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Using Computer-Based Graphing Methods To Enhance Integrated Science Process Skills

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INTRODUCTION

Students of today face many complicated and formidable challenges in education. One imposing modern advance -- our society's increasing dependence on technology -- compels our educational institutions to graduate a well-informed, scientifically literate populace. Today's students must learn how to cope with complex interacting systems and with a rapidly expanding knowledge base. Our schools need to develop instructional methods which not only enable the presentation of factual material, but which also promote the development of techniques for interpreting and handling knowledge. According to Lippert (1987), having cited the National Commission on Excellence in Education (1983), "Society's future depends on a citizenry that can 'think and reason creatively and deliberately, develop sound judgments of information, and understand and contend effectively with rapid and constant change...' " (p. 477).

Science education, in particular, faces the task of developing instructional methods to promote the learning of higher-level cognitive skills. Lippert (1987) has pointed out that there seems to be a serious lack of basic research in developing instructional methods that can demonstrate a student's acquisition of higher-level cognitive skills. Furthermore, national assessments of educational progress and reform such as "Science for All Americans" (American Association for the Advancement of Science, 1989) and others of a similar nature have described weaknesses in student performances in the areas of cognitive skills, making inferences, and interpreting the meaning of scientific data.

Sherwood, Kinzer, Bransford, and Franks (1987) have concluded that science educators must come to the realization that science education is more than a simple presentation of factual content. They further stated that students should be exposed to the processes of scientific inquiry and higher-level cognitive skills. Likewise, Pizzini, Abell, and Shepardson (1988) have stated that science education must constantly strive to develop an environment conducive to higher-level thinking. They emphasized the need to incorporate student thinking into the science curriculum through the use of higher-level cognitive skills. Russell and Chiappetta (1981) have concluded that problem-solving methods should permeate the entire science curriculum. Moreover, they stressed that the teaching of science concepts along with memorization of information leads to improvements in higher-level thinking and to a better recall of knowledge. Similarly, Rivers and Vockell (1987), having cited the Committee on Science, Engineering and Public Policy (1984), stated, “in addition to traditional competencies, students increasingly should learn the thinking skills to manage information, formulate effective probing questions, test hypotheses, make judgments, express themselves logically and lucidly, and solve problems” (p. 403).

NATURE OF THE PROBLEM

Measuring the attainment of higher-level cognitive skills is an elusive task, due to the lack of basic research into methods that would verify acquisition of these higher-level skills. Fortunately, new technologies such as the microcomputer, now available to the classroom teacher, have the potential to facilitate the learning of cognitive problem-solving strategies and to promote an increase in scientific literacy rates. The microcomputer should provide students with a useful way to manage and to process amounts of information now approaching staggering proportions. White (1987) has explained that for the human mind to assimilate prodigious amounts of information, it becomes necessary to handle the information through pattern recognition, a visualization of data. We must, therefore, develop instructional systems that will allow students to comprehend and to interpret data through visual means to aid pattern recognition.

Friedhoff (1989) has stated that "visualization, because of the computer, is emerging as a distinctive new discipline" (p. 16). He further stated that "the field of visualization should not be so absorbed by the miracles that are its technical basis that it ignores a larger interest in the way in which images can be used to enhance the power of our thinking" (p. 16). The question we should now ask is this: which instructional strategies will prove useful in developing critical thinking skills within this emerging discipline of visualization? Research performed by McKenzie and Padilla (1984), Mokros and Tinker (1987), Talley (1973), and Siemankowski and MacKnight (1971) has concluded that in order to be successful in science two critical areas must be mastered: graphing abilities and spatial abilities.

Visualizing a data pattern in three-dimensional space once required a well-developed imagination. Fortunately, students today can augment their mental capabilities with the use of a computer system as an aid in performing detailed analyses involving a variety of data variables. We live and work in a three-dimensional environment; however, our educational materials tend to confine our minds to two-dimensional boundaries. Two-dimensional representations of information, which until now have dominated educational planning, need to be extended through the use of techniques suited for the recognition of complex spatial patterns. Building upon the research efforts of Siemankowski and MacKnight (1971) and Goodstein and Howe (1978), we can ask the following question: Given that students with limited abilities relating to the conceptualizing of three-dimensional space fare poorly in learning science concepts, is it possible through the use of a three-dimensional teaching strategy involving the use of computer generated images to enhance a student's spatial skills? One area in science where a student can utilize spatial abilities involves the construction and interpretation of graphs.

GRAPHING SKILLS

Gallagher (1979) determined that certain science skills shared common goals and objectives with other fields, such as mathematics, and therefore offered students a chance for the development of cognitive strategies transferable to many interdisciplinary areas. The amount and quality of technical scientific information collected make it imperative that students are instructed in two areas critical to the understanding of the scientific method: data interpretation and hypothesis formulation. This can be accomplished to some extent through an increased emphasis on graphing methods utilizing three- dimensional techniques. A number of research studies have shown that understanding graphing concepts is clearly essential to the development of a scientifically literate mind.

Padilla, M.J., McKenzie, D.L., & Shaw, E.L. (1986) stated that while the need for the condensing and interpretation of data was necessary for intelligent survival, students received very little instruction in using various graphing skills. McKenzie and Padilla (1984) stated that a need for graphing instruction was established by the emphasis placed on this skill in the science education literature and in most of the important science curriculum projects in use. They further stated that “in science we are often concerned with predicting relationships between variables and attempting to substantiate the existence of these relationships” (p. 3). They concluded from their research that in order for students to understand complex scientific relationships a thorough mastery of graphing skills was required. Padilla et al. (1986) stated that “a lack of graphing instruction is a severely limiting factor in the understanding of many complicated scientific concepts” (p. 25). Based on the results of their study concerning graphing abilities, they concluded that there was a distinct need for more training beyond the mere plotting of points, especially if graphs were to be used in the interpretation of data. Their research also showed that seventh- and eighth-grade students performed less successfully in graphing than high school students.

