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ABSTRACT

It was hypothesized that distinct conceptual relationships are better displayed in a unitary complex science diagram relative to a text description. A second hypothesis stated that the placement of a textual description adjacent to a unitary complex science diagram generally will divert the learners' attention to the theoretically less effective unit, the textual description. Adjunct verbal questions relative to a prose criterion posttest were used to facilitate the learners' inspection behavior. Two hundred seven high school biology students constituted the sample used in the experiments. Five treatment groups were formed: (1) word (black and white, block) diagram, (2) word diagram with prose, (3) picture-word (colored, stylized) diagram, (4) picture-word diagram with prose, and (5) prose. Four orthogonal comparisons of the means (p less than .05) supported the hypotheses. The word and picture-word science diagram treatments were independently more effective than a prose description and more effective than the multi-media or combination of the same diagram and prose. It was suggested that the effectiveness of certain multi-media science instructional presentations can result in learning interference. (Author/EB)

LEARNING INTERFERENCE AND IMAGERY CONSIDERATIONS ASSOCIATED WITH SCIENCE DIAGRAMS AND PROSE MEDIA*

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INTRODUCTION

Instructional diagrams used to present cyclic schema and pathways in science adjacent to a textual description represents an increasingly common way of displaying distinct conceptual relationships in modern secondary and collegiate science textbooks. Exemplary support for this generalization is illustrated in a comparative examination of the first and third editions of the popular Green Version B.S.C.S. high school biology textbooks (B.S.C.S., 1963, B.S.C.S., 1973a) and between earlier general college biology textbooks and more recent texts (e.g., Weisz, 1959, 1971 and Keeton 1967, 1973). These science diagrams (e.g., B.S.C.S. 1973 a, b: Yellow Version, p. 556, Green Version, p. 225) usually are chosen by instructional designers to present distinct relationships (e.g., sequential and interacting biological mechanisms associated with photosynthesis) among subsumed concepted (e.g., chlorophyll, water).

Science diagrams can vary widely in terms of cognitive content, spatial organization, affective attributes and position within an instructional display. They theoretically allow instructional designers to accentuate criterion verbal and pictorial displays identifying the more relevant, distinct units and their interrelationships. Diagrams also can concentrate selected, criterion information within a more optimal learning spatial organization, thereby increasing the probability of learner attention and encoding of criterion relationships.

