lower-level earth science concepts in a hierarchy would better facilitate recall and problem solving than a curriculum following a topical style. Both sets of materials were based on concepts commonly found in middle school earth science courses. The audiovisual materials contained the same concepts and comparable vocabulary.

The study attempted to extend previous research involving hierarchically organized materials. Prior studies typically have involved brief written passages in the range of one to two pages or short audiotapes. The effect of longer materials has remained an important research issue (Meyer & Freedle, 1984). A longer intervention allows students more time to assimilate and reflect on the material being taught as they practice and review content. Mayer (1985) suggested that if learners have a better grasp of the functional relationships between science concepts, they should obtain an improved explanatory framework for problem solving. Students who possess superior conceptual knowledge, then, are more likely to be competent in solving a range of domain-specific problems (Prawat, 1989). The intervention phase for this study lasted 6 weeks.

Finally, the study attempted to control for background knowledge in two ways. First, middle school students were selected for this study because of their generally limited understanding of formal scientific principles and theories. Although these students may begin their study of earth science with some misconceptions, they also tend to have only a broad and descriptive (vs. principled) knowledge of science (Perkins & Simmons, 1988).

Second, much research on revised materials has involved college students, who vary in the degree to which background knowledge may have affected their understanding or recall of a passage. A learner's background knowledge has been shown to play an important role in determining what is learned or recalled (Dee-Lucas & Larkin, 1986; Hultsch & Dixon, 1983; Taylor & Samuels, 1983). Thus, all students were taught the same 4-week introductory course on physical science principles. Providing the same initial background knowledge, then, allowed a more precise examination of the specific effects of the two discourse styles on retention and problem solving.

Method

Subjects

Subjects were eighth graders at one school in a medium-sized, middle-class district. Forty-six students, 20 females and 26 males, from two earth science classes participated. After 4 weeks of preliminary instruction in physical science concepts and principles, students were matched on the reading comprehension subtest of the Metropolitan Achievement Test (Psychological Corporation, 1978) and the science subtest of Comprehensive Test of Basic Skills (McGraw-Hill, 1983) and then randomly assigned to either an experimental or comparison group within each of the two classes. This resulted in four groups: two conditions for each class.

Students were generally at or above grade level in reading and science. Mean performance on the Metropolitan Achievement subtest in reading corresponded to the seventy-fifth percentile, and on the Comprehensive Test of Basic Skills subtest in science, the mean was at the seventieth percentile. A one-way analysis of variance was performed on the raw scores from each measure, and nonsignificant differences were found among the four groups.

Materials

Contents of the preintervention phase. For the first 4 weeks, all students were taught a set of basic physical science principles. Students were shown the causal relationship between changes in temperature and the velocity of molecules. With the aid of computer graphics, students saw how two objects of different temperatures, when in contact, gradually move toward the same temperature (i.e., the principle of conduction). Concepts such as density and convection were also taught along with the principles of static and dynamic pressure. These principles were presented as "informal quantitative functions" (Mayer, 1985); that is, descriptions showed the quantitative relationship between variables but lacked the mathematical formulas expressing these relations.

Convection is a central but difficult concept in earth science and requires a synthesis of many of the specific concepts and principles just mentioned. Figure 1 presents a diagram of the model used to show students how these concepts and principles work in concert to form a convection cell.

Causal discourse style. Students in the experimental group continued in the audiovisual materials that were organized around a causal discourse style. This program, which is largely contained in the *Earth Science* videodisc course (Systems Impact, 1987), evolved from a comprehensive review of the material typically covered in eighth-grade physical and earth science courses. The videodisc materials contained brief graphic demonstrations of concepts and the occasional use of archival footage to present ideas. Short films and slides were also shown to these students. These visual aids constituted, on average, 40% of the instructional time for each lesson.