Padilla et al. (1986) recommended introducing graphing skills in earlier grades and emphasizing subskills on which student performance was poor. Of the subskills listed as those in which improvement was needed, they identified the higher-level cognitive skills of graph interpretation and hypothesis formulation as important to the development of an improved science curriculum. Mokros and Tinker (1987) suggested that “more knowledge about the development of the ability to produce and interpret graphs might lead to improved pedagogical approaches to mathematics and science..." (p. 371).

Which graphing strategy enhances a student's spatial skills? McKenzie and Padilla (1984) have stated that no single instructional strategy of those examined in their study of three different types of teaching methods appears superior to others in regard to students' level of graphing achievement. Their study examined the use of graphing through the traditional two-dimensional construction of graphs on paper. An extension of McKenzie and Padilla's research would be to look at other possible instructional strategies that teach graphing techniques through the use of computer technologies.

McKenzie and Padilla (1984) have found that students classified as transitional/formal operational thinkers tend to score higher than concrete operational students in graphing achievement. What effect would the manipulation of data in a three-dimensional space have upon the cognitive abilities of transitional/formal operational thinkers and concrete operational thinkers? McKenzie and Padilla (1984) have determined that spatial scanning ability (the ability to scan a wide spatial field for comprehension) shows minimal relationship to graphing achievement. If the instructional strategy included three-dimensional graphing, would the enhancement of a student's spatial orientation ability lead to higher achievement levels?

According to Talley (1973) the more experience a student possesses in visualization, the higher the level of achievement obtained by the student. Siemankowski and MacKnight (1971) have found strong evidence supporting the link between science achievement levels and spatial conceptualization. In addition, Bishop (1978) has stated that educators have been slow to incorporate the spatial conceptualization methods developed by Piaget. She further added that teachers need to promote spatial techniques within their curriculum areas. Bishop (1978) has explained that graphing is an important spatial modeling tool used to represent an abstract concept. Moreover, she explained that topological and Euclidean characteristics of spatial thinking (as defined by Piaget) are united in the interpretation and construction of graphs. Pallrand and Seeber (1984) have pointed out that while studies into visual-spatial ability have been recognized as important, little is done to relate research to education.

Pallrand and Seeber (1984) also concluded that processes associated with spatial-visual thought are closely related to data interpretation and abstract reasoning. Furthermore, they have stated that students exposed to activities stressing spatial abilities perform at higher cognitive levels. In support of these statements, previous research by Siemankowski and MacKnight (1972), McGee (1979), Bishop (1979), Mitchelmore (1980), Tobias (1976), Talley (1973), and Poole and Stanley (1972) has also shown a strong relationship between spatial abilities and scientific achievement. It is the purpose of this research study to investigate an instructional strategy potentially capable of aiding students in the development of higher-level cognitive skills.

Braunstein (1976) related spatial perception to a form of problem-solving. He indicated that the same heuristic methods used by human subjects to achieve correct solutions were also central in the development of problem-solving skills. It was our belief that the student, if exposed to spatial graphs through computer-based programs, would develop heuristic methods of analyzing data. This study attempts to determine whether students benefit from the use of three-dimensional graphing concepts. Past difficulties in using three-dimensional instructional graphing methods are eliminated through the use of computer generated graphs. The computer allows students functioning at the concrete level of cognitive development to deal with abstract forms of data interpretation through the manipulation of that information in various spatial settings.

RELATIONSHIP OF GRAPHING ABILITY TO COGNITIVE AND SPATIAL SKILLS

Moses (1980) concluded that problem-solving performance correlated significantly both with spatial skills and with cognitive reasoning skills. The relationship of spatial skills and cognitive reasoning skills to graphing ability was investigated by Dan L. McKenzie and Michael J. Padilla. In their research studies, McKenzie and Padilla (1984) focused on the need to develop teaching strategies that were designed to teach graphing competencies. The studies investigated three instructional strategies: (1) an activity-based approach, (2) a written simulation-based approach, and (3) a combination of activity and written simulation-based instruction. The student characteristics examined included cognitive development and spatial ability. McKenzie and Padilla (1984) stated that no single instructional strategy of those examined appeared to be superior to the others in regard to level of graphing achievement attained by students. All teaching strategies involved the use of two-dimensional graphing methods, and none involved the use of computer graphing techniques.

In the McKenzie and Padilla (1984) study the students were limited to only one orientation of data visualization through the construction of a two-dimensional graph. Would the introduction of a new graphing strategy using the capability of the computer result in a different conclusion? Mokros (1985), in citing DiSessa (1984), stated, “by linking the concrete and the abstract, the computer may serve as an important 'carrier' of problem-solving skills” (p. 6). The possibility existed that students could enhance cognitive mapping abilities through two-dimensional and three-dimensional computer graphing methods, thereby influencing a student's heuristic skills on measures concerning graph interpretation and hypothesis formulation, in addition to measures dealing with achievement on domain-specific science knowledge.

Moses (1980) found that problem-solving performance correlated significantly with spatial skills and cognitive reasoning skills. More importantly, it was found that the type of visualization process used further enhanced problem-solving skills. The addition of two-dimensional and three-dimensional computer-based graphing methods would allow the students a chance to rotate data configurations in space; a strategy requiring the use of higher-level perceptual abilities. Wavering, Perry, Kelsey, and Birdd (1986) found that classroom activities which required understanding and use of perspective caused great difficulty for students in middle school and high school. In another study, Doyle (1980) found that precise understanding of spatial conceptualization was important in children because Euclidean concepts provided a basis for the further understanding of scientific principles.

He listed chemistry, geology, astronomy, biology, and physics as fields of science where spatial conceptualization was important to student achievement.

Holford and Kempa (1970) stated that "the recognition of spatial relationships in plane-drawings and photographs is often an essential prerequisite to the understanding and application of fundamental ideas" (p. 265). In addition, Talley (1973) found that students with greater experience in visualization performed at higher cognitive levels which led to higher achievement levels. Siemankowski and Macknight (1971) stated "this difference in ability among students to comprehend science principles is, to a large extent, caused by the ability of some students to conceptualize three-dimensional models clearly" (p. 56).