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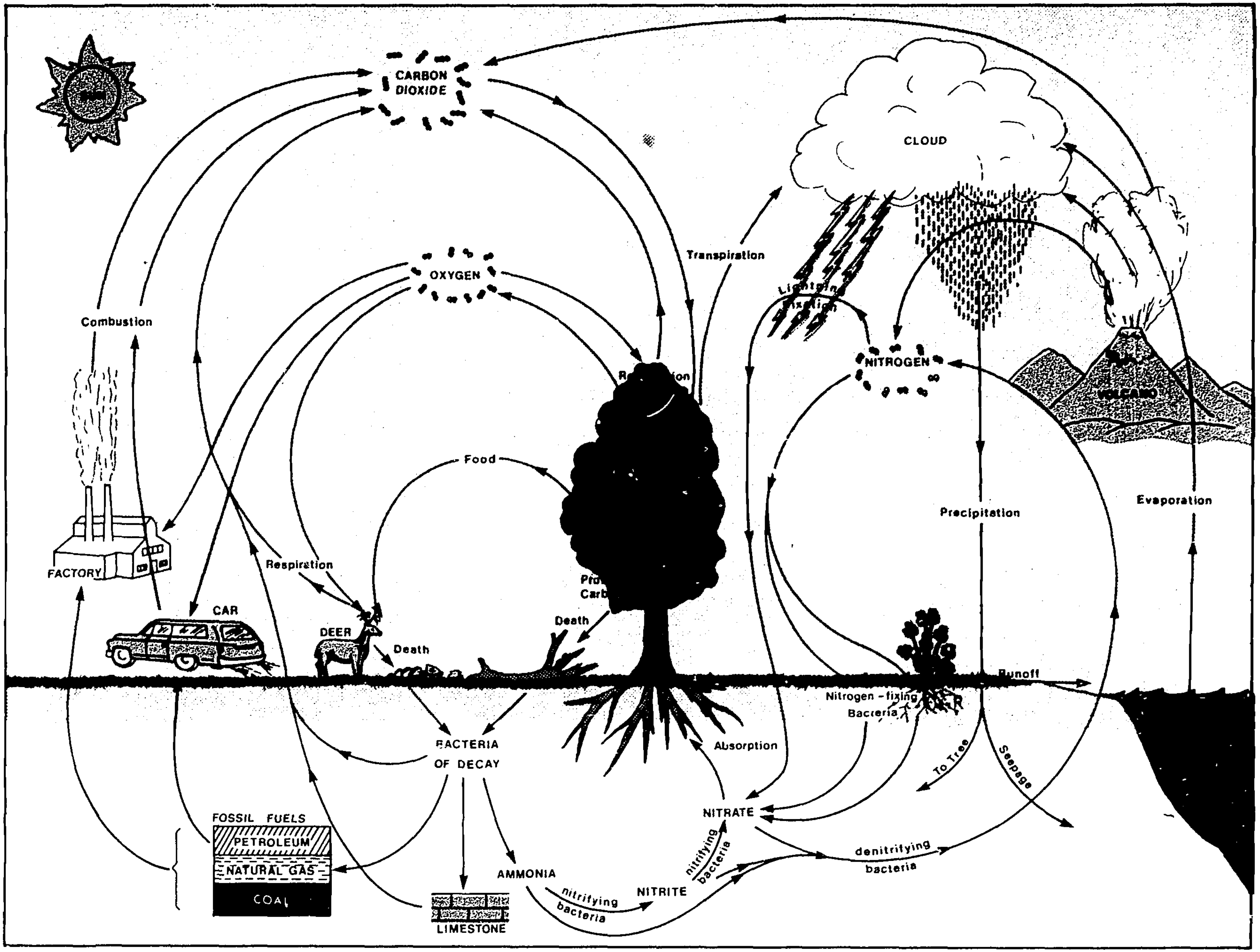
CARBON DIOXIDE
OXYGEN
CLOUD
NITROGEN
VOLCANO
Combustion
Transpiration
Food
Respiration
FACTORY
CAR
DEER
Death
Death
Precipitation
Evaporation
Runoff
Nitrogen-fixing Bacteria
To Tree
Seepage
Absorption
BACTERIA OF DECAY
NITRATE
NITRITE
AMMONIA
nitrifying bacteria
nitrifying bacteria
denitrifying bacteria
FOSSIL FUELS
PETROLEUM
NATURAL GAS
COAL
LIMESTONE

The present study examined certain instructional qualities of unitary complex science diagrams (i.e., a single diagrammatic presentation of distinct relationships among concepts constituting intra-and inter-disciplinary science information), specifically a single complex block work diagram and a single complex picture word diagram. The relatively inexpensive and easy-to-prepare block word diagram usually consists of words (i.e., verbal labels of concepts) and uncolored block figures (e.g., rectangles and circles) joined by arrowed lines indicating distinct conceptual relationships. The more expensive and increasingly popular picture word diagram (see page 2) usually consists of colored stylized line drawings of concrete concepts and logically positioned verbal labels of more abstract concepts joined by diagrammatic arrowed lines. The proper design and use of unitary complex science diagrams should facilitate the learner's ability to identify translated and rephrased sets, subsets and compound sets of certain accented conceptual relationship units in terms of a prose ("non-diagrammatic") posttest. Theoretically, this instructional diagram type represent a more effective instructional display under certain conditions relative to the common teacher presented and student attended to "equivalent" text description <u>or even</u> a combination of the diagram adjacent to a text. The present study examines this twofold issue and its implications for instructional designers of science curriculums.

<u>Processing Distinct Conceptual Relationships</u>

A unitary complex science diagram has the potential of capitalizing on two theoretical and empirically supported characteristics of effective instructional stimuli: visual imagery and optimal learning organizational displays of information.

Visual imagery research has been clearly established that the image-evoking quality of a stimuli (i.e., the extent to which a learner can generate a mental picture of the stimuli upon demand) is highly indicative of the chance that stimuli can be verbally recalled (Paivio, 1973, Holliday, 1973). Therefore, an instructional questioning technique, such as the use of adjunct verbal questions relevant to a criterion posttest should facilitate inspection behavior of a unitary complex science diagram resulting in a higher potential recall of criterion portions of this diagram type. This higher probability of information recall in turn should be reflected in significantly higher posttest scores relative to subjects receiving certain other information display types (e.g., textual medium) with a theoretically lower image evoking quality.

