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PROGRAMMING COMPUTER GRAPHICS AND THE
DEVELOPMENT OF CONCEPTS IN GEOMETRY

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
Nancy Jo Dziak, B.S., M.A.

******

The Ohio State University
1985

Reading Committee:  Approved By
Dr. Fred Damarin  Fred L. Damarin
Dr. Philip Clark  Advisor
Dr. Suzanne Damarin
Dr. Gerald Winer  Department of Psychology
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DEDICATION

To the students
of Mohawk Middle School in Columbus, Ohio,
and all those who care for them.
ACKNOWLEDGMENTS

I wish to thank my advisor, Fr. Fred Damarin, for providing me with many years of patient and careful teaching. I am also grateful to Dr. Suzanne Kidd Damarin. Her expertise in computers and mathematics education greatly helped this dissertation become possible. Thanks to committee members Dr. Gerald Winer and Dr. Philip Clark for their suggestions and their confidence in my abilities.

I shall always be indebted to Dr. Delos Wickens and Dr. Carol Wickens for nurturing my early interest in psychology and research, and for offering years of generous personal support.

Finally, I would like to thank my family: Mrs. Lillian Dziak, Beverly, Richard, and especially my father, the late Peter Dziak, for their constant love and respect.
**VITA**

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<tr>
<th>Year</th>
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<tbody>
<tr>
<td>November 18, 1953</td>
<td>Born - Lakeside, Ohio</td>
</tr>
<tr>
<td>1976</td>
<td>B.S., Psychology, The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1981</td>
<td>M.A., Developmental Psychology, The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1978-1979</td>
<td>Graduate Research Associate, U.S. Army Grant, Instructional Effects on Classical Conditioning, The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1979-1982</td>
<td>Graduate Teaching Associate, Introductory Psychology, The Ohio State University, Columbus, Ohio</td>
</tr>
<tr>
<td>1982-1983</td>
<td>Graduate Research Associate, TABS-Math Project, The Ohio State University College of Education, Columbus, Ohio</td>
</tr>
<tr>
<td>1983-1984</td>
<td>Psychology Consultant, Battelle Memorial Institute, Columbus, Ohio</td>
</tr>
<tr>
<td>1984-1985</td>
<td>Instructor of Psychology, University of Wisconsin Center-Manitowoc, Manitowoc, Wisconsin</td>
</tr>
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**PAPER PRESENTED**

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INTRODUCTION

Computers have had an escalating impact on our society for the past three decades. The advent of microcomputers in 1975 brought computer access within the financial reach of individuals and many primary and secondary schools. This arrival of the "computer age" is prompting changes in school curricula and forcing reevaluation of what is needed to train students to be employable adults (NCTM, 1980). Over one half of all the schools in the United States now have computers (Greenfield, 1984). Computer literacy requirements are being proposed across the country, and instruction in computer programming is becoming common. In addition, there appears to be a trend toward introducing programming to younger and younger children.

As partial support for these changes in the schools, many claims have been made concerning the cognitive benefits of learning to program. Most of these claims, however, appear to be generated more by expectation and excitement than by empirical evidence.
The push to teach computer programming to children is gaining momentum, and we know very little about the immediate or far reaching effects of such instruction. Marketing pressure from hardware and software companies is increasingly affecting decisions made by school authorities. It is unfortunate that many of these decisions are being made without the benefit of input from research. Current studies concerning the effects of computer programming instruction are therefore particularly timely. It is hoped that results from such studies will have a significant impact on the use of computers in the schools and on the development of prototypic curricula.

The present study concerns instruction in programming graphics. Elementary graphics are normally included in introductory courses, therefore thousands of students are exposed each year to this type of training. Surprisingly, there has been very little research done on this topic (Pea and Kurland, 1984). As is the case for computer programming in general, we know little about the cognitive effects of learning to program graphics. Does this training transfer to other tasks? Are there sex, age, or grade differences in the acquisition or generalizability of this skill?
The present study is designed to address these questions. Specifically, this research will examine some cognitive effects of learning to program low resolution graphics, in BASIC, on the Apple IIe computer. Lines and pictures are created on the graphics screen by programming the computer to plot small rectangles of color using a series of horizontal and vertical coordinates. As a result, when students learn to program graphics they receive extended practice in the use of a coordinate system and in visualizing their intended graphics display. It is hypothesized that this repeated practice in locating points in two dimensions, planning the direction and intersection of lines, and constructing shapes on the screen will improve the students' abilities in spatial orientation and elementary geometry.

The following review begins with a description of the two major theories devoted to the development of the child's conception of geometry. The subsequent discussion will show how experience with programming computer graphics may be useful in facilitating this development.
CHAPTER I

LITERATURE REVIEW

The Development of Concepts in Geometry

Piaget - The Construction of Euclidian Space

Overview. The two major works by Piaget concerning the development of geometric and spatial thinking are The Child's Conception of Space (Piaget and Inhelder, 1956) and The Child's Conception of Geometry (Piaget, Inhelder, and Szeminska, 1960). These books are considered to be a two volume series on the same general topic (Flavell, 1963). The Child's Conception of Space describes three phases in the development of geometric thought: topological, projective, and Euclidean space constructions. Topological space develops first and lays the foundation for the construction of both projective and Euclidian space.

Topological relations include enclosure, continuity, proximity, separation, and order. The child at this stage can recognize, for example, that two objects
or features are close together or far apart. He can understand that in a series of objects A, B, C, object B is between A and C. He can differentiate between a toy being inside a box or outside a box. There is, however, no conservation of distance or angles, and there is no distinction between straight and curved lines. There is also no understanding that objects are related in a common space. Each object in a sense has its own space. The area between two objects or features might be viewed as belonging to the space of one of the objects, or it may not be considered at all (see review by Smock, 1976). Topological relations constitute the child's conception of space until about the age of 4, at which time notions about projective space begin surfacing.

Construction of projective space involves the ability to relate two or more objects in the same space. An object may be seen from a "point of view" or perspective, or objects may be related to one another, as in the construction of a straight line. The child now can identify not only near and far relations, but those of right and left, in front of, behind, above, and below. Construction of projective space begins with identifying straight lines at about age 4. The child's perspective taking then gradually improves and becomes
less egocentric with the arrival of concrete operations. Finally, at formal operations the child possesses a coordinated system of perspectives. He or she understands parallel and perpendicular lines and can conserve angles.

Much of the construction of projective space develops concurrently with concepts of Euclidian space. Euclidian space adds the quantification of distance to concepts about object relations. The child now can tell, not only that object A is above or below object B, but how far above or below B object A is located.

The Child's Conception of Geometry is devoted entirely to describing the construction of Euclidian space, beginning with spontaneous measurement and progressing through conservation of length and area, measurement of length and area, and locating a point in two dimensions. The following discussion will be restricted to a description of the Piagetian tasks for conservation and measurement of area and locating a point in two dimensions. These skills are directly related to the understanding and use of a two-dimensional coordinate system.