The physical science principles taught during the first 4 weeks of instruction were linked causally to a variety of large-scale terrestrial phenomena, such as major circulation patterns in the atmosphere, oceans, and mantle. For example, using their understanding of convection cells, students were taught that the movement of material in the mantle occurs in a convection-like pattern over millions of years. The earth's core was identified as the heat source responsible for this constant circulation. Stu-

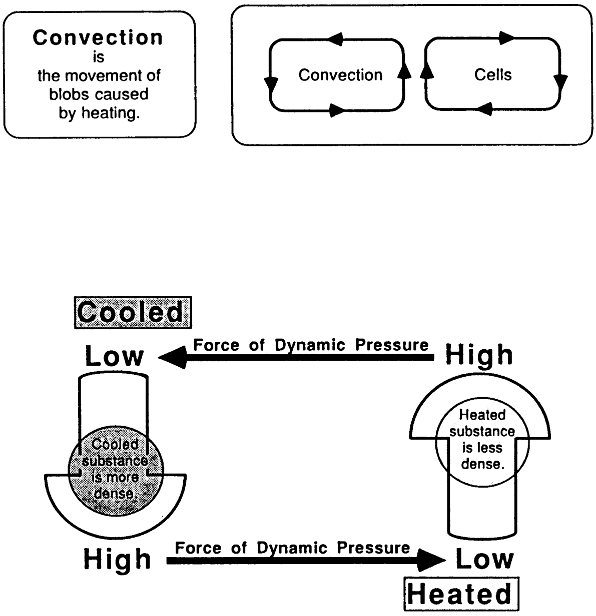

FIG. 1.—Convection cell method. From "Science Instruction at the Secondary Level: Implications for Students with Learning Disabilities," by J. Woodward and J. Noell, 1991, *Journal of Learning Disabilities*, **24**, 227–284. Copyright (1991) by the Donald D. Hammill Foundation. Reprinted by permission.

dents were shown how movement in the upper layers of the mantle near the lithosphere was causally related to mid-ocean trenches, plate tectonics, subduction zones, earthquakes, volcanic activity along fault lines, and mountain building near coastal regions. Convection cells formed a basis for explaining this large-scale pattern of movement and its subsequent effect on other geological phenomena. Figures 2 and 3 depict the relation between the physical science principle of convection and a range of earth science phenomena.

Other physical science principles such as static pressure were applied to common earth science topics such as the rock cycle and the weathering process. This explanation linked the three basic types of rocks, and it relied heavily on the initial explanations of how heat, temperature, and the principle of static pressure are related. Deteriorating surface rocks, many of which are igneous in origin, were shown as sediments accumulating in low areas and piling up. Over time, the increasing weight of the materials transformed basic sediments such as lime, mud, and sand into sedimentary rocks. Further increases in pressure and temperature changed these rocks into metamorphic materials.

Thus, terrestrial phenomena, at least as they are commonly covered in eighth-grade earth science materials, were linked causally to underlying physical principles such as pressure, temperature, and velocity as much as possible. Naturally, the initial physical science principles did not apply directly to some earth concepts (e.g., the direction of major air masses affecting North America, the formation of fossils). In these instances, presentations and discussions focused on the distinct features of a concept and its explicit relation to other concepts taught in the course.

Figure 4 illustrates the organization of knowledge for the causal group. The figure is by no means comprehensive, but it exemplifies how knowledge was hierarchically organized and more importantly, how it was linked causally where possible. At the highest level were the physical science principles from the preintervention phase, followed by causally related earth science concepts at the next level. At the lowest level

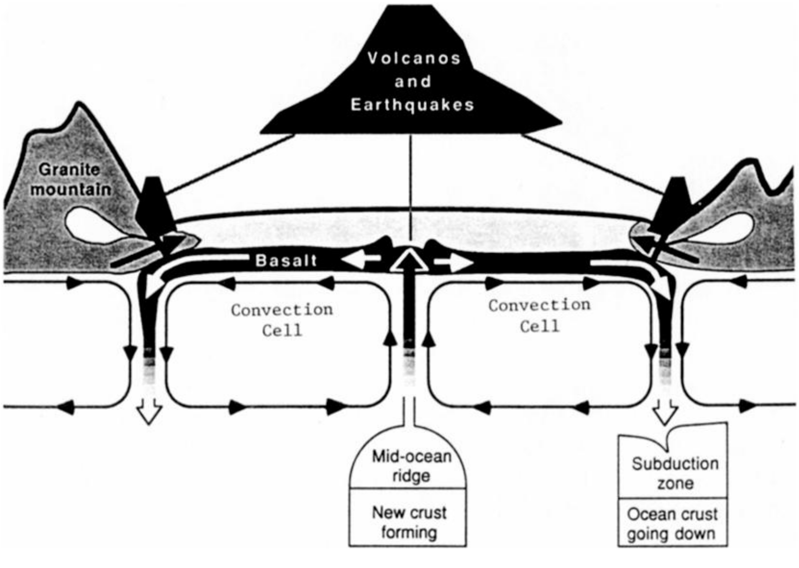

FIG. 2.—Mantle convection and its effect on terrestrial phenomena. From "Science Instruction at the Secondary Level: Implications for Students with Learning Disabilities," by J. Woodward and J. Noell, 1991, *Journal of Learning Disabilities*, **24**, 227–284. Copyright (1991) by the Donald D. Hammill Foundation. Reprinted by permission.