A second established characteristic of effective instructional stimuli associated with visual imagery is the spatial arrangement and organizational display of criterion relationships (Keele, 1973). Various verbal-pictorial display types have been shown to possess an informational organization more conducive to recall relative to a variety of corresponding verbal displays. Based upon this widely accepted empirical evidence, Spangenberg (1973) investigated the effectiveness of a unitary complex verbal pictorial display containing 20 paired associates. He found that more multiple associations and meaningful intregation of selected information could be increased when picturable concepts were displayed as pictures proximal to their verbal labels under conditions of maximal structural coherence. According to Spangenberg, maximal structural coherence refers to display stimuli that tend to form a single image or unit in the learner's mind. His results and rationale regarding the effectiveness of structurally coherent non-prose displays theoretically support the use of simple and more complex cyclic schema and pathway displays found in science textbooks. In theory, those learners who attend to, mentally encode and generate criterion stimulus cue-linkages (i.e., distinct conceptual relationships displayed in the diagram) can actually visualize in their minds a part (stimulus cue) of the display upon demand which in turn facilitates the mental visualization of an adjacent portion (response) of the diagram. This phenomena should facilitate recall of one or more criterion relationships presented in the instructional material as evidenced in higher posttest scores.

Selective Attention or Learning Interference

Attention has been defined as "the process whereby learners translate nominal stimuli into effective stimuli" (Anderson, 1970). The nominal stimuli represent the intended instructional environment placed before the learner. The effective stimuli are those the learner actually (selectively) attends to in order to achieve the desired terminal behavior. Cue selection or selective attention by learners is an established phenomena in terms of simple, paired associate learnings (Anderson, 1970) and in some more complex, school-relevant learning types (Holliday, 1971). The selective attention hypothesis is directly related to learning interference (Keele, 1973) and has instructional design implications for multi-media presentational displays in science.

Learners usually favor textual descriptions over other displays types in most verbal learning situations as suggested by their generally observed perference for the prose medium (Fleming, 1962) and by their general desire to follow the path of least effort (Underwood, 1963). If students are able to "learn" the information to their satisfaction by using a preferred instructional unit type (e.g., textual medium), there seems little reason for them to attend to an additional presentational display (e.g., unitary complex science diagram). The selective attention hypothesis suggests that certain dual or multi-media approaches are not always the most desirable instructional method, contrary to an almost universal practice in science education. Therefore, if a learner is given the combination of a complex unitary science diagram displayed adjacent to an "equivalent" textual medium, he probably will attend to the text and usually neglects the theoretically more appropriate diagrammatic medium. In this case the textual presentation interferes with learning by diverting the learner's attention.

The Experiments

Two concurrent experiments in the present study examined two separate unitary complex science diagrams and a single "equivalent" textual description in terms of two instructional research hypotheses. The first hypothesis stated that distinct conceptual relationships as previously described are better displayed in a unitary complex science diagram relative to a text description. The second hypothesis stated that the placement of a textual description adjacent to a unitary complex science diagram generally will divert the learner's attention to the theoretically less effective unit, the textual description. Adjunct verbal questions relative to a prose criterion posttest were used to facilitate the learner's inspection behavior.

METHOD

Subject

Two hundred seven high school students enrolled in an introductory biology course in the Calgary (Alberta, Canada) public schools constituted the sample used in two concurrent experiments.

Materials

Selected biogeochemical cycles commonly presented in a secondary school science textbook constituted the treatment materials for three main reasons. First, these interdisplinary science cycles (i.e., oxygen, carbon dioxide, water, nitrogen) contain numerous distinct conceptual relationships and represent school-relevant content that has recently attracted a considerable amount of attention from developers of unified science and environmental science curriculums. Second, these cycles are commonly presented in a combined textual and diagrammatic fashion as illustrated in practically all science textbooks that attend to these concepts. Third, this science information could theoretically be presented in either a text, block-word diagram or picture word diagram.

Five instructional treatments and a single criterion test were developed for this study. These treatments (see Figure A) consisted of a: (1) textual description (T) (2) a picture word diagram (PWD) (3) a picture word diagram adjacent to the textual description (PWD + T) (4) a block word diagram (BWD) and (5) a block word diagram adjacent to the textual description (BWD + T). All treatments contained the same two or three adjunct questions on each of the 10 pages of instruction. The textual instructional materials within PWD + T, BWD + T, and T consisted of ten pages of a logically sequenced text. The picture word or block word diagram displayed on each of the ten pages of the diagram treatments within PWD + T, BWD + T, PWD, and BWD were identical. This repeated exposure to the same diagram theoretically reinforced the mental image of the diagram in the learner's mind.