Obviously, there is a need to develop a child's spatial skills if education is to produce scientifically literate individuals. How should we as educators approach the development of these spatial skills? Talley (1973) explained that knowledge level science facts usually become obsolete in short time intervals. He stated that conceptual schemes should be emphasized in order to develop within the student conceptualization abilities for the further development of critical thinking skills. His suggestion was to apply the use of three-dimensional models to permit the conversion of abstractions and observations into workable concepts and usable data. Talley (1973) in his study concerning the use of three-dimensional visualization through the use of concrete models concluded that "individuals who have lower visualization skills will perform essentially at the knowledge- comprehension levels, while those individuals who have developed more enhanced visualization skills will perform more consistently at higher levels of conceptualization and reasoning" (p. 268).

Carlson (1976) stated that a research design concerning the understanding of space must have as part of its design an underlying theoretical framework. The framework suggested by Carlson was Piaget's theory of cognitive development as it related to a child's understanding of space. Piaget and Inhelder (1956, 1960), divided a child's spatial development into the following three areas: 1) Topological space, 2) Projective space, and 3) Euclidean space.

In a study done to explore children's understanding of Euclidean space, Carlson (1976) determined that students were not capable of locating exactly a point in three-dimensions until approximately the sixth grade level, and that activities requiring quantitative understanding of three-dimensions will not be meaningful to students until the sixth grade level. Goodstein and Howe (1978) concluded that one way to apply Piaget's theories of cognitive development to the area of science education was to provide concrete exemplars to concrete operational thinkers to help them begin to understand conceptual knowledge.

In citing Herron (1975), Goodstein and Howe (1978) stated that students at the concrete level who were exposed to a formal topic can be given concrete models which resembled the abstract concept, and that time would allow the students to acquire a “surrogate” (p. 361) concept which can be utilized until the real concept was mastered at a later time. In a science research study designed to test the hypothesis that instructional methods in which learners used concrete models and exemplars of a concept would lead to higher levels of cognitive development, Goodstein and Howe (1978) found that three factors must be accounted for in any research design of a similar nature. Their results indicated that each of the following factors must be considered: “the cognitive level of the learner, the conceptual level of the material, and the method of instruction” (p. 365). Each of these factors were addressed in our study with the emphasis placed on the development of a student's three-dimensional conceptualization skills.

Siemankowski and Macknight (1971) found strong evidence that science-oriented students and non-science-oriented students differed in their abilities to conceptualize three-dimensional space. Because science students were exposed constantly to concepts requiring the visualization of data in three-dimensions, students lacking this spatial ability found it difficult to grasp basic science concepts, and therefore, performed poorly in science courses. Siemankowski and Macknight (1971) also found that a high correlation existed between three-dimensional conceptualization and successful grades in college science courses.

The conclusions indicated that in order for a student to achieve a mastery of scientific concepts certain essential skills pertaining to graphing interpretation and spatial visualization needed development through carefully planned instructional strategies. In a review of previous research studies pertaining to three-dimensional spatial abilities, it became apparent that an instructional strategy using the capabilities of the microcomputer to simulate three spatial dimensions might aid in the development of these essential skills. Perhaps an instructional strategy involving the microcomputer would allow students to develop graphing interpretation skills and spatial visualization skills beyond the two-dimensional plane of reference and allow students to acquire proficiency in their heuristic abilities as they relate to data interpretation and hypothesis formulation skills, along with the acquisition of domain-specific science knowledge.

STATEMENT OF THE PROBLEM

The intent of this study was to investigate the extent to which specific problem-solving abilities, the integrated science process subskills of data interpretation and hypothesis formulation, could be enhanced through the implementation of an instructional strategy that compares the use of two-dimensional and three-dimensional computer-based graphing methods. The study also examined the acquisition of domain-specific science knowledge as a result of these treatments. The interpretation of graphing data, the formulation of hypotheses, and the acquisition of science knowledge were also examined for their relationship to subject characteristics concerning cognitive ability levels and spatial orientation ability levels. An existing earth science program developed specifically for the improvement of critical thinking and problem-solving skills was used as the medium into which commercial graphing software was incorporated.

METHODOLOGY

SUBJECTS

The subjects for this study were 89 eighth-grade students attending a junior high school in an upper middle class suburb of Allentown, Pennsylvania. The treatment groups consisted of four intact earth science classes. The students ranged in age from thirteen to fourteen years old, and each had some previous experiences with computers as a result of seventh-grade instruction. Each of the four sections was randomly assigned to one of two treatment levels. The treatments consisted of a two- and three-dimensional instructional graphing strategy.

HARDWARE AND SOFTWARE

The hardware consisted of sixteen IBM microcomputers which were used by both treatment groups. The students used the IBM PS/2 Model 25 microcomputer. The IBM PS/2 Model 25 is the computer IBM has targeted for the educational market and is functional for many end user situations.

The software selected for the three-dimensional computer-based graphing treatment groups was a program from Golden Software, Inc. named Surfer (1989). Surfer allowed the creation of three-dimensional surfaces with the ability to rotate the surface and change the viewing angle. It also supported the labeling of axes, the scaling of X, Y, Z dimensions, the viewing of top and bottom surfaces, the moving of text on screen, and the mixing of fonts and colors. The Surfer interface consisted of easy-to-read menus and proved user-friendly at the junior high school level. Surfer may be used on any IBM PS/2 model with 320 KB of RAM, DOS 2.0 or higher, and at least one double-sided disk drive. Surfer also supports all IBM printers and, therefore, allowed students to produce hard-copies of their investigations.

The software selected for the two-dimensional treatment groups also from Golden Software, Inc., was a program named Grafit (1989). This program allowed the creation of high resolution X-Y graphs through the inputting of data and the selection of options from a menu. Options included the addition of labels, titles, and legends to the graph, along with the ability to determine manually or automatically the graph scales used to set axis length. Similar to the Surfer program, the graphs can be viewed on the screen or plotted via a printing device. The Surfer program and the Graphit program provided similar program features to each of the treatment groups, and differed only in the number of dimensions displayed in the graphs generated.