Locating a Point in Two Dimensions. In this Piagetian task the subject is presented with two identical, white, slightly translucent pieces of paper. One sheet has a red dot in the upper right quadrant.
The subject is provided with a ruler, sticks, and pieces of thread, and asked to put a red dot in exactly the same spot on the second sheet of paper. Since the paper is translucent, the correct response can be easily verified by placing sheet #2 on top of the original.

This is a particularly illustrative task; the sequence of responses is quite clear and informative. In the early stages, up to age 6½, subjects attempt to place their red dot by visual inspection. The materials provided for measuring are either not used at all or are not properly used. After age 6½ one-dimensional measurements are observed. A child may measure obliquely from the corner to the dot, or make one horizontal or one vertical measurement. Children aged 6½ to 7 demonstrate transition to two-dimensional measurement. They will still measure obliquely from the corner but will try to maintain the slope while transferring the ruler. A trial and error discovery of two-dimensional measurement occurs between ages 7 to 8½. The subject, after much practice, will take both horizontal and vertical measurements. Finally, after about age 8½, subjects will easily begin by measuring in two dimensions, and they can readily explain their reasons for doing this.
Conservation of Area. Understanding the notion of area requires a conceptual step beyond locating a point in two dimensions. The child cannot simply count e.g. 3 units across and 4 units up. He or she must think in terms of square units, which requires a coordination of two dimensions before the task has even begun.

There are several tasks reported in Piaget (1960) for testing conservation of area. One involves a toy cow and toy houses on a play meadow. Another involves rearranging unit squares in a figure. A third deals with cutting and relocating sections of a piece of paper. The following is a discussion of the third task.

Initially, a square piece of paper is shown to the child. It is then cut, and the sections are reassembled. For example, the square paper may be cut diagonally and the two sections put together to form a triangle. The child is then asked if this new shape has the same amount of "space" or "room" as the original.

As Piaget points out, the terminology used in asking questions is more of a difficulty in area tasks than in any of the length or distance tasks. With conservation of length the child can use intuitive notions of distance traveled or "steps". In area tasks, however, the young child probably has no inherent
notions about "space" or "room". Otherwise, the child would most likely be able to conserve area.

The conservation of area tasks elicit a familiar series of responses often seen in other types of conservation. Up to the age of 6, children regard any change of shape as a change in the amount of area. Intermediate responses occur between ages 6 and 7 and involve occasional conservation. Non-conserving responses usually occur with the largest perceptual alteration. For example, if a rectangle is cut into pieces and reassembled into another four-sided figure, an intermediate child would say that the area is the same. If the rectangle is cut and reassembled into a pyramid, however, the area is said to be different. Operational conservation usually emerges after age 7. At this stage the child can conserve through many different types of transformations, and can verify the response by reversing the transformation or by using a middle term to place on top of the cut sections.

Measurement of Area. The use of a middle term to verify conservation responses marks the beginning of the ability to measure area. In the task for measurement of area, the subject is asked to compare various figures: a right triangle, a rectangle, and an irregular figure. The child is given small cut-outs of squares and triangles and is asked, for example, if the right triangle is the same size as the irregular figure.
Ability to measure areas emerges around age 7. Younger children may simply compare the two shapes visually and not use any of the small cut-outs. If prompted, however, they may use just a few cut-outs and then make a judgment. After about age 7, children will superimpose the cut-outs on the figure and count the number of sections. Around age 8, children become able to use unit interaction of just one cut-out to measure the whole figure.

**Underlying Principles.** In addition to the previously described sequencing of topological, projective, and Euclidian space constructions, there are two other fundamental principles particularly important to the development of geometric thought. First, Piaget's descriptions are mainly concerned with the child's mental representations, not perceptions. He sees the child developing mental models of space and spatial relations, models that allow the child to measure length, distance, area, and angles and establish "... a picture of space as a kind of all-enveloping container made up of a network of sites or subspaces. Within the container are objects, the things contained, which move from site to site, now occupying or filling a given site, now leaving it unoccupied and empty." (Flavell, 1963, p. 335).
The construction of this spatial model is essentially the result of the child's actions, actions involving the manipulation of objects in space. This is the second underlying principle, not only of the construction of Euclidian space, but also of the development of virtually all cognitive structures (Piaget, 1950). Piaget writes, "Operations are nothing but interiorized actions whose efferent impulses do not develop into external movements" (1954 p.141). Piaget's conviction that actions are fundamental to cognitive development is further elucidated in his reflections on education (Piaget, 1970). He strongly encourages teachers to allow and foster students' learning through the student's own actions.

Verification. Since the translation of Piaget's original works on conservation, huge numbers of studies have appeared in the literature. Although only a relatively small portion of these involve conservation of length and area, research on conservation of weight, number, mass, and volume provide insight into similar developmental processes. In a review of the conservation studies, Carpenter states, "Piaget's description of the development of conservation has generally been confirmed using a great variety of experimental procedures, materials, and types of transformations" (1976, p.52).
A popular focus of recent research has been the testing of the ages which Piaget claims mark the beginning of conservation. Studies of conservation of length using the standard Piagetian tasks generally find conservation occurring between the ages of 6 and 8. Divers (1970) found that children aged 7 understand transitive relations involving length. Steffe and Carey (1972) also identified transitive relations of length, with implied conservation, at the age of 7. Swada and Nelson (1976) found the beginning of length conservation in children 5 and 6 years old. Music (1978) stressed the importance of motor activity in children's judgments about distance. For example, young children judge the distance across a room as farther if they must carry a sack of objects, then if they are empty handed. Also, the distance is considered less if the child runs rather than walks across the room. Shantz and Smock (1966) generally confirmed Piaget's ages for conservation of distance and use of a coordinate system.

Not surprisingly, Piaget's descriptions of the development of spatial and geometric thought has had (at least in theory) an impact on educational practice. There is not always a good match, however, between Piagetian theory and classroom applications. Kidder (1978, 1976) implies that the original Piagetian tasks
for conservation of length may be too limited to provide an educationally useful test of conserving operations. He found that, although children from 6 to 8 can conserve length with the two sticks task, most 9, 11, and 13 year old children cannot conserve through Euclidian transformations (slides, rotations, and reflections). Such transformations require more complex mental representations. Curricula for teaching geometry to children often use Piagetian theory as a base, even though this may not be entirely appropriate. Kidder (1978) observes, "Attempts have been made, and are being made, to apply Piagetian theory directly in the classroom. This is so even though Piaget discourages such a practice" (p.225).

As previously mentioned, Piaget offers some general guidelines to educators. Several of these are reflected in the following recommendation of UNESCO, 1956 "The Teaching of Mathematics in Secondary Schools":

"20. It is important (a) to guide the student into forming his own ideas and discovering mathematical relations and properties himself, rather than imposing ready-made adult thought upon him; (b) to make sure that he acquires operational processes and ideas before introducing him to formalism; (c) not to entrust to automatism any operations that are not already assimilated." (Piaget, 1970, p. 48)

In regard to actual classroom applications, however, there appears to be a gap between Piaget's description
of the development of geometric thinking and instruction in geometric concepts.