Two concurrent experiments were performed. The picture word diagram experiment examined the relative effectiveness PWD and PWD + T, and PWD and T. The block word diagram experiment compared BWD and BWD + T, and BWD and T. The two diagrams used in the four diagram instructional treatments represented the only difference between these experiments. The two diagram types differed in terms of the positions of the verbal labels, arrowed lines joining the labels and the associated block figures or colored drawings. Both diagrams and the textual description contained the equivalent 37 concepts and conceptual relationships associated with the criterion information. Of course, the two diagrams and the textual description could not be considered redundant display units because the instructional advantages and limitations of the individual medium types, a common point of confusion. (Holliday, 1972). An identical 1000 word textual description with ten subtitles (one subtitle per page) was used as a common treatment group in both experiments and was included in PWD + T and BWD + T.

The objective in the design of individual instructional units (text, picture word or block word diagrams) was to present certain biogeochemical cycles in the most effective fashion given the limitations of the particular unit type. For example, BWD was limited to a black and white display using only block figures, verbal labels (printed words) of criterion concepts, and arrowed lines indicating criterion conceptual relationships.

The picture word diagram consisted of a colored stylized line drawing of concrete criterion concepts (e.g., tree) joined by diagrammatic arrowed lines indicating selected conceptual relationships. Verbal labels were used to clarify the meaning of most drawings. The more abstract concepts (e.g., "nitrifying bacteria" and "nitrite") verbal labels were positioned adjacent to other logically appropriate abstract concepts and drawings of concrete concepts (e.g., "nitrifying bacteria" label was positioned adjacent to the "nitrite" label and beneath the ground level illustrationed in the diagram).

The block word diagram consisted of verbal labels, uncolored block figures (circles and rectangles) and arrowed lines indicating selected conceptual relationships. The verbal label "plant" was used to indicate any green plant in BWD and a picture of a tree represented the equivalent concept in PWD; otherwise, the verbal labels in both diagrams were equivalent.

Twenty-two identical adjunct verbal questions represented the instructive techniques used to direct the learner's attention to all learning materials in each treatment group. These questions in those treatments containing diagrams (PWD, PWD + T, BWD, BQD + T) were placed directly below the diagram in attempt to persuade the subjects to answer the questions by using the diagrams and not just the text material. The questions required subjects to inspect the instructional materials and identify selected distinct conceptual information commonly presented in all treatments.

Thirty-two multiple choice, verbal prose criterion test items were generated from translated or rephrased adjunct questions and the corresponding answers (a question set) contained in the treatments. Each posttest item required subjects to recall and identify a part or a whole, more than one question set unit. In other words, the correct identification of a subset,

set and a combination of sets of accented conceptual relationship units was required. Subjects ability to identify conceptual information not clearly defined in the learning materials was not evaluated in the present study.

Procedure

Subjects were randomly assigned to the five groups. Subjects were instructed to learn the material and answer the adjunct questions. They also were told that the results of their total scores on the adjunct questions and on the subsequent multiple choice verbal posttest covering the biogeochemical cycles material would be a good indicator of their ability to understand science information and that scores would be communicated to their biology teacher.

Content validity was examined through personally (individually, face to face) conducted interview of 33 high school biology teachers. They were asked to judge and comment on the instructional treatment materials and the criterion test in terms of "instructional effectiveness" of the materials and the "appropriateness" of the information sampled by the test considering the target sample population.

Two weeks prior to the present experiments, five aptitude pretests were administered and evaluated in an aptitude treatment interaction study (Holliday, Brunner and Donais, 1974) and a correlational pilot study. Subjects were led to believe that the five pretests constituted their entire contribution to this "special" testing program. The criterion pretests scores generated by the textual description treatment groups were used in the present study. The criterion pretest and the subsequent posttest scores were compared and used as a quasi-control.