LEARNING MODULES

Instructional modules from the Crustal Evolution Education Project (CEEP) (National Association of Geology Teachers, 1979) were used for this study. Stoever (1977) stated that these learning modules deal with current scientific research into the composition, history, and processes of the earth's crust. The modules used concrete operational experiences along with attempting to approach abstract concepts. The CEEP modules chosen for the study were those that emphasized graphing techniques, and in particular, those which allowed the plotting of three variables in an X, Y, Z space. In order to insure equivalence levels among the five modules, a panel of educators were selected to review the changes to each module. A questionnaire, prepared by the researcher, was given to the eight-judge panel to comment on the parallel nature of each CEEP module used in the research study. The results of the questionnaires returned indicated that the changes in the modules were appropriate and that both treatment groups would be using graphing packets of equivalent content.

INSTRUMENTATION

The "Group Assessment of Logical Thinking" (GALT) test, developed by Roadrangka et al. (1982) was utilized to group the students into two cognitive levels (concrete operational and transitional/formal operational). This test, according to Roadrangka, V., Yeany, R.H., & Padilla, M.J. (1983), possessed the following characteristics: 1. The test measures six logical operations: conservation, proportional reasoning, controlling variables, combinatorial reasoning, probabilistic reasoning, and correlational reasoning. 2. The test uses a multiple-choice format for presenting options for answers as well as the justification or reason for that answer. 3. Pictorial representations of real objects are employed in all test items. 4. The test is suitable for students reading at the sixth grade level or higher. 5. The test has sufficient reliability and validity to distinguish between groups of students at concrete, transitional, and formal stages of development. 6. The test can be administered in one class period to a large group by individuals who serve simply as proctors. (p. 3).

The authors used the Fog Index devised by Gunning (1968) to produce an examination suitable for a sixth grade reading level. The authors also added pictorial representations to further reduce reading difficulties. Construct validity of the GALT test was determined through the use of convergent validation, a method proposed by Campbell and Fiske (1959). As an additional check of construct validity, the scores of GALT were subjected to a factor analysis. Criterion-related validity was determined through intercorrelations between the GALT test and the Test of Integrated Process Skills II (TIPS II), developed by Okey, J.R., Wise, K.C., & Burns, J.C. (1982).

Reliability of the GALT test was determined using Cronbach's Alpha. In addition, the authors used as a second check on reliability the degree to which the GALT scores correlated with other measures. The results of the GALT assessment produced a test consisting of 12 multiple choice items with a reliability estimate of .85 using Cronbach's Alpha and an overall validity coefficient of .71. The GALT test was used to divide students into two levels of cognitive development: concrete operational thinking and transitional/formal operational thinking. The GALT authors recommended the use of a 12-item test. The following were the recommended cognitive levels determined from the test scores: (a) concrete operational -- 0 to 4, (b) transitional -- 5 to 7, and (c) formal operational -- 8 to 12.

The spatial orientation tests selected for the study were the Card Rotation Test (S-1) and the Cube Comparisons Test (S-2) from the Kit of Factor Referenced Cognitive Tests (Ekstrom, R.B., French, J.W., & Harman, H.H., 1976) Both tests were suitable for junior high school levels, with both tests having a multiple choice format. The Card Rotations Test consisted of two parts, each having 10 items, with a reliability of .89 for the complete test. As described by Ekstrom et al. (1976) the Card Rotations Test was defined in the following manner: “Each item gives a drawing of a card cut into an irregular shape. To its right are six other drawings of the same card, sometimes merely rotated and sometimes turned over to its other side. The subject indicates whether or not the card has been turned over" (p. 150). The Cube Comparisons Test consisted of two parts, each having 21 items, with the total test having a reliability of .84. Ekstrom et al. (1976) described the Cube Comparisons Test in the following manner: "Each item presents two drawings of a cube. Assuming no cube can have two faces alike, the subject is to indicate which items present drawings that can be of the same cube and which present drawings that cannot be of the same cube" (p. 150). Both tests were used to divide students into two levels of spatial orientation ability (low, and high) based upon their ability to perceive spatial patterns and to orient objects in three-dimensional space.

Burns, Okey, and Wise (1985) developed a test to assess five integrated process skills (stating hypotheses, identifying variables, operationally defining, designing investigations, and graphing). The Test of Integrated Process Skills II (TIPS II), recommended for grades 7 to 12, consisted of 36 items and has a total test reliability of .86 using Cronbach's Alpha. The subscale component reliabilities as determined by the test authors were as follows: (a) identifying variables -- .57, (b) operationally defining -- .62, (c) stating hypotheses -- .65, (d) graphing and interpreting data -- .64, (e) designing investigations -- .49. In this research study, only the subscale items pertaining to hypothesis formulation and data interpretation were considered. The subscale items pertaining to hypothesis formulation were items 4, 6, 8, 12, 16, 17, 27, 29, and 35. The subscale items pertaining to data interpretation were items 5, 9, 11, 25, 28, and 34. We concluded that the TIPS II test could be used in all science curriculum areas and was reliable instrument for measuring student competence in the integrated science process skills.

To measure student achievement levels in the area of domain-specific knowledge, an examination consisting of test questions originally used in the pilot testing and evaluation of the Crustal Evolution Education Project (National Association of Geology Teachers, 1979) was utilized. The KR-20 reliabilities determined from the posttests used in the evaluation of each Crustal Evolution Education Project module ranged from a low of .83 to a high of .88 (N = 1000). Each question on the test was related to a specific objective in the CEEP modules. The test consisted of 25 multiple choice questions.

EXPERIMENTAL DESIGN

According to Campbell and Stanley (1963), one of the most widespread experimental designs in educational research involves an experimental group and a control group both given a pretest and a posttest, but in which the control group and the experimental group do not have pre-experimental sampling equivalence (p. 47). Campbell and Stanley (1963) and later Cook and Campbell (1979) consider such a design as quasi-experimental and encourage the utilization of such quasi-experiments. Because intact science classes were used in creating the two- and three-dimensional computer-based graphing treatment groups, we felt that the nonequivalent control group design of Campbell and Stanley (1963), in which the treatment can be randomly assigned to one group or the other and still be under the experimenter's control, offered the best model upon which a study of this nature could be based.