A theory is needed that combines both formal instruction in geometry and Piagetian principles of development. Two Dutch mathematics educators, P.M. van Hiele and D. van Hiele-Geldof, have formulated and attempted to implement such a theory.

van Hiele - Levels of Geometric Thought

van Hiele and van Hiele-Geldof (1958) studied the role of intuition in geometry and the development of geometry learning in the child. Until recently, (Wirszup, 1976), their work was largely ignored in the United States. Frendenthal (1973) helped popularize their writings in Europe. Mathematics educators in the Soviet Union, however, have been interested in their work since 1960. In the early 1960's, researchers at the Soviet Academy of Pedagogical Sciences conducted studies that lent validity to the van Hiele theory and developmental levels (Stolyar, 1965).

Levels. Because of translation difficulties, descriptions of the van Hiele levels differ somewhat depending upon the source. Descriptions in various amounts of detail can be found in Mayberry (1983), Geddes (1982), Burger (1981), and Wirszup (1976). The following is taken from Burger (1981). It is felt
that this description is the clearest and most concise of those available in English. There are 5 levels; the context of each and the form of reasoning required are briefly described. (In Burger (1981) the levels are numbered 0 to 4. In Wirszup (1976) they are numbered 1 to 5. To avoid confusion, the Burger descriptions are renumbered here from 1 to 5.)

Level 1 (visualization)
Context: basic geometric shapes (triangles, squares, rectangles, parallelograms, rhombi, other polygons, circles, etc.).
Form of Reasoning: visual identification and comparison of the shapes as a whole. At this level the student learns to recognize and name simple shapes.

Level 2 (description)
Context: properties of geometrical shapes.
Form of Reasoning: informal analysis of the component parts of shapes (sides, angles, diagonals, lines of symmetry, etc.), and a comparison of different shapes according to their properties. At this level, the student establishes some necessary properties of geometrical shapes.
**Level 3** (abstraction)

Context: relationships among the properties of shapes.

Form of Reasoning: logical partial ordering of the properties of shapes leading to the formulation of abstract definitions and class inclusions (eg. parallelograms rectangles squares). At this level the sufficiency of properties to determine a shape is learned.

**Level 4** (deduction)

Context: a geometrical system complete with undefined terms, postulates, an underlying logical system, defined terms, and theorems.

Form of Reasoning: deduction of statements within the constraints of the mathematical system. At this level, the student learns of the necessity for each component in the mathematical system and studies the classical results in Euclidian geometry.
Level 5 (rigor)

Context: various geometries

Form of Reasoning: rigorous mathematical study within several geometries, a study of the properties of the systems of postulates, (e.g. the incompleteness of Euclid's postulates, and the completion by Hilbert.)

Theory. The van Hieles saw the development of geometric thought as a progression of discontinuities: "The discontinuities are... jumps in the learning curve, and these jumps reveal the presence of levels. The learning process has stopped; later on it will start itself once again. In the meantime, the pupil seems to have 'matured'. The teacher does not succeed in further explanation of the subject. He and the other students who have reached the new level seem to speak a language which cannot be understood by the pupils who have not yet reached the new level!" (van Hiele, 1958, p. 75).

In regard to their discussion of discontinuities, the van Hieles resemble Piaget. Unlike Piaget, however, the van Hieles explain development as mainly the result of instruction or a "process of apprenticeship", rather than a consequent of maturation.
The "apprenticeship" which leads to progress from one level to the next consists of five phases. The first phase is called "information". The student learns to generally recognize the field of investigation by examining the instructional materials presented to him. Next, the student engages in "directed orientation". He or she explores the materials, and the subject matter is presented in a manner that allows the characteristic structures to progressively appear to the student. Later, in the "explanation" phase, the acquired experiences are linked to linguistic symbols, and the student can take part in classroom discussions about the topic in question. During the next phase, called "free orientation", the student knows many of the methods and materials that have been presented, but these concepts are not effectively organized. Finally, in the "integration" phase, the student acquires a coordinated overview of the methods at his or her disposal (Wirszup, 1976, p.83).

A central principle underlying the child's progression through these phases is that it is best for the child to learn geometry in a manner akin to guided discovery. The structure of the subject matter is supposed to "progressively appear" to the child, and not be simply
imposed by the teacher. This recommendation of discovery type learning is similar to Piaget's guidelines for the establishment of teaching techniques that foster active learning.

**Current Research.** Two recent NSF projects, one at Oregon State (Burger, 1981) and another at Brooklyn College (Geddes, 1982), have employed van Hiele's theory and levels to assess the geometric thinking of some primary and secondary school students here in the United States. Preliminary findings indicate that the theory is useful for such an assessment, and that in general, student grade level is related to their estimated van Hiele level.

In both projects, students were interviewed and asked to make judgments about shapes based on the shapes' geometric properties (see Appendix A for sample items from Burger, 1981). Reports of these interviews indicate that students in the primary grades tend to categorize geometric shapes mainly in terms of visual characteristics. Many students as old as 13 and 14 have difficulty with deductive reasoning and with making appropriate class inclusions involving geometric shapes. Secondary school students who have studied geometry are better at deduction, but are often confused about the roles of postulates and theorems. In addition, secondary school students rarely understand the idea of a mathematical system.
Critics of the present U.S. geometry curriculum suggest that van Hiele's theory may be a useful tool for revising current instruction (Coxford, 1978, Wirszup, 1976). They complain that in most American schools today geometry is barely mentioned during the elementary years. Then, in the tenth grade, the students are presented with a formal geometry under the assumption that they have already progressed through several lower levels of geometric thinking. The goal of a van Hiele type curriculum would be to foster the gradual development of an intuitive sense of geometry, and to provide instruction in related mathematical procedures that would generalize to other areas of logic and measurement.

One technique that may help foster a student's intuitive sense of geometry would be to encourage the student to use geometry in some applied context. If this were also a motivating context, the educational gains could be significant. Programming computer graphics is an application of geometric concepts involving a two-dimensional coordinate system and some properties of simple shapes and lines. Programming is also a motivating experience for many students (Greenfield, 1984). In addition, the activity of programming graphics incorporates many of the important developmental principles
previously discussed. The following section will elaborate on these educationally and developmentally useful features of graphics programming.

Programming Graphics - Applied Elementary Geometry

An Example. The Apple BASIC graphics screen, in low resolution, is arranged in a 40 by 40 grid of rectangles (informally called squares). The squares are numbered as indicated in Figure 1. Plotting pictures on the screen involves designating a point or set of points to be colored. For example, "PLOT 5,10" means color in the square that is five squares across and ten squares down. Horizontal and vertical lines can be plotted point by point, or more easily, by using the commands HLIN and VLIN. For example, "HLIN 0,39 at 7" draws a horizontal line from square 0 to square 39 at 7 squares down on the vertical axis.

Now consider some of the mental processes involved in using this graphics system. Suppose a child wanted to construct the picture of a house shown in Figure 1. He or she would obviously need to understand how to locate a point in two dimensions. This requires the operations of conservation and measurement of length, combining the squares to make the door and window a particular size involves conservation and measurement
Figure 1. Example of 40 x 40 grid for low resolution Apple graphics with a sample picture.
of area. Locating the door in the middle of the house requires some knowledge of symmetry. In order to draw the square forming the body of the house, the child must have some notions about the properties of a square: equal length sides that meet to form four right angles.