RESULTS

Four orthogonal comparisons of the means supported the two *a prior* hypotheses. See Table I and II. The complex picture word (PWD) and block word (BWD) diagram treatments were independently more effective than the textual description (T) as predicted by the first (i.e., processing distinct conceptual relationships) hypothesis. Two separate analyses of variance tests supported the hypothesis (PWD > t: $F = 15.98$, $df = 1/81$, $p < .001$) (BWD > T: $F = 436$, $df = 1/81$, $p. < .05$). The second (Selective Attention) hypothesis was supported by two additional analyses of variance tests (PWD > PWD + T: $F = 7.41$, $df = 1/82$, $p. < .01$) (BWD > BWD + T: $F = 4.51$, $df = 1/80$, $p < .05$). As predicted the unitary complex science diagram treatments were independently more effective than the textual description or a combination of the diagram and text media.

Content validity generally was supported by the 33 judges. Two judges indicated that the textual description was expressed in a relatively more concise fashion than biology textbooks ordinarily used in tenth grade biology class. All judges indicated that the two diagrams would be instructionally effective if the subjects would attend to this stimulus type. All judges agreed that the criterion test was a fair sampling of the instructional material in terms of the statedobjective described previously. In a more objective analysis, comparison of the verbal prose criterion pretest and posttest scores lent significant ($F = 29.50$, $df = 1/80$, $p. < 0001$) support to the instructional effectiveness of the textual description. See Table III.

DISCUSSION

The results of the two concurrent experiments increase the credibility of the two research hypothesis in terms of potential guidelines for instructional designers in science. Neither experiment was originally conceived nor did they prove that a unitary complex diagrammatic presentation of this information type with criterion relevant adjunct verbal questions represents the optimal instructional unit. In fact, a properly developed textual description represents an effective instructional presentation as suggested in the analysis of the pretest-posttest scores. A unitary complex science diagram display apparently can accentuate criterion verbal and pictorial displays identifying the more relevant, distinct units and their relationships.

A school-relevant limitation of the unitary complex science diagram display can be inferred from Fleming's theoretical contention that students generally refuse to examine or are unable to process certain instructional picture types because of inadequate "picture" reading training. If the development of adjunct verbal questions in association with this diagram type is a prerequisite for its relative effectiveness, instructional designers might be reluctant to incorporate these somewhat unconventional diagrammatic information displays within learning materials. This particular hypothesis is worthy of empirical analysis. Unfortunately, the characteristics of most educational materials is dictated by their ability to sell or be adopted by teachers who are not always cognizant of relevant education theory and research (Koran and Holliday, 1974, Travers, 1970). The traditional instructional design standards of historical presidence and well-meaning pedagogical intuition must be supplemented by theoretical and empirically based guidelines.

Studies in science education generally have failed to properly deal with most multi-media questions (Koran, 1970); consequently, reliable instructional guidelines are not available. In particular, Smith, Shagrin and Poorman (1967) and Holliday (1971) in science education and Conway (1967) and Hsia (1971) in a more general analysis have not found persuasive evidence either supporting nor denying the general use of multiple sensory approaches. As a consequence, Koran (1970) and Holliday (1972) have recommended that particular subsystems of multi-media systems be evaluated in terms of established theory and research relevant to school-related learning objectives. This was a major goal of the present study.

There seem to be two commonly cited rationales for the almost indiscriminate use of multi-media instructional programs in science. First, multiple exposure of instructional stimuli presented in varied media will result in the display of additional criterion-related stimuli (cue summation theory as described by Severin, 1967) relative to a single medium display. This theory represents an over simplication of instructional stimuli in terms of cognitive overload and learning interference theoretically experienced in certain learning situations. The second reason states the learner usually is in a better position to determine which medium or media best fits his needs in relation to the specific learning task.

Research by Hartman (1961) and Samuels (1967) suggests an opposing principle under selected conditions. They have shown that learning interference can occur in some dual media systems. Koran (1971) found that the optimal medium is dependent upon certain aptitudes or learner characteristics. Selected multi-media presentations undoubtly represent a powerful instructional technique in many instances; however, this principle clearly cannot be extended to all situations (Holliday, 1971).