In addition, Dwyer (1978) stated that "multidimensionality of both the dependent variables and independent variables in the typical instructional situation demands that multivariate experimental designs be employed to answer questions basic to efficient and effective use of visual stimuli" (p. 244). Therefore, following the design recommendations of Campbell and Stanley (1963), Cook and Campbell (1979), and Dwyer (1978) the experimental design of this study consisted of a 2 x 2 x 2 fixed effects model. Because median scores of the experimental groups were used to create the spatial orientation levels, further replications of the study should utilize the same median values in order to maintain a fixed effects design. The use of other values to determine spatial orientation levels would create a random effects model and would not correspond to the design of this study.

The three-way design had as independent variables two levels of treatment (three-dimensional computer-based graphing and two-dimensional computer-based graphing), two levels of cognitive reasoning (concrete operational thinking and transitional/formal operational thinking), and two levels of spatial orientation ability (high spatial orientation ability and low spatial orientation ability). The dependent variables consisted of gain scores obtained from pretest and posttest scores measured by two different testing instruments (TIPS II and CEEP Achievement). The TIPS II test measured data interpretation skills and hypothesis formulation skills, while the CEEP Achievement test measured domain-specific science knowledge.

EXPERIMENTAL PROCEDURE

The procedural methods employed in this research design were based on procedures developed by Dwyer (1972, 1978). Dwyer's design was adapted to apply to a self-paced instructional format. According to Dwyer (1978), adhering to his situational guidelines would serve to identify which type of visualization instruction was most successful and efficient in facilitating student achievement of learning objectives. Dwyer listed the following procedural guidelines to serve in the systematic evaluation of visualization research: (a) research should be limited to one content or learning area, (b) criterion tests should be constructed to measure student achievement levels, (c) audio taping should be utilized to insure equivalent instruction, (d) visual illustrations should be designed to coincide with the oral instruction, (e) multiple versions of the visual sequences should be designed, (f) students should be randomly assigned to treatment groups, (g) student should be placed into control groups and experimental groups, (h) all groups should be pretested, (i) standardized tests should be used to obtain scores that can be used in multivariate experimental designs, (j) each group should have equivalent instructional times, (k) students should be posttested to measure their level of instructional attainment, and (l) data obtained from the research should be subjected to appropriate statistical techniques. Each of the guidelines was followed except for the use of a control group.

Linn, Layman, and Nachmias's (1987) chain of cognitive accomplishments was also used as a guide in the design of this research study involving computer-based graphing strategies. Prior to the treatment, each group was assigned a learning module (Graphing by B.K. Hixson (1988)) dealing with graphing concepts to insure that each student is familiar with basic graphing terminology. This packet represented the first link in the chain of cognitive graphing accomplishments.

All instruction in this study was provided by one of the researchers (Drahuschak). As an introduction to the Crustal Evolution Education Project (CEEP), each group was given assignments in their textbook dealing with the concept of plate tectonics. Each group was also given an introductory learning module from the CEEP packet of laboratory investigations in order for the students to become familiar with the style and format of the CEEP modules. The treatment groups were introduced in a computer laboratory session to the graphing programs utilized during the investigation. This general introduction to the graphing software was considered the second link in the chain of cognitive graphing accomplishments.

The third link in the chain of cognitive graphing accomplishments was provided by the treatment. Five CEEP modules were presented to each of the treatment groups for investigation. The modules were designed to take approximately two class periods per module for completion. One treatment group, consisting of two classes, used three-dimensional computer-based graphing techniques within the lessons. Another treatment group, also consisting of two classes, used two-dimensional computer-based graphing techniques. Upon completion of the modules, the treatment groups were given posttests consisting of the TIPS II Test and the CEEP Achievement Test. These posttests provided the fourth and final link in the chain of cognitive graphing accomplishments. Appropriate statistical tests were then used to determine any significant differences between groups with respect to the dependent measures.

STATISTICAL ANALYSIS

The results of this study were analyzed using a three-factor analysis of variance (three-way ANOVA). The analysis was performed through the use of the SuperAnova statistical package (Gagnon, 1990) which was run on an Apple Macintosh IIcx microcomputer. The analysis assessed the main effects of treatment, cognitive reasoning, and spatial orientation ability on the dependent measures of data interpretation, hypothesis formulation, and domain-specific science knowledge (See Tables 1, 2, 3 and 4). The measures consisted of gain scores obtained from testing instruments designed to appraise each of the variables. Along with the analysis of main effects, all interactions between factors were addressed. Statistical tests were performed at the .05 level of significance.

In evaluating the raw data collected during the experimental phase of this research study, it became apparent that a subsidiary analysis of the pretest/posttest scoring results might indicate significant gains within treatment groups on measures of the dependent variables (See Tables 5, 6, and 7). While the subsidiary analysis was not part of the original experimental design, researchers sometimes find it appropriate to surpass the original design scheme in order to examine unanticipated outcomes of their research which might be of interest and value.

STUDY LIMITATIONS

Four intact classes of eighth-grade students were used to form two treatment groups of two classes per group. Classes were randomly assigned to treatment groups as opposed to a random assignment of students to treatment groups. The rigidity of student scheduling made it necessary to proceed in this manner for the selection of treatment groups. According to Kamil, Langer, and Shanahan (1985):

> Assignment of students to various groups is a particularly troublesome problem for experimental research in instructional problems. Since most students are already assigned to classes, researchers often are faced with the problem of having to give one class one instructional treatment and another class a completely different treatment. When researchers have to deal with classes, they often randomly assign more than one class to a treatment to replicate that part of the experiment. This minimizes the chance that a single class of different ability will affect the results of the study (p. 96).

Only eighth-grade students were involved in the research study due to the unavailability of other grade levels. A non-graphing control group was possible but would have implied utilizing only three of the available four classes as treatment groups, since intact groups were to be used. This would have resulted in a lower sample size in each of the treatment levels. We decided that the larger sample sizes for treatment groups were preferable to using a control group.

All of the instruction during the study was given by one of the investigators (Drahuschak). One benefit was the minimization of teaching differences between classes that would arise from varied teaching techniques. A classroom observer was utilized to verify, through audio taping and general observations, that all treatment groups were instructed in an equivalent manner. Due to the limited number of computers used, two students shared each microcomputer. An attempt was made to hold problems which arise from such use to a minimum.