The most difficult task in constructing this house, however, is drawing the roof. There are three main features that the child may discover. First, the roof will not be pointed unless it contains an odd number of squares. The height of the roof is related to the width of the house. As the width of the house increases, the height of the roof increases. To make the roof, one cannot simply start connecting squares to form a diagonal on one slope then arbitrarily stop and begin drawing the other slope. Unless the child is very fortunate, the roof will not be symmetrical, or it may not exactly meet both sides of the house. The child needs to calculate the width of the house, find the mid-point, extend up a vertical line, and draw the diagonal until it intersects that line.

It is quite possible, of course, to draw the roof using trial and error methods, and this is frequently done. Adjustments made through trial and error, however, can still be quite instructive. The student must supply
coordinates for each square or line that is drawn. When a line is relocated the coordinates change, often in a systematic manner. For example, a horizontal move of one wall of the house requires a change in all the X coordinates, but the Y coordinates remain the same. Programming these kind of changes forces the student to examine the relations among the sets of numbers used as coordinates.

**Underlying Processes.** There are several other basic characteristics of this programming activity that support its educational potential. First, it is active. The child is actively constructing pictures on the screen and making and correcting his or her own mistakes. The importance of action to the child's learning and development has already been discussed. Second, it is representational. The child can imagine in a perceptual sense a picture to be drawn, but in order to program it the student must overlay this network of spatial locations. Third, programming is motivating. Students enjoy most kinds of programming. Perhaps this is because in many ways a computer is like a television set, only better because it is interactive (Greenfield, 1984). Children seem to particularly enjoy programming graphics. Graphics are relatively easy to program, and they are, literally, colorful.
There appear to be good reasons to expect that instruction in programming graphics may have some beneficial effects in addition to the simple transmission of a technical skill. Occasional research on the educational advantages of computer programming instruction has been conducted over the past 13 years. There is some indication that there are cognitive benefits of learning to program, particularly in the area of mathematics.
Most of the previous research on computer programming has not concerned the cognitive benefits of learning to program, but has focused on programming rules, memory organization, and debugging strategies. Brooks, (1977) generated a model that identifies 104 rules necessary for a particular type of programming activity. Green and Barstow (1978) describe over a hundred rules that most programmers posses for sorting and searching algorithms. Several studies concern memory organizational differences between expert and novice programmers (Adelson,.1981; Reitman, 1980; Schneiderman, 1977). McKeithen (1981) found that experts used different mnemonic strategies for remembering chunks of programming commands. Experienced programmers organized the terms according to meaning or function, whereas novices grouped the terms according to surface characteristics such as word length or spelling. Mental representations of programs have been examined by DuBonlay, O'Shea and Monk (1981) and Hoc (1977). Expert/novice differences in debugging strategies have been studied by Gould (1975), Gould and Drongowski (1974), and Youngs (1974). Gould (1975) found that experts tend to read programs for flow
of control, while novices read programs line by line.

Richard Mayer has attempted to analyze processes involved in learning BASIC and has offered some specific recommendations for teaching BASIC to novices (Mayer, 1979). He has also experimented with different techniques for instruction in programming and has determined that learning and transfer, to tests of programming concepts, can be increased by providing concrete models and encouraging students to reformulate technical information in their own words (Mayer, 1975, 1976, 1981). His work on concrete models and the use of advance organizers is built on information processing models similar to those of Greeno (1973).

Much of what is claimed about the basic cognitive processes involved in computer programming appears to be based on intuitive analyses of what programmers do. It seems as though such abilities as general intelligence, mathematics ability, analogical reasoning, and knowing the principles of conditional logic would be important to competent programming. There is, however, a remarkable lack of research in this area. Although instruments such as the Programmer's Aptitude Test have been available since 1956, a reliable relation between these scores and performance in the workplace has not been established (Bell, 1976). The need for research
Programming and Improvement in Logical and Mathematical Abilities

As early as 1969, Feurzeig et al. advocated that children be taught programming in mathematics classes. He felt that learning to program would help the development of mathematical concepts in four basic ways:

1. Programming provides justification for and illustration of formal mathematical rigour.
2. Programming encourages the study of mathematics through exploration.
3. Children achieve insight into certain mathematical concepts through programming.
4. Programming provides a language in which children may describe their own problem solving processes.

There appears to be modest evidence for all four of these claims. Ross and Howe, in their review (1981), state that, "In terms of statistical results the research of the last decade into "mathematics through programming" has been more encouraging than discouraging, but only mildly so."
There is some indirect evidence that learning to program improves understand of mathematical rigour. Howe, O'Shea, and Plane (1980) report a small study of 11 year old boys who were taught mathematics using LOGO. After two years, the teacher rated the students in the study as better able to express mathematical ideas and their own understanding difficulties. DuBonlay (1978) taught LOGO programming to Scottish teacher trainees and found that, after the instruction, several of them had increased insight into the importance of clear, precise explanations. Papert (1980) reports that many children learning LOGO adopt a systematic, testing approach to writing programs.

The exploration of mathematics through programming has received some attention. Papert, in his popular book *Mindstorms* (1980), cites numerous examples of childrens' spontaneous explorations while working with LOGO and Papert's Turtle Geometry. Dwyer (1975) has studied curricula that successfully used BASIC as a tool for the encouragement of exploring a wide variety of unique problems, such as operating a mechanical band-organ. Howe et al. (1979) describe several examples in which a child will take advantage of mistakes in programming and produce a different and better product than that which was originally intended.
Several studies have demonstrated that programming helps provide insight into mathematical concepts. Feurzeig et al. (1969) report that a group of seven to nine year old children acquired a "meaningful understanding of concepts like variable and procedure after learning to debug programs. Milner (1973) found increased comprehension of the notion of a variable in 11 year old children after they learned to write recursive programs. Howe et al. (1979) also found improved understanding of variables in 11 year old boys following instruction in LOGO. Clement, Lochhead, and Soloway (1982) report that college students could more easily solve algebra word problems in the context of writing a computer program: than by simply writing an algebraic equation. They note that, "Computer programming apparently encourages an active, procedural view of equations that many students fail to use in the context of algebra".

There appears to be some support for the Feurzeig claim that programming provides a language for the description of problem solving processes. Statz (1973) found improvement in problem solving on tasks requiring recursion and anagrams, after subjects had received instruction in LOGO. Seidman (1981) reports that learning conditional branch statements in LOGO affects
subjects' understanding of conditional logic. Papert and Goldstein (1972) encourage the teaching of the terminology of programming in order to provide the student with concepts about algorithms and procedures that are useful in problem solving activities.

Pea and Kurland (1984) have criticized several of these studies which are often cited as support of transfer of training from programming. They argue that, in the Howe et al. (1979) study, teacher evaluations may have been unreliable, since the raters were aware of which students had received the LOGO training. The Dwyer (1975) and Howe et al. (1979) research showed an increase in math exploration using both BASIC and LOGO, but Pea and Kurland point out that this exploration was only within the computer environment. They further note that phrases like "meaningful understanding" are often not operationalized, and that many of the research reports are merely anecdotal.