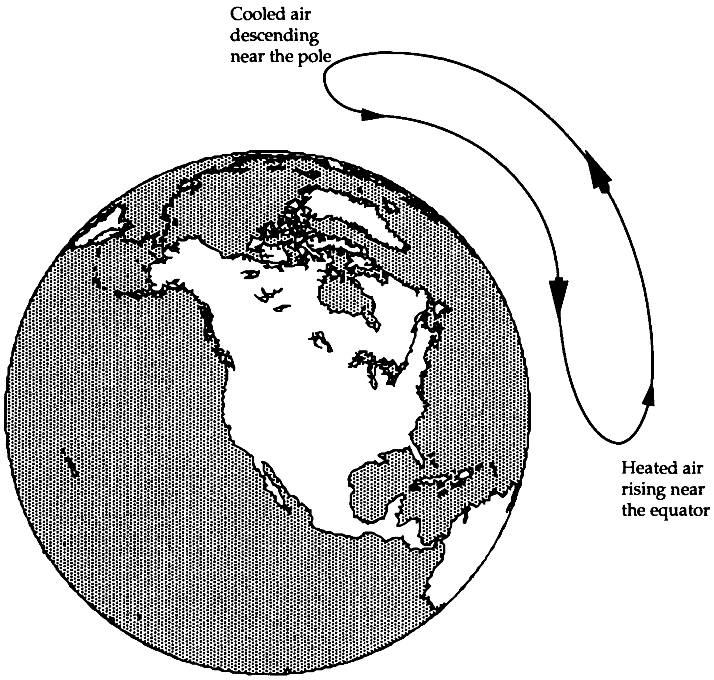

FIG. 3.—Atmospheric convection in the Northern Hemisphere. From "Science Instruction at the Secondary Level: Implications for Students with Learning Disabilities," by J. Woodward and J. Noell, 1991, *Journal of Learning Disabilities*, **24**, 227–284. Copyright (1991) by the Donald D. Hammill Foundation. Reprinted with permission.

of the hierarchy, traditional earth science concepts or facts that do not fit a causal style are described or presented topically. Many of these concepts describe or further classify a topic (e.g., the three different types of earthquake waves).

Topical discourse style. It is important to emphasize that all of the students in this study were taught the same physical science principles (i.e., the preintervention phase) during the first 4 weeks of instruction, under identical teaching conditions. However, once students were assigned to separate treatments, those in the topical group were taught the same earth science subjects as the causal group but in a discourse form similar to the way subjects are presented in traditional commercial materials.

Rather than causally linking all major terrestrial patterns to convection as described previously, the same earth science topics were presented sequentially as a collection of descriptions. Broad themes commonly found in textbooks (e.g., the rock cycle; the earth's surface processes; seasons, climate, and weather; the earth's internal processes) were used to organize these topics.

Tornadoes, for example, were explained in the larger context of climate and weather. Students were taught about high pressure (anticyclones) and low pressure (cyclones). This information was followed by discussions of fronts, changes in weather, and weather forecasting. Each topic was described in appropriate detail, but the causal links between topics and underlying physical science principles were missing. Students were shown cutaway models of the earth similar to Figure 2, but no causal relationship between mantle convection and the different earth science phenomena was drawn.

To control for the effects of the medium, students in the topical group were shown an approximately equal amount of audio-