The Test of Integrated Process Skills II (TIPS II) used to obtain measures on the process skills of data interpretation and hypothesis formulation was recommended by Burns et al. (1985) for grades 7 to 12. The test readability level, however, was determined to be at 9.5 using the Fog formula. General observations of students taking the TIPS II examination did not indicate student difficulty with reading the test questions. The higher readability level may be associated with the science terminology found in the examination.

The graphing software used in this research study was intended for students at the high school/college level. It was difficult for students to acquire proficiency in the programs utilized. Students were only exposed to the basic commands necessary to interact with the graphing software. Because of the unavailability of software for junior high school students with the capabilities required for this research study, it was necessary to select a graphing program designed for a more sophisticated audience. The software selected provided the necessary graphing features needed to perform the study in a format that posed few difficulties when used by the students in this study.

In the experimental design, it was decided to use gain scores as a means of evaluating the dependent variables. The use of gain scores presented limitations in the results of the study due to factors such as regression toward the mean and ceiling effects. While gain scores are not as reliable as a single score, they do provide a degree of change measurement that covers the length of the study. The time allotted for the study was limited by the availability of computer time and by curriculum constraints. Therefore, a time period of longer than 11 weeks was not feasible for an extension of this study.

RESULTS AND CONCLUSIONS

A major goal in science education has been to develop, within the science curriculum, problem-solving strategies that would enable a student to develop higher-level cognitive thinking processes. Because science knowledge is increasing at a rapid pace, new instructional teaching strategies are needed to help students develop heuristic methodologies in the analysis of scientific data. This study attempted to isolate one specific area of the science curriculum that was essential to a student's success, an area that also involved the need to evaluate data in a visual format. It examined the use of visual-spatial methods to enhance performance in the integrated science process skills of data interpretation and hypothesis formulation through the relationship between visualization skills and higher cognitive reasoning abilities. The instructional strategy selected for this research study involved the utilization of microcomputer-based two- and three-dimensional graphing software.

Statistical analysis revealed no significant differences on measures of data interpretation and hypothesis formulation related to the variables of treatment, cognitive ability, and spatial orientation ability (see Tables 2 and 3). The results indicated that the two- and three-dimensional computer-based graphing treatments did not show a significant enhancement of these integrated science process skills.

Conclusions reached by Padilla et al. (1986) provide some guidance in understanding the difficulties encountered in attempting to enhance these integrated science process skills. They determined that junior high school students had difficulty interpreting information obtained from graphs. They further explained that the lack of emphasis placed on graphing skills in the curriculum becomes a severely limiting factor in a child's understanding of scientific concepts. The fact that students showed no significant positive gains on these measures may have indicated that students lacked familiarity with graphs requiring the comparison of two or more variables. Perhaps a more sustained use of computer graphing methods in the curriculum, or more sensitive evaluation instruments, or the use of randomized treatment and control groups might reveal significant differences in student performance levels in regards to data interpretation and hypothesis formulation skills.

No significant differences were observed on a measure of domain-specific science knowledge relating to the two independent variables of two- and three-dimensional computer-based graphing treatments and spatial orientation ability. However, a significant improvement of this measure was found in relation to the independent variable of cognitive ability (see Table 4). The transitional/formal operational thinkers showed significant improvement in science achievement as a result of computer-based graphing strategies ($F(1, 81) = 4.792$, $p = .0315$). The result supported past research efforts (e.g. Cantu and Herron, 1978, and Nakayama, 1988) which stated that regardless of the teaching strategy, formal operational thinkers always outperform concrete operational thinkers. Furthermore, Chiappetta (1976) stated that "one of the primary goals of science education is to promote intellectual development to the point where most individuals can function at the formal operational level, at least within the content of science" (p. 259). However, Chiappetta discoverd that the majority of adolescents, including those students classified as formal operational thinkers, function at the concrete operational level of thinking in regards to science subject matter presented in our secondary schools. Perhaps specific teaching strategies such as computer-based graphing can compel students who have attained formal reasoning levels of thinking to perform at this higher skill level rather than regressing to lower developmental stages.

In evaluating the pretest/posttest mean scores collected during the experimental phase of this research study (see Table 1), it became apparent that a subsidiary analysis of the pretest/posttest scoring results might indicate significant gains within treatment groups on measures of the dependent variables The results of the subsidiary analysis are presented in Tables 5, 6, and 7. A subsidiary analysis of the experimental data indicated that students in both the two-dimensional treatment group (mean gain score = 2.24) and the three-dimensional treatment group (mean gain score = 2.71) showed significant gains in domain-specific science knowledge (two-dimensional group ($t(44) = 4.99$, $p = .00001$), three-dimensional group ($t(43) = 4.43$, $p = .00006$)) indicating that both groups benefited significantly from the treatments which used computer-based graphing methods. It is not possible to attribute these knowledge gains directly to the use of computer-based graphing, since the study did not include a control group. However, it is evident that the achievement gains took place in an instructional setting where computer-based graphing was a major component.

Perhaps the computer-based graphing strategy provided the students with “objectification” (Friedhoff, 1989, p. 169) -- the portraying of a phenomenon through form, color, texture, and motion. Friedhoff (1989) stated that “visualization often serves the purpose of objectifying a relationship between an independent and a dependent variable” (p. 169). It is possible that in this research study objectification of data occurred through the use of computer technology. This allowed students to visualize variable relationships by depicting abstract material through visual graphical representations. Barba (1991) stated that electronic learning lends itself to the presentation of information at Bloom's taxonomy levels of knowledge and comprehension. Future extensions of the study are needed to verify whether these results show that students are achieving higher outcomes as a result of processing information in an efficient manner through the utilization of a computer-based graphing strategy.

An analysis of the results of the pretest and posttest mean scores on the measure of data interpretation (see Table 6) indicated no significant differences. However, significant statistical results were obtained in a subsidiary analysis of pretest/posttest scoring within the two- and three-dimensional computer-based graphing treatment groups in regards to the integrated science process skill of hypothesis formulation (see Table 1 for pretest/posttest mean scores). The results of the t-test analysis showed that significant pretest/posttest scoring differences on this measure occurred only within the two-dimensional computer-based graphing treatment levels. The two-dimensional treatment group (mean gain score = .56) showed significantly higher posttest scoring on this measure ($t = 2.28$, $p = .0272$) indicating an enhancement in the integrated science process skill of hypothesis formulation as a result of computer-based graphing methods. Without the proper control groups in the experimental design, the significant difference found on this measure cannot be attributed soley to computer-based graphing strategies.