These criticisms are well taken, but the previous research findings do not warrant dismissal. Instead, the past research should be viewed as possibly indicating a trend, and improved and more formal research techniques should be employed in the future. Pea and Kurland recommend several research modifications, they write,
"... these studies suffer in not linking level of programming skill to specific outcomes expected, and the critical studies of 'low level' transfer expected from level I and II (elementary) programming skills remain to be carried out."

Computers and Improvement in Geometric and Spatial Abilities

For over a decade, Seymour Papert has been using LOGO and his Turtle Geometry to teach children mathematical concepts and the "powerful ideas" encountered in programming. Papert (1980) claims that the use of Turtle graphics teaches a new kind of geometry. (The "turtle", seen as a small triangle, leaves a line trail as it moves around the computer screen.) Distance is measured in "turtle steps", and angles are made by turning the turtle right or left from 1 to 360. The child learns experimentally that, e.g. to draw an equilateral triangle each angle must be made with a turn of 120. The manner in which the turtle draws, and the ease with which right and left turns are made, makes LOGO graphics particularly useful for promoting an understanding of angles and arcs. Papert's reports are encouraging, but his research is based mainly on observations made of a relatively small number of selected children in a specialized laboratory.
Except for Papert's and his associates' work with LOGO, there is little other research on programming graphics and geometrical thinking. There is, however, some information concerning the effects of certain computer games and videogames on spatial and mathematical abilities.

**Games.** The computer graphics screen, being designed as a system of X and Y coordinates, conveniently lends itself to games that require the user to specify coordinates. Two such games are Harpoon and Sonar. The following descriptions of both games are provided by their developer, James Levin (1981).¹

"Harpoon is a computer game (written in Pascal for an Apple II Computer) that presents the players with a drawing of a shark's fin on the computer screen, with two perpendicular lines intersecting over the shark. Each line has its endpoints labeled with numbers. The program asks the players to specify the position of the shark left and right and then its position up and down. After they enter the two numbers, a 'harpoon' flies across the screen to the position they have specified. If that spot is close enough to the shark, then the harpoon hits the shark, and the shark sinks out of view. If the harpoon misses, then a 'splash' occurs on the screen to mark the spot, and the players can try again using the splash mark as feedback.

Sonar is another game program (also written in Pascal for the Apple II Computer) that teaches math skills within the framework of a game. This game is similar to Harpoon, as the players have the goal of hitting a shark with a harpoon. But in Sonar, the shark doesn't initially appear on the screen, but is hidden underwater. The player's 'sonar' readout tells where the shark is hiding, giving X and Y coordinate
numbers. The players try to move the 'crosshairs' to that spot on the screen. Then the harpoon flies to that spot and if it is close enough to the shark's position, the shark surfaces and then is harpooned. Otherwise, the harpoon splashes into the water, and the coordinate numbers of their guess are displayed as feedback."

Levin (1981) reports that both games have been tested with 10 year old students, and that these children found the games "challenging and motivating". The students' skills at identifying positions within the coordinate system developed quickly. When working in only one dimension, children reached proficiency (a deviation of $\pm 3\%$ on the first guess) within :10 games. Levin suggests that students learn to have an "intuitive feel" for numbers by freely converting between numbers and line lengths.

In addition to these educational computer games, some videogames involve similar spatial skills. Small and Small (1982) describe strategies for the videogame "Battlezone" as requiring mental rotation and visualization of images in three dimensions. The once popular videogame "Space Invaders" is described as requiring the simultaneous coordination of horizontal and vertical axes and the ability to predict the intersection of imaginary lines (Lowery and Knirk, 1982).

Almost no formal research has been conducted on transfer of videogame skills to spatial and geometric skills. There is one unpublished study conducted at
the Harvard Graduate School of Education that has examined this transfer issue (Gagnon, 1984). Subjects in the study, 58 undergraduate and graduate students, were exposed to five hours of spaced practice at videogames. Two games were used: Targ, a two-dimensional maze game and Battlezone, a three-dimensional war game. Subjects were pretested and post-tested using three spatial ability tests: the Guilford-Zimmerman Spatial Orientation Test (in which judgments are made about positions of a boat bow relative to the test taker), the Guilford-Zimmerman Spatial Visualization Test (in which judgments are made about the rotation of an alarm clock), and the Employee Aptitude Survey Visual Pursuit Test (in which subjects trace lines through a circuit board maze). Gagnon found significant correlations between videogame scores and spatial test scores. Male subjects scored higher than female subjects on the spatial tests & on the baseline measure of one of the videogames. There was no overall effect of the videogame practice, but there was a treatment by sex interaction. Female subjects in the treatment group improved on the spatial visualization test significantly more than did female subjects in the control group. There was no significant improvement for male subjects2.
To date, research on the possible transfer of programming skills to geometric and spatial abilities has been limited and largely anecdotal. Despite the widespread inclusion of graphics programming into school curricula, this particular type of programming has received virtually no research attention. Most of the work on transfer of training concerns the language LOGO, yet BASIC is the resident language in essentially all microcomputers purchased by schools. There is no available research information on the cognitive requirements for, or possible benefits of, learning to program BASIC graphics. It is this dearth of information that motivates the present study.
CHAPTER II

HYPOTHESES AND SUMMARY OF UNDERLYING PRINCIPLES

Transfer of Training

The limited evidence for transfer of programming skills to other cognitive abilities may appear more substantial when considered in light of the difficulties encountered in demonstrating any type of problem solving transfer, even in adults. Although it has long been recognized that transfer of training is central to learning and education (Ferguson, 1956, 1954; Messick, 1984), research indicates that subjects generally have great difficulty noting similarities between "problem isomorphs" (problems with identical underlying logic but slightly different appearances) (see Bryant, Brown, and Campione, 1983; Gick and Holyoak, 1982; Simon and Hays, 1976). Problem isomorphs are examples of near transfer. Many of the programming studies have attempted to find transfer to tasks requiring related but different underlying strategies (far transfer). These studies focused on transfer to general problem solving or to a broad range of spatial abilities.

The present study will include tests to assess three different levels of transfer. A test of graphics
programming competence will assess near transfer. It is a paper and pencil version of activities performed at the computer. A test of van Hiele levels of geometric thought will be used to measure medium transfer. The items on this test include examples of the kinds of shapes, lines, and logic required for graphics programming. The third test is a standardized test of spatial orientation (far transfer). This test requires the subject to make judgments about the orientation of various shapes in two dimensions. As Pea and Kurland (1984) recommend, this study will examine low level transfer from elementary programming skills, and the tests will assess tasks and processes closely related to actual programming activities.

Hypothesis I

Training in programming BASIC computer graphics will transfer to:

a. a paper and pencil mastery test
b. a test of van Hiele levels of geometric thought
c. a test of spatial orientation (Card Rotations).