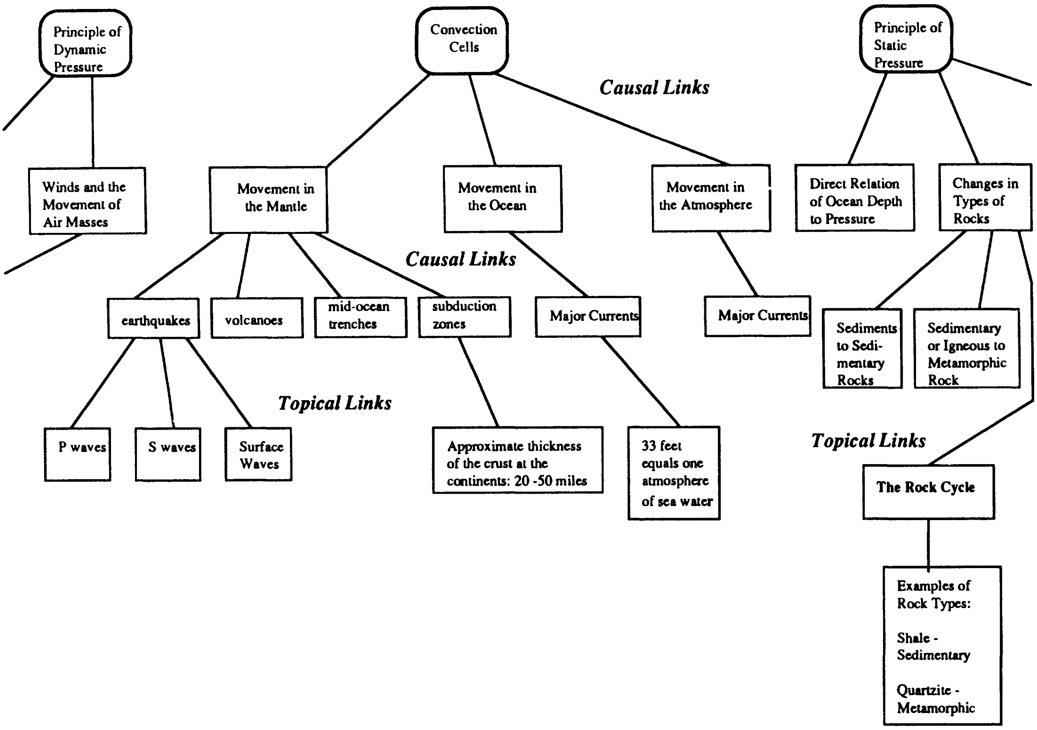

FIG. 4.—Organization of knowledge for the causal group

visual material as those in the causal group. Videodisc segments from the *Windows on Science* program (Optical Data, 1988), slides, and movies accompanied the presentation of earth science topics. Dramatic archival footage of tornadoes from the videodisc program, for example, was used to show their destructive power. Complementing this presentation were class discussions and lectures that emphasized the time of year, general locations (e.g., "tornado alley" in the Midwest), and average wind speeds of tornadoes.

Figure 5 shows the organization of knowledge for the topical group. The hierarchical structure depicts relations between sets of conceptions. More important, the initial physical science principles were linked topically to earth science material. That is, information was presented sequentially, with the physical science principles occurring first in the preintervention phase, followed by the same earth science concepts presented to the causal group.

Procedures

Students were taught 40 minutes per day for 10 weeks. During the first 4 weeks—the preintervention phase—all participants in both groups were taught the same physical science principles (e.g., conduction, dynamic pressure, convection). This was done to provide a common background knowledge. What varied during the subsequent 6 weeks of the study was the discourse style used to link these principles to terrestrial phenomena (i.e., causally for students in the experimental group and topically for those in the comparison group).

Informal criterion measures, which were developed for this portion of the curriculum, were administered weekly during the preintervention phase. These measures helped ensure that all students mastered the physical science materials so that there would be no discrepancy between groups when the intervention began. Weekly results indicated that virtually all of the stu-