We suggest that perhaps the two-dimensional computer-based graphing strategy proved less abstract to this treatment group because of previous exposure to this type of graphic representation. Levine and Linn (1977) stated that the number of variables in a task often influence the difficulty of that task. They also stated that being familiar with the materials used in a task is important to task performance. Students are exposed to graphing exercises at lower grade levels and generally perform simple computations using two variables. Possibly the two-dimensional computer-based graphing treatment group attained significantly higher scoring on this measure as a result of having fewer variables to analyze along with having past graphing experiences to draw upon.

It appears from the results obtained in this research study that future replications using a control group may find that a computer-based graphing strategy allows students to comprehend abstract graphing concepts and, therefore, perform at higher reasoning levels. Apparently, students at a formative level of development benefited from the direct experience of data manipulation in a computer-based graphing environment. This is compatible with Cantu and Herron's (1978) reasoning that a student's comprehension of abstract concepts could improve if instruction can provide perceptible attributes which can serve to the students as “pseudo examples” (Cantu and

Herron, 1978, p. 136). Barba (1991) stated that "visualization increases learner interest, motivation, curiosity, and concentration" (p. 166). Dwyer (1978) stated that visualization provides instructional feedback and facilitates information acquisition. Perhaps the manipulation of data through computer-based graphing techniques allowed the students to visualize better the relationship between variables and to perform at higher cognitive levels.

Sayre and Ball (1975) suggested that specific instructional strategies could facilitate the development of formal thinking. This study provides a paradigm for the classroom teacher to fully implement a teaching strategy geared specifically to developing higher level cognitive processes. Significant statistical results obtained in this study indicate that a computer-based graphing strategy could enhance a student's science process skill abilities. Gesshel-Green (1987), in studying the effectiveness of graphing packages, found that students who use computerized graphing packages outperform traditionally instructed students on measures of long term retention, motivation, and cooperation. Similarly, Heid (1988) found that students need less time to formulate concepts when using computer-based graphing techniques.

We believe that the results obtained in this study indicated that a science classroom teacher could easily incorporate computer-based graphing strategies into the curriculum with the intended purpose of enhancing a student's science process skill development through a cognitive approach. This research study indicates that the use of two- and three-dimensional graphing techniques is a potentially viable instructional strategy which can be introduced at an eighth-grade level. A computer-based graphing strategy allows the students to use an information processing approach to science education. Naisbett (1982) stated that we live in an information processing age. Yet, according to Barba (1991), "our pedagogical methods do not reflect the times in which we live" (p. 168). Barba (1991) further stated that "we do not teach students to actively access multiple sources of information as they engage in the learning process" (p. 168). The use of a computer-based graphing strategy in this research study provided the students with an opportunity to develop proficiency in their heuristic abilities. Future replications of this study using proper control groups could determine whether the significant results found within treatment groups on measures relating to the acquisition of integrated science process skills could be attributed to the use of computer-based graphing strategies.

While the results of this research study did not find significant differences in favor of the three- dimensional computer-based graphing treatment, we still recommend that educators given a choice of instructional graphing strategies should incorporate three-dimensional graphing techniques into their curriculum. Tufte (1983) explains that "data-rich designs give a context and credibility to statistical evidence" (p. 168). Tufte further states that "high-density graphics help us to compare parts of the data by displaying much information within the view of the eye..." (p. 168). He recommended that the data density and the size of the data matrix be maximized within reason. We conclude from the results obtained in this research study that educators can follow Tufte's suggestion by using three- dimensional computer-based graphing strategies in an instructional setting to maximize a student's visualization of algorithmic representations.

In summary, this research study produced some encouraging results concerning the use of computer-based graphing strategies at an eighth-grade level. The significant results concerning the enhancement of integrated science process skills and the acquisition of domain-specific science knowledge need to be analyzed further with experimental designs utilizing proper control groups. We feel that computer-based graphing strategies are viable instructional methods that can be successfully incorporated into the science curriculum. According to Slayer and Smith (1986), the utilization of computerized graphing packages in implementing a computer-based graphing strategy allows students to function at higher cognitive levels and to ask those "what if" types of questions associated with advanced cognitive development.

RECOMMENDATIONS FOR FURTHER STUDY

Curriculum constraints and computer availability limited the extent of this research study. The use of two- and three-dimensional computer-based graphing strategies needs to be incorporated into the science curriculum for a sustained period of time. Through an extended use of computer-based graphing strategies, researchers should have an opportunity to determine whether students can acquire visualization skills of a more complex nature regarding the use of three-dimensional graphing methods. We also strongly recommend that in future replications of this study proper control groups be utilized within the experimental design.

In order to continue with research concerning computer-based graphing strategies for students at the junior high school level, new types of three-dimensional graphing software need to be developed and evaluated for younger students. Presently, the software available for graphing in three dimensions is aimed at a more sophisticated audience. Similarly, new learning modules designed specifically for enhancing three-dimensional capabilities need to be developed.

A follow-up study should address whether students can develop data interpretation skills through computer-based graphing strategies. This present research study was unable to find any enhancement of this integrated science process skill as a result of computer-based graphing. However, extended computer time and software designed for the appropriate age group could provide significant results in this area. In addition, future research should investigate motivational strategies associated with the use of computer-based graphing packages. Ausubel (1978) stated that "motivation is absolutely necessary for the sustained type of learning involved in mastering a given subject matter discipline, such as science" (p. 397). Dunne (1984) explained that the use of learner control over the instructional program is one type of motivational strategy currently being used in science software. Graphing packages allow the user to manipulate and to transform data into visual images that promote learner interest. Barba (1991) indicated that certain areas of student performance benefited from computer assisted instruction: achievement, learning retention, learning time, and learner attitude. Further research into the use of computer-based graphing strategies may find significant gains associated with each of these learning outcomes. In addition, future research might employ new emergent technologies described by Friedhoff (1989) as combining computers with holography, image processing, computer graphics, computer stereopsis, and animation to investigate visualization strategies as a means of developing heuristic modes of learning.