There will be a main effect for treatment; improvement in test scores of the treatment group will be significantly greater than improvement in test scores of the control group.

d. There will be a different amount of transfer for each test. The most transfer will be to the mastery test, the least transfer to the spatial orientation test.
Sex Differences

Research on sex differences in spatial abilities rather consistently demonstrates an advantage for males (see Maccoby and Jacklin, 1974; Nyborg, 1983 for reviews). This advantage generally begins at puberty and increases until about age 17.² An international study of mathematics abilities in students in 19 countries found that at age 10, boys outscored girls by 1/4 of a standard deviation. At age 14, the advantage for boys increased to 1/2 of a standard deviation, and by the last year of secondary school, boys outscored girls by 1 full standard deviation (Comber and Keeves, 1973). Declines in mathematical abilities in girls between the ages of 11 and 15 years have been reported by Ross and Simpson, (1971). Stafford (1972) found that boys began to outscore girls on tests of quantitative reasoning after age 12. Post-pubertal advantages for males on tests of spatial orientation and visualization have been reported by Emmett (1949), Maccoby, (1966), Slater (1971).

Various theories have been formulated in an attempt to account for these differences. Genetic influences, brain lateralization, and environmental pressures may all play a role. Theories related to hormonal changes, however, appear to have the most substantial empirical support (Nyborg, 1983).
In the context of the present study, socialization influences may have an important effect. Often, videogames are a child's first contact with any kind of computer. The violent themes of most videogames attract males and seem to discourage females (Greenfield, 1984). Malone (1981) demonstrated that the appeal of an educational computer game could be altered by varying the amount of aggression-like reinforcements. When the reinforcements were made more aggressive, the game's popularity increased for boys and decreased for girls. If boys are highly motivated to play videogames, this excitement may generalize to other types of computers. Computers are associated with mathematics and, indirectly, with male-dominated occupations requiring advanced mathematics. Finally, television shows and commercials for computers usually cast males in the roles of persons who receive, program, and purchase computers. All of these social influences may combine to provide extra motivation for males to learn programming and relate programming to other activities.

Although the Gagnon (1984) study did find a treatment effect for females and not for males, the large body of research on sex differences in spatial abilities and the motivational factors just discussed support the following hypotheses.
Hypothesis II

There will be sex differences favoring males.

a. Test scores of males will be significantly higher than scores for females on all three instruments.

There will be a sex by treatment interaction.

b. Within the treatment group, male subjects will improve significantly more than female subjects.

Age Effects

Descriptions of the development of the child's conceptions of space and geometry demonstrate that spatial abilities improve with age (Laurendeau and Pinard, 1970; Piaget, 1960). Although most Piagetian tasks involving geometry are accomplished by age nine, conservation and measurement of volume may not be achieved until age 11. Conservation through transformations may not be achieved until after age 13 (Kidder, 1976, 1978). The child's ability to program computer graphics would be expected to increase with improved logical reasoning abilities. Various kinds of logical reasoning capacities continue to develop up to age 15 (Flavell, 1963). Studies involving van Hiele levels found increases in levels of geometric thinking with age. They also noted that older children are better able to benefit from clues, hints, and instructions concerning solution strategies (Burger, 1981; Geddes, 1982).
**Hypothesis III**

Test scores and the amount of transfer of training will increase with age.

a. Scores on all three tests will significantly increase as the subjects' ages increase.

b. There will be a treatment by age interaction; the amount of improvement in the treatment group will significantly increase as the subjects' ages increase.

**Grade Effects**

Grade and age effects are confounded with one another. The van Hiele theory, however, would support a prediction of improved test scores on the basis of grade alone. They propose that the level of geometric thought is greatly influenced by formal instruction in geometry. The research on children in different grades shows, in general, an increase in van Hiele level with increases in the subject's grade. (Burger, 1981; Geddes, 1982).

**Hypothesis-IV**

Test scores and the amount of transfer of training will increase with grade.

a. Scores on all three tests will significantly increase as the subject's grade increases.
b. There will be a treatment by grade interaction; the amount of improvement in the treatment group will significantly increase as the subject's grade increases.

**Predictions from Standardized Tests**

There has been little research concerning the cognitive abilities required for programming, although there is clearly a need for such information (Pea and Kurland, 1984). This type of data would be useful in identifying the optimal grade or age level for programming instruction. Such information may also help identify students with particularly strong programming potential. Since programming graphics is essentially an exercise in applied mathematics, it is expected that, out of a battery of eight standardized test scales, a test of applied mathematics will be the best predictor of graphics programming skill (cf. Cronbach, 1984).

**Hypothesis V**

Out of a battery of eight standardized tests, the best single predictor of programming skill will be a test of applied mathematics.

This will be demonstrated by the applied mathematics test score being identified as the first predictor in a stepwise multiple regression.
CHAPTER III

METHODS

Tests

Test of van Hiele Levels of Geometric Thought

Past attempts to test children for levels of geometric thinking, according to the van Hiele theory, have focused on the child's verbal reports concerning properties of shapes (Burger, 1981; Geddes, 1982). Because of the anticipated large numbers of subjects in the present study, it was considered preferable to administer a paper and pencil test rather than conduct individual interviews. In addition, a focus on the properties of lines rather than shapes seemed more appropriate.

When a child programs the computer to draw pictures, he or she generally programs a series of lines, and locates them at the appropriate coordinates to form shapes. Recall that these lines can be constructed one square at a time (e.g. PLOT 6,5; PLOT 7,5; PLOT 8,5), or can be drawn using HLIN and VLIN (e.g. HLIN 6,8 at 5). Since the students receive extended practice working with lines rather than shapes, it was thought that
any improvement in geometric thinking might be better tapped by test items that referred to lines.

As with shapes, lines can be regarded as possessing various properties. One line drawn on the computer screen has length, and by virtue of the manner in which it is programmed, it has direction (e.g. horizontal line from 6 to 8 at 5). If a comparison is made of two lines on the screen, they can be parallel, perpendicular, intersecting (or heading for an intersection), and non-intersecting (or separating from one another). These main properties of lines, in the context of programming computer graphics, were used to develop items for assessing the subjects' van Hiele level of geometric thought. In addition, four test items were taken directly from reports of previous research (Burger, 1981). The following is an item by item description of the geometry level test used in the present study (see Appendix B for parallel forms of all tests).

Level I - Visualization.

Item 1 - visual comparison of different types of lines.
Item 2 - identification and naming of simple lines.
Item 3 - similar to Burger (1981), comparison of simple shapes.
Items 4, 5, and 6 - taken from Burger, this set of items could measure levels 1, 2, or 3 depending on the student's answers to item 6.

**Level 2 - Description.**

Item 7 - informal analysis of shapes, lines of symmetry.
Item 8 - comparison of the properties of both lines in order to predict the location of their intersection.
Item 9 - comparison of the properties of lines, prediction of their intersection, subtle introduction of the concepts of parallel and perpendicular.

**Level 3 - Abstraction.**

Item 10 - simple test of inclusion, the shaded area could include any number of vertical or slightly angled lines that fall within the middle third of the screen. Which of the examples to the right are included in this set?
Item 11 - the student must assess whether or not the combined properties of all three lines are sufficient to cause joint intersection.
Item 12 - the student must assess whether or not the properties of each line, when combined, are sufficient to form a square.
Level 4 - Deduction.