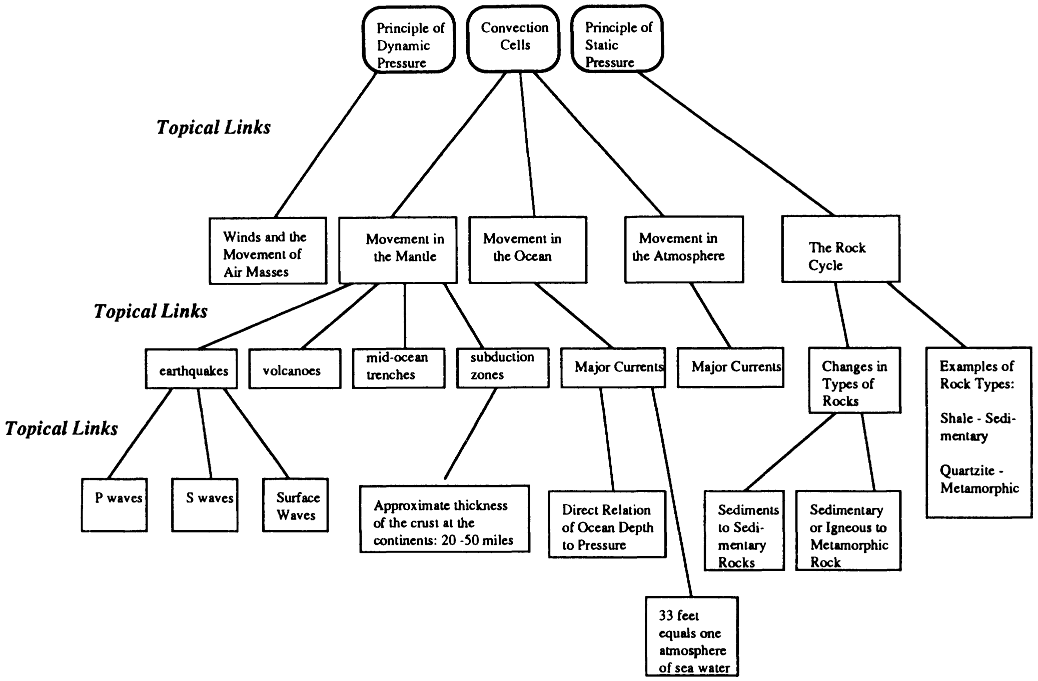

FIG. 5.—Organization of knowledge for the topical group

dents had learned the basic physical science principles at an 85% level or higher, and, hence, there were no significant differences between groups when students were randomly assigned to each condition. The subsequent intervention is described below.

Causal instruction. Students in this group continued instruction with the aid of many audiovisual materials (i.e., videodisc segments and occasional films). The basic physical science principles were linked causally to a range of earth science phenomena. This instruction did not entail further instruction on the physical science principles.

Direct explanation (Duffy et al., 1987) was used throughout each lesson in order to control the number of concepts and the amount of vocabulary taught during the intervention. The teacher elaborated on the concepts and conducted brief discussions during most class periods. Students also completed written exercises covering the day's lesson.

Topical instruction. Lessons for this group also followed the direct explanation method. The teacher began each lesson by reviewing briefly several key concepts from the previous lesson and providing an overview of the day's material. The teacher asked questions to check for understanding and conducted brief discussions with the class.

Slides, short movies, and videodisc segments (i.e., *Windows on Science*) were shown to explain the concepts further and to control for the amount of audiovisual material presented. Finally, as was the case in the causal group, students completed brief written exercises covering the day's lesson. The overall content of instruction, although it followed a different discourse style, was the same as that of the causal group.

Two researchers with considerable public school experience were responsible for all of the teaching. One was the author and the other was a graduate student. Both were thoroughly familiar with the two curricula used in the intervention. Neither was an earth science teacher. This was done intentionally to control for possible presentational biases that may have resulted from using experimental teachers in the study. Assignment of teachers to treatment was counterbalanced, with the two researchers changing groups halfway through the 6-week intervention (i.e., the researcher who was instructing the two classes of causal students switched at the end of 3 weeks and taught the two classes of topical students, and vice versa). The total time for instruction was controlled in this study; both groups received the same amount of teaching and independent work over the 6 weeks.

Measures

All students were administered four measures. Two of the measures—the *Physical Science Test* and the *Earth Science Test*—were designed to assess students' retention of the key conceptual information covered over the entire 10 weeks of the study (i.e., material from the 4-week preintervention phase and the 6-week intervention). The *Physical Science Test* (16 items) covered information from the first 4-week preintervention phase, conceptual material that was the same for all of the students. Items for this measure are located in the uppermost level of the hierarchies presented in Figures 4 and 5.

The *Earth Science Test* (50 items) involved concepts (e.g., subduction, the Coriolis force, condensation, relative humidity) that were presented to both groups during the intervention. Items for this measure reflected the concepts common to the two curricula used in the intervention. As stated earlier, these curricula were designed to control for concepts and related vocabulary. The concepts for this measure are located in the middle levels of the hierarchies presented in Figures 4 and 5. Internal consistency reliability (coefficient alpha) for the *Physical Science Test* was .71, and for the *Earth Science Test,* the key criterion measure, it was .86.

Each of these tests was based on a sample of 75 eighth-grade students who were taking earth science at the time but did not participate in the study. The *Physical Science Test* was administered as a posttest only; the *Earth Science Test* was given as a posttest and again, 2 weeks later, as a maintenance test.