Edwin A. Abbott in 1884 developed in his classic book Flatland: A Romance of Many Dimensions (1991) a world consisting of only two dimensions. We, on the other hand, inhabit a world of three spatial dimensions in which according to Tufte (1990) our information displays are tied to “endless flatlands of paper and video screen” (p. 12). Tufte (1990) further stated that “escaping this flatland is the essential task of envisioning information -- for all the interesting worlds (physical, biological, imaginary, human) that we seek to understand are inevitably and happily multivariate in nature. Not flatlands.” (p. 12). It was the intended purpose of this research study to examine one possible escape route from flatland through a specific instructional strategy that allowed the manipulation of data in two- and three-dimensions. It is hoped that this study will encourage other educators to search for teaching methods that allow for the development of visualization skills through computer-based instructional strategies.

TABLE 1

Pretest and Posttest Mean Scores and Standard Deviations of all Dependent Measures Across Treatments, Levels of Cognitive Ability, and Levels of Spatial Orientation Ability

	Domain Science Knowledge		Data Interpretation		Hypothesis Formulation	
	Mean	SD	Mean	SD	Mean	SD
Treatment						
Two-Dimensional[a]						
Pretest	9.49	3.34	3.87	1.38	4.33	1.87
Postest	11.73	4.01	3.47	1.65	4.89	1.94
Three-Dimensional[b]						
Pretest	9.84	3.03	3.91	1.49	4.41	1.96
Posttest	12.55	3.94	3.95	1.64	4.84	2.07
Cognitive Ability						
Concrete[c]						
Pretest	9.15	2.83	3.55	1.33	3.81	1.67
Posttest	11.00	3.50	3.34	1.57	4.27	1.66
Transitional/Formal[d]						
Pretest	10.85	3.64	4.67	1.36	5.67	1.80
Posttest	14.74	3.82	4.56	1.55	6.22	2.06
Spatial Orientation Ability						
High Ability[e]						
Pretest	10.90	3.42	4.40	1.19	4.93	2.20
Posttest	13.93	4.02	4.43	1.41	5.50	2.21
Low Ability[f]						
Pretest	9.03	2.88	3.58	1.44	4.08	1.68

Posttest	11.22	3.66	3.29	1.65	4.54	1.81

a$\underline{n}$ = 45. b$\underline{n}$ = 44. c$\underline{n}$ = 62 d$\underline{n}$ = 27 e$\underline{n}$ = 30 f$\underline{n}$ = 59

TABLE 2

Three-Factor Analysis of Variance Concerning Graphing Treatment Levels, Cognitive Ability Levels, and Spatial Orientation Ability Levels on Data Interpretation Gain Score Measures

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment (T)	1	1.648	1.648	0.813	0.3700
Cognitive Level (C)	1	0.009	0.009	0.005	0.9465
Spatial Level (S)	1	1.983	1.983	0.978	0.3256
T * C	1	3.745	3.745	1.847	0.1779
T * S	1	1.371	1.371	0.676	0.4133
C * S	1	0.319	0.319	0.157	0.6928
T * C *S	1	1.625	1.625	0.802	0.3733
Residual	81	164.210	2.027		

TABLE 3

Three-Factor Analysis of Variance Concerning Graphing Treatment Levels, Cognitive Ability Levels, and Spatial Orientation Ability Levels on Hypothesis Formulation Gain Score Measures

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment (T)	1	1.089	1.089	0.342	0.5603
Cognitive Level (C)	1	0.002	0.002	0.001	0.9791
Spatial Level (S)	1	0.148	0.148	0.047	0.8297
T * C	1	7.317	7.317	2.297	0.1335
T * S	1	5.950	5.950	1.868	0.1755
C * S	1	0.614	0.614	0.201	0.6550
T * C *S	1	2.587	2.587	0.812	0.3701

Residual	81	258.024	3.185

TABLE 4

Three-Factor Analysis of Variance Concerning Graphing Treatment Levels, Cognitive Ability Levels, and Spatial Orientation Ability Levels on Domain-Specific Science Knowledge Gain Score Measures

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Treatment (T)	1	8.458	8.458	0.691	0.4082
Cognitive Level (C)	1	58.644	58.644	4.792	0.0315*
Spatial Level (S)	1	0.172	0.172	0.014	0.9060
T * C	1	0.270	0.270	0.022	0.8822
T * S	1	27.440	27.440	2.242	0.1382
C * S	1	0.011	0.011	0.001	0.9762
T * C *S	1	2.283	2.283	0.187	0.6670
Residual	81	991.257	12.238		

*$p < .05$

TABLE 5

Mean Domain-Specific Science Knowledge Pretest/Posttest Scores and Associated t-Test Values by Two- and Three-Dimensional Computer-Based Graphing Treatments

Treatment Level	n	Pretest		Posttest		t-Test
		Mean	SD	Mean	SD	
Two-Dimensional	45	9.49	3.34	11.73	4.01	4.99*
Three-Dimensional	44	9.84	3.03	12.55	3.94	4.43*

* $p < .0001$

TABLE 6

Mean Data Interpretation Pretest/Posttest Scores and Associated t-Test Values by Two- and Three-Dimensional Computer-Based Graphing Treatments

Treatment Level	n	Pretest		Posttest		t-Test	
		Mean	SD	Mean	SD		
Two-Dimensional		45	3.87	1.38	3.47	1.65	-1.77
Three-Dimensional	44	3.91	1.49	3.95	1.64	0.23	

TABLE 7

Mean Hypothesis Formulation Pretest/Posttest Scores and Associated t-Test Values by Two- and Three-Dimensional Computer-Based Graphing Treatments

Treatment Level	n	Pretest		Posttest		t-Test	
		Mean	SD	Mean	SD		
Two-Dimensional		45	4.33	1.87	4.89	1.94	2.28*
Three-Dimensional	44	4.41	1.96	4.84	2.07	1.51	

* $p < .05$

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