Varying types of prose and especially non-prose instructional displays and criteria clearly deserve more empirical attention by instructional researchers in science education. Classroom-related studies that have examined the effects of instructional adjunct pictures on verbal comprehension have not been encouraging and illustrate the probable reason for the dearth of research in the area of "non-prose" instructional stimuli and criterion measures. For example, Dwyer (1967, 1970, 1972) found that adjunct labeled pictures of the heart generally were not effective instructional stimuli when subjects were verbally asked to identify those structure-function relationships commonly taught in high school biology classes. A critical review of his numerous science picture studies is available elsewhere (Holliday, 1973a). Samuels (1970) more generally examined research related to the effectiveness of adjunct instructional pictures, including science content studies. He concluded that "There was almost unanimous agreement that pictures, when used as adjunct to the printed text, do not facilitate (verbal) comprehension." However, an analysis of pictorial research related to science instruction (Holliday, 1973b) revealed that most of the reviewed science pictorial studies suffered from methodological or treatment content problems.

Contrary to the findings of these pictorial experiments, Holliday (1973c) found that one type of picture can facilitate a form of verbal comprehension. He investigated the effects of simplifed line (block) drawings of plants with an occasional verbal label and an adjacent descriptive caption of each drawing. When these adjunct "textbook-like" pictures were added to a prose description of auxin, high school subjects attained higher scores on a verbal comprehension posttest. In a follow-up study, (Holliday and Harvey, 1974) junior high school subjects were randomly assigned to a pictorial (adjunct labeled pictures plus text) and non-pictorial (text only) instructional treatments. These adjunct pictures were line drawings of geometric configurations with verbal quantitative labels. The text was a prose description of density, pressure and Archimedes' Principle. Analysis indicated that the pictorial treatment was more effective in terms of a verbal quantitative (non-pictorial) comprehension posttest. Visual imagery and the processing of varying organizations of instructional displays provide the theoretical and empirical framework in terms of a discussion on pictures use in science curriculum materials.

CONCLUSIONS

The educational significance of this study is two fold. First, a unitary complex science diagram can be a more effective display type than an "equivalent" textual description of distinct conceptual relationships when adjunct verbal questions relevant to a prose criterion posttest are used to facilitate learner's inspection behavior. Second, a dual media science instructional presentation can result in selective attention or learning interference away from the most effective instructional unit. These findings have implications regarding the use of multi-media instruction, an almost universal practice in science education. The present study also provides selective generalizing support for many of the highly structured, laboratory experiments in visual imagery, attentional and organizational processing theory and research to a situation more closely related to science instruction in the classroom.

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TABLE I

Observed Posttest Means and Standard Deviations generated in the Picture Word Diagram Experiment

Instructional Treatments	n	Means	Standard Deviations
Picture Word Diagram (PWD)	41	19.52	5.4
Picture Word Diagram and Textual Description (PWD + T)	42	15.76	7.1
Textual Description (T)	41	14.24	6.6

TABLE II

Observed Posttest Means and Standard Deviations generated in the Block Word Diagram Experiment

Instructional Treatments	n	Means	Standard Deviations
Block word Diagram (BWD)	41	17.37	6.9
Block word Diagram and Textual Description (BWD + T)	42	14.12	6.9
Textual Description (T)	41	14.24	6.6

TABLE III

Observed Pretest and Posttest Means and Standard Deviations for the Textual Description Treatment

Test	n	Means	Standard Deviations
Pretest	41	7.93	4.1
Posttest	41	14.24	6.6

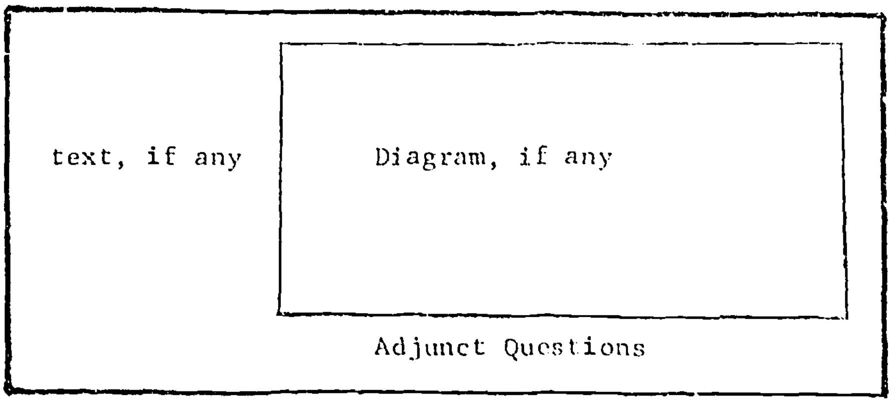

Figure A: Format of a page from the Treatment Materials