A third measure, the *Application Problems Test,* was administered as a posttest. This 27-item test assessed students' ability to apply the physical and earth science concepts taught over the entire 10 weeks of instruction to novel, challenging problems. Most of the items on this measure were presented in two parts. The student first predicted an event or indicated a condition, followed by the selection of an appropriate principle that explained the event. For example, students were presented with a diagram showing a set of high- and low-pressure areas moving in an easterly direction toward Dallas, Texas, as shown in Figure 6. Changing conditions resulted in an extreme low-pressure system amid several highs. The students were asked to predict what was most likely to happen as well as the physical science principle that best explained this phenomenon (dynamic pressure in this instance).

Other problems asked about the subduction process of oceanic and continental crust plates, the large-scale movement of air masses over the United States, and the transformation of sediments into sedimentary and metamorphic rocks. These problems were unlike any of the exercises presented to either group during the intervention. Internal consistency reliability of this measure was .79, based on the same sample of 75 eighth graders who did not participate in the study.

A 33-item *Key Facts Test* was the fourth measure administered to all students. Items were drawn from the lowest levels in the hierarchies in Figures 4 and 5. This test was constructed as a criterion-referenced measure of automaticity (i.e., how quickly students could recall facts presented during the

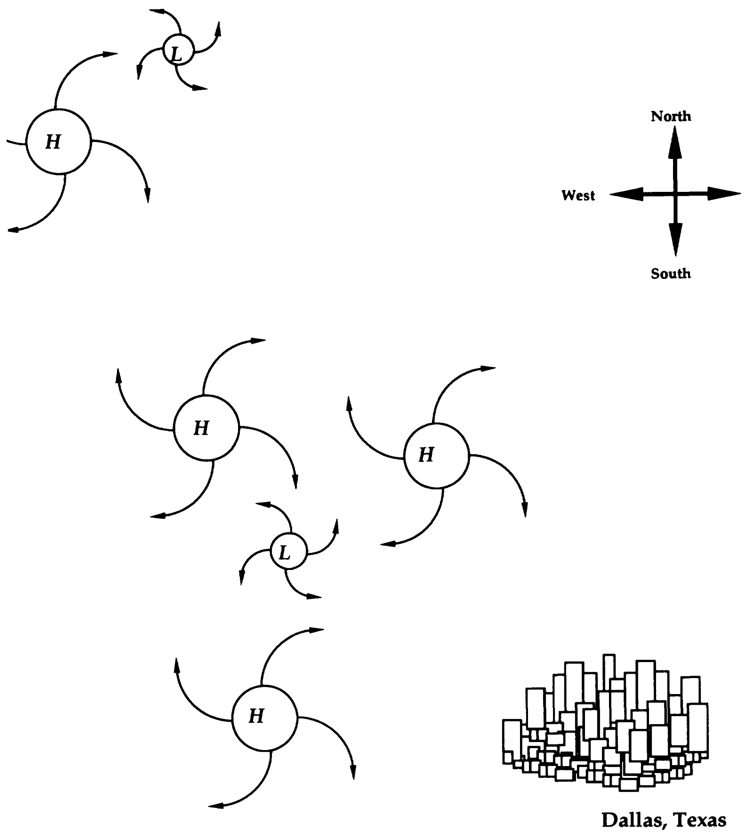

FIG. 6.—Item from applications problem test

first 4 weeks of instruction). The test was group-administered, and students were given 3 seconds to write answers to each question (e.g., How many feet of sea water equals 1 atmosphere? What part of the earth receives the most solar energy?). The 3-second time constraint, which is a common limit for math facts, helped gauge students' retrieval rate. The *Key Facts Test* was administered three times: at the end of the preintervention phase, as a posttest at the end of the 6-week intervention, and 2 weeks later as a maintenance test.

Results

Physical Science Test

A one-tailed t test was performed on the *Physical Science Test,* which was administered as a posttest only. This test covered the material that was taught to all students during the first 4 weeks of the study. Table 1 provides descriptive statistics for the correct number of responses for each group on the four dependent measures. Means have been converted to a percentage correct. Results of the t test for the Physical Science Test show a significant difference between the groups favoring the causal group $t\,(1,44) = 1.95$, $p = .03$.

Earth Science Test

A 2 × 2 (treatment by time of test) analysis of variance with repeated measures on one factor was performed on the *Earth Science Test.* Items on this test covered the same key concepts presented to both groups during the 6-week intervention. Table 1 provides descriptive statistics for the correct number of responses for this measure.