Item 13 - simple mathematical deduction including one variable, this deduction takes place within the constraints of the laws of arithmetic.

Item 14 - deduction involving transitive relations.

Items 15 and 16 - parallel and perpendicular lines are defined. The student must make deductions within this described system.

The final item is an applied example of locating a point in two dimensions. This was not intended to test van Hiele level, however, it could be construed as a more difficult version of item 11. There are no level 5 items. The mathematical Rigor level is far beyond the anticipated capacities of any potential subjects.

The items just described, and their parallel forms, are the end result of three iterations of testing. Three pilot studies were conducted and appropriate revisions were made following each study. The pilot research included a total of 97 subjects with an age range of 5 to 16 years. Following each study, the items that were retained were those that discriminated among subjects and were correlated with subject age.
Mastery Test

This is a pencil and paper test that measures graphics programming competence. The subjects are given examples of graphics output and asked to write programs that would produce such output. They are then given example graphics programs and asked to draw the expected output. Results from pilot testing suggested only minor revisions in wording.

Spatial Orientation Test

Card Rotations is a marker test for the spatial orientation factor in the Kit of Factor Referenced Cognitive Tests (E.T.S., Ekstrom, French, Harman, and Dermen, 1976). It requires subjects to make judgments about shapes that have been rotated in two dimensions. Although the test manual suggests that this test is suitable for grades 8 - 16, pilot testing indicated that the test was usable with children in grades six, seven, and eight. Reliability of this test averages .85. It is composed of two parallel forms each timed for three minutes.

Subjects

Subjects were 95 males and females who participated in the study by completing both the pretests and post-tests. The subjects were sixth, seventh, and eighth grade students.
at a midwest urban middle school. Racial composition of the school was approximately 40% inner-city blacks, and 60% poor and working class whites. The white students were bussed in from a distance of about six miles.

Two classes at each grade level were included in the study. The classes were selected according to mathematics ability and scheduling constraints. All classes used in the study were described by their mathematics teachers as having average ability for their grade in that particular school. All six classes were scheduled to participate in the study on the same eight days.

There were 22 sixth grade, 39 seventh grade, and 34 eighth grade students. Overall there were 43 males and 52 females included in the study. Subjects' ages were 11, 12, 13, 14, and 15. The number of subjects at each age were 7, 30, 31, 21, and 6 respectively. Additional breakdowns by age, sex, and treatment group are included in Tables 1 and 2.

**Procedure**

**Apparatus**

Eight Apple IIe computers with black and white monitors, and one disk drive attached to each, were used in the treatment. On the fifth and sixth days,
Table 1
Subject Breakdown by Grade, Sex, and Treatment Group

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Codes:
TX = treatment - 0 = control group, 1 = treatment group
SEX - 0 = males, 1 = females
Table 2

Subject Breakdown by Age, Sex, and Treatment Group

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</tbody>
</table>

Codes:
TX = treatment - 0 = control group, 1 = treatment group
SEX = 0 = males, 1 = females
three additional computers with color monitors were added. Class sizes ranged from 10 to 14 students. Sharing of computers was rotated among subjects.

The computer programming instruction was given in a computer laboratory located in the basement of the school. The room was large, approximately 30 x 30 feet, with computer tables along the walls, a chalkboard, and one large work area located in the middle. The room was comfortably warm, well lit, and isolated from the rest of the building.

Design

The study was conducted using a standard pretest/post-test control group design (Campbell and Stanley, 1963). The design is summarized in Figure 2. For the control group, the "alternate activity with teacher" consisted mainly in review of recent lessons and additional exercises, and some in depth study of topics that were of particular interest to the students. The teachers agreed not to teach any topics related to geometry to the control group during the study.

Treatment

Subjects were randomly divided into treatment and control groups. Form I of Card Rotations, Mastery, and the van Hiele geometry level test was given to all
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<tr>
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</table>

*Figure 2. Design of the study.*
subjects as a pretest (see Appendix B for verbal test instructions). After completing the pretests, the subjects were then told which of them would be included in the computer class (the treatment group), and which of them would remain in the class with their regular teacher (the control group).

The nature of the study was explained to all subjects in general terms. The importance of the control group was emphasized. Subjects were told that they had been randomly assigned to groups, and that the control group students would eventually be allowed to learn about the computers from their regular mathematics and science teachers. It was further explained that there were only eight computers in the laboratory, and therefore it was not feasible to take the entire class down to the laboratory at one time.

The study was conducted on Tuesdays and Thursdays over a period of four consecutive weeks. Pretesting was done on the first Tuesday. The following six Tuesdays and Thursdays were treatment days, and post-testing was done on the last Thursday. The treatment consisted in six class periods of 50 minutes each, conducted over a period of 20 days. The content of each session was as follows:
Day 1 - orientation to computers and class procedures, FOR...NEXT command.

Day 2 - beginning graphics programming, description of the graphics screen as coordinate system, practice with prewritten programs.

Day 3 - more graphics, plotting shapes point by point, introduction of the commands HLIN and VLIN.

Day 4 - plotting horizontal and vertical lines, making rectangles, making the student's initials in block form.

Day 5 - subjects work out a picture of their own on the graphics worksheet, and begin to program that picture as a project.

Day 6 - subjects finish projects and run them on color monitors.

The worksheet and instructional materials were previously developed by the Technology and Basic Skills in Mathematics project conducted at The Ohio State University College of Education. Eight instructional booklets had been developed, each focusing on a different BASIC programming command. The first booklet in the series of eight is called FOR...NEXT. It was used here on day 1 because it includes an orientation
to the computer and because this command is sometimes used in graphics programming. The following five days of treatment used the booklet entitled Graphics. (see Appendix C for these materials).

**Standardized Test Scores**

The following information was collected from school records of both treatment and control group subjects:

- birthdate
- sex
- aptitude test scores
  - language
  - non-language
  - total
  - date of testing
- achievement tests
  - reading
    - vocabulary
    - comprehension
    - date of testing
  - arithmetic
    - computation
    - concepts
    - applications
    - date of testing

The standardized aptitude test that had previously been given to the students was the Short Form Test of Academic Aptitude (SFTAA). This is an instrument derived from the California Test of Mental Maturity (CTMM), California Testing Bureau, 1961. The achievement test scores were from the Comprehensive Test of Basic Skills (CTBS), California Testing Bureau. Student
scores were reported in stanines (10 - 90), with a mean of 50 and a standard deviation of 20. In general, overall student scores were about 1/2 standard deviation below the mean.
CHAPTER IV
RESULTS

Reliabilities

Tests for spatial orientation (Card Rotations), van Hiele levels of geometric thought, and course mastery were each administered as pretests and post-tests using parallel forms. Reliabilities could be calculated using the correlation between parallel forms or Cronbach's Alpha, a measure of internal consistency. These figures are reported in Table 3.