TABLE 1. Descriptive Statistics for Correct Answers on the Four Tests by Students in the Two Groups

	Posttest			Maintenance Test		
	M	SD	Mean % Correct	*M*	SD	Mean % Correct
Physical science test:						
Causal group	12.87	2.39	80	...	...	...
Topical group	11.04	3.53	69	...	...	...
Earth science test:						
Causal group	39.1	5.98	78	39.3	5.86	79
Topical group	23.8	7.26	48	24.4	8.09	49
Applications test:						
Causal group	21.35	3.66	79	...	...	...
Topical group	14.31	5.36	53	...	...	...
Key facts test:						
Causal group	29.3	3.68	89	29.4	3.3	89
Topical group	24.8	5.88	77	25.3	5.41	78

NOTE.—$N = 23$ for each group.

The analysis shows a significant main effect for instructional method ($F(1,44) = 61.5$, $p < .0001$). There was no significant drop in scores from posttest to maintenance test for either treatment group, nor was any significant interaction found.

Application Problems Test

A one-tailed t test was performed on the *Application Problems Test,* which was administered immediately after the intervention as a posttest. Table 1 presents the posttest descriptive statistics for the causal and topical groups. Results of a t test show a significant difference between the groups favoring the causal group $t(1,44) = 5.2$, $p < .0001$.

Key Facts Test

This measure was administered three times: at the end of the preintervention phase, as a posttest 6 weeks later, and as a maintenance test (i.e., 2 weeks after the posttest). The purpose of this measure was to assess automaticity in earth science facts. Performance at the preintervention phase for the causal group was 27.7 (SD = 4.05), or 84% correct. For those in the topical group, it was 27.5 (SD = 4.03), or 83% correct.

A 2 × 3 (treatment by time of test) analysis of variance with repeated measures on one factor was performed on this measure. Table 1 presents descriptive statistics for the posttest and maintenance test administration of this measure. The analysis showed a significant interaction between treatment and time $F(2,88) = 4.72$, $p < .01$. A test for simple main effects was conducted, indicating significant differences between instructional groups favoring the causal condition on both the posttest ($F(1,44) = 9.39$, $p < .01$) and maintenance test ($F(1,44) = 9.38$, $p < .01$).

Discussion

One goal of this study was to address a fundamental problem in previous research (e.g., Kelly et al., 1990; Moore & Carnine, 1989); that is, media was a confounded variable in comparisons of well-designed audiovisual materials and modified print materials. By controlling for medium, my colleague and I were in a better position to examine the effects of two methods for organizing science concepts. The potential effects of different media on learning are summarized elsewhere (Kozma, 1991; Salomon et al., 1991).

Thus, the main results of this study corroborate, and in many respects extend, past research on discourse styles. Students taught with the causal structure significantly outperformed those in the comparison group on the kinds of measures commonly used in discourse studies. That is, retention of material as measured by the *Physical Science, Earth Science,* and *Key Facts* tests significantly favored students in the causal condition, and effects for key facts and concepts were maintained over time. These findings are consistent with past research (Meyer, 1984; Meyer & Freedle, 1984), which has shown weaker effects on measures of retention for a collection of descriptions or topical approach.

Yet a more detailed examination of these measures reveals the potential effects of longer interventions on retention. Prior research suggests that ideas located highest in a hierarchy are retained better than those at lower levels (Eylon & Reif, 1984; Meyer et al., 1989; Walker & Meyer, 1980). This pattern can be found in the topical treatment during the posttest phase, where mean performance on the *Physical Science Test* (concepts highest in the hierarchy) was 69% as compared to the mean retention of 48% on the *Earth Science Test* (concepts at the next level below).

However, this was only marginally the case with the causal group, whose mean performance scores were 80.4% and 78.2%, respectively, on the physical science and earth science measures. Furthermore, the highest mean levels of retention were on the *Key Facts Test,* items lowest in the hierarchy.

Students in both groups were equivalent on the *Key Facts Test* before the intervention. Yet significant differences favoring the causal group developed by the posttest and maintenance test phases. This finding is noteworthy insofar as neither group of students continued to practice these facts systematically during the intervention. Instead, students were exposed to them on an incidental and context-dependent basis. For example, in the unit on the oceans, students were reminded that 33 feet equaled 1 atmosphere of sea water.

Although these results are at odds with prior research into discourse styles, they are understandable in this instructional context. Unlike much research on discourse styles and revised science materials, the intervention in this study lasted 6 weeks rather than one or two sittings involving short passages or audiotapes. Practice and review were consistent instructional practices for both conditions. This was especially the case in the preintervention phase, where all students learned the background knowledge (i.e., high-level physical science principles and related facts) necessary for the earth science instruction.

Because this intervention was much longer than most discourse studies, the effects of the different discourse styles rather than levels of information in a hierarchy became critical. Topical discourse, by definition, entails a collection of topics—each of which may be adequately described—but there are few explicit relations *between* topics. For the learner who is new to a formal discipline, the cumulative effect of such a collection is diminished retention, and, as Meyer (1984, p. 12) points out, "few expectations other than generally knowing that more is to come."

Significantly lower retention of facts for students in the topical group in the posttest and maintenance test phases indicated the effects of the topical style. Weaker links to other concepts and principles resulted in information that was more isolated in memory and with fewer retrieval cues available for the learner. These findings are consistent with basic research on the role of elaboration in retrieval (Gagné, 1985) and similar to the findings of studies involving low- and high-knowledge individuals (Voss & Bisanz, 1985; Voss, Vesonder, & Spilich, 1980). Detailed, lower-level information is easier to relate to higher-level information for learners who have a more integrated knowledge of a subject. Thus, although the lowest-level information in this study was topically linked, concepts and principles above it were integrated causally.

By contrast, the cumulative effects of the causal discourse heightened student understanding. The reasons for this have to do with fostering conceptual understanding as a part of knowledge acquisition. Students like the ones who participated in this study have a much more difficult time than sophisticated learners or experts in detecting important concepts and the relation between concepts in complicated material such as science (Dee-Lucas & Larkin, 1986, 1988; Mayer, 1985).

The explicit causal links between the physical science principles of the preintervention phase and the subsequent earth science concepts rendered a more comprehensible and conceptually sophisticated picture of earth science than what occurred as a function of the weaker, topical linkages. Put another way, the acquisition of new knowledge (new earth science concepts) is best served when prior knowledge (underlying physical science principles) is utilized. Conceptual understanding is enhanced when the fit between new information and prior knowledge is explicit and well structured (Gagné, 1985; Glaser, 1990; Prawat, 1989; Voss, 1987).

The effect of an integrated, conceptual understanding can then be seen in its transfer to problem solving. In science, explanatory frameworks provide a superior base for solving problems than do descriptive frameworks (Bromage & Mayer, 1981; Mayer, 1985). Comparative performance on the *Application Problems Test* corroborates this view of knowledge utilization. On this measure, students were asked to solve problems involving relations between a common phenomenon and underlying physical science principles. Success on these exercises required students to detect the most salient features of the problem and then functionally to relate these features to underlying principles.

For example, one problem presented a natural setting where heavy rainfall was causing increasing runoffs and mud deposits from the side of a mountain. Students were asked to project into the distant future the effects of these deposits, the type of rock formation that would evolve, and what would explain this kind of formation. As stated earlier, these problems were unlike problems or exercises presented over the 6-week intervention, where relations between the types of sediments and their sedimentary rock forms as well as the role of static pressure were much more explicit. Students in the causal group successfully completed these problems at a much higher level than those in the topical group.

The overall results of this study suggest that a causal approach, or what Mayer (1985) calls an "explanative structure," is an effective means of improving science instruction for novice students. Science is a natural content area for the causal discourse style, and when knowledge is organized as such, it takes on the character of a strong schema (Anderson, 1984). This discourse style also affects science learning at a deeper level.

A well-developed understanding of a content area ideally teaches students, particularly novice students, a keener sense of the discipline—a sense of its "logic" (Resnick, 1987). Science educators (Linn, 1987; Mullis & Jenkins, 1988) argue that students should learn more than facts and concepts. Hypothesis formation and testing, the ability to work from data, and deductive and inductive logic should play a central role in learning. By using a causal structure that relates physical science principles to terrestrial phenomena, students were introduced to a common logic of the sciences: the hypothetical deductive method of explanation.

Combining the logic of the discipline with domain-specific knowledge is a new and markedly different way of constructing expository material for young secondary students. A good deal of thoughtful analysis is required to identify and carefully organize key concepts in science. Yet in science instruction for learners who are new to the formal aspects of a discipline, a shift from the topical to more effective forms of discourse can foster a better understanding, one that enhances retention and problem solving. It underscores the contemporary view that knowledge of a domain and the ability to think about or solve problems in that domain are competencies that develop hand in hand and not separately.

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