The reliability for Card Rotations and the geometry test are somewhat low. The pre and post-tests were administered 24 days apart, however, and the subjects were in school taking classes that might have affected their mathematics and verbal abilities during this time.

There is a notably large difference between the treatment and control groups on the correlation between parallel forms of the geometry test. A possible explanation for this concerns motivational differences between the two groups. During the
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pretesting all subjects appeared sufficiently motivated to perform well on the tests. During the post-testing, however, some female control subjects seemed uninterested, and a few were irritated at having to take the tests again and receive nothing in return.

The mastery test was quite reliable. Correlations between parallel forms of the mastery test were not calculated because virtually all subjects scored zero on the pretest.

**Analyses of Pre-treatment**

**Control Group/Treatment Group Differences**

The purpose of the analyses contained in Tables 4 through 7 is to identify any differences between the treatment and control groups that might bias the results or confound later analyses.

There is only one instance of any significant effect including treatment group. That is a 3-way treatment x sex x grade interaction in the error term of the analysis of the geometry pretest (Table 5). As can be seen in Figures 3 and 5, the reason for this interaction is a grade related difference in the superiority of the treatment or control groups dependent on sex. For the sixth grade males, the control group has a higher mean on the pretest. For
the sixth grade females, the treatment group has a higher mean score. Just the reverse is true for the eighth grade. For the males, the treatment group has the higher score. For the females, the control group's mean is higher. Since subjects were randomly assigned to treatment groups, there is no apparent reason why this difference should occur. If it is found that there is a significant grade effect in the pre/post-test analysis, however, this interaction would pose a problem.

Eight treatment by sex ANOVA's were run using each of the standardized test scores as the dependent variable. There were no significant pre-treatment differences between treatment and control groups in any of these analyses.

Hypotheses

Hypothesis I

This hypothesis predicted a main effect for treatment on all three tests. There is a large main effect for treatment on the mastery test (Tables 8 and 9). This is in both the age x sex x treatment, and the grade x sex x treatment ANOVA's. The control subjects
scored zero on both the mastery pretest and post-tests. The mean mastery test score for the treatment group post-test was 10.5 out of a possible 18 points. There are no main effects for treatment on the geometry test (Tables 10 and 11) or the Card Rotations test (Tables 13 and 14).

Hypothesis II

Hypothesis IIa predicts significantly higher test scores for males than for females. This is the case for the Card Rotations pretest (Table 7). This is the only significant main effect for sex. Hypothesis IIb predicts more improvement for males than females, a treatment by sex interaction. There was a treatment by sex interaction, but it indicated more improvement for females rather than males (Table 11). This interaction occurred in the treatment x sex x grade ANOVA for the geometry test. This interaction is graphed in Figures 3 through 8. As can be noted from the plots, the females in the treatment group improved more than did the females in the control group. For the males, however, the control group improved more than the treatment group. The means and post hoc comparisons for this interaction are contained in Table 12.
Hypothesis III
Hypothesis IIIa predicted a significant increase in test scores with increases in age. There were no significant effects for age (Tables 8, 10, 13). The highest mean score on the mastery test was 12, for the 13 year old subjects. Twelve year old subjects scored the highest on both Card Rotations and the geometry test; 47.9 and 24.3 respectively.

Hypothesis IIIb predicted increasing improvement with age, a treatment by age interaction. There were no treatment by age interactions (Tables 8, 10, 13).

Hypothesis IV
Hypothesis IVa predicted an increase in test scores with grade. The mastery test increases with grade: 8.7, 10.2, 11.8, for sixth, seventh, and eighth grades respectively, but these differences are not significant. The geometry test also increases with grade: 22.3, 23.4, and 23.7 for sixth, seventh, and eighth grades, but this too is not significant. On the Card Rotations test, the seventh grade outscored both the sixth and eighth grades. Hypothesis IVb predicted increasing improvement with grade, treatment by grade interactions. There are no treatment by grade interactions (Tables 9, 11, 14).
Hypothesis V

This hypothesis predicted that the applied mathematics standardized test score would be the best predictor of scores on the programming mastery test. This test was not even significant in the regression analysis. The best predictor, with a multiple R of .41, was the non-language test (Table 15).

Table 16 displays significant correlations involving standardized test scores and the mastery, geometry, and card rotations tests. Non-language standardized test score does reflect the highest correlation (of the standardized test subtests). The highest correlation with mastery, considering all tests, is the geometry post-test. This indicates that similar skills may be required for both tests, and that some transfer of training could be expected.
Figure 3. Geometry test pretest scores for males.

Figure 4. Geometry test post-test scores for males.
Figure 5. Geometry test pretest scores for females.

Figure 6. Geometry test post-test scores for females.
Figure 7. Geometry test difference scores for males.

Figure 8. Geometry test difference scores for females.
### Table 4

**Geometry Pretest - Age x Sex x Treatment ANOVA**

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Table 5
Geometry Pretest - Sex x Grade x Treatment ANOVA

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Table 6
Card Rotations Pretest - Age x Sex x Treatment ANOVA

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Table 7  

Card Rotations Pretest - Sex x Grade x Treatment ANOVA

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Table 8
Mastery Test - Pre/Post-test Difference Scores in Age x Sex x Treatment (TX) ANOVA

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<td>F</td>
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<td>0.753</td>
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<td>6.868</td>
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<td>0.697</td>
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<td>3917.930</td>
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<td>41.680</td>
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Table 10

Geometry Test - Pre/Post-test Difference Scores in Age x Sex x Treatment ANOVA

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<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
<th>DF</th>
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<th>F</th>
<th>SIGNIF OF F</th>
</tr>
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<tbody>
<tr>
<td>MAIN EFFECTS</td>
<td>75.686</td>
<td>6</td>
<td>12.614</td>
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<tr>
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<td>3.192</td>
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<td>0.673</td>
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<td>9</td>
<td>30.622</td>
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<tr>
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<td>39.757</td>
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<td>0.073</td>
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<td>64.285</td>
<td>3.619</td>
<td>0.061</td>
</tr>
<tr>
<td>3-WAY INTERACTIONS</td>
<td>70.329</td>
<td>4</td>
<td>17.582</td>
<td>0.990</td>
<td>0.418</td>
</tr>
<tr>
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<td>70.329</td>
<td>4</td>
<td>17.582</td>
<td>0.990</td>
<td>0.418</td>
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<tr>
<td>EXPLAINED</td>
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<td>19</td>
<td>22.190</td>
<td>1.249</td>
<td>0.244</td>
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<tr>
<td>RESIDUAL</td>
<td>1332.211</td>
<td>75</td>
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<td>94</td>
<td>18.658</td>
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Table 11
Geometry Test - Pre/Post-test Difference Scores in Grade x Sex x Treatment (TX) ANOVA

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F</th>
<th>Signif of F</th>
</tr>
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<td></td>
</tr>
<tr>
<td>Sex</td>
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<td>0.894</td>
<td>0.059</td>
<td>0.809</td>
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<tr>
<td>Grade</td>
<td>20.179</td>
<td>2</td>
<td>10.089</td>
<td>0.662</td>
<td>0.519</td>
</tr>
<tr>
<td>TX</td>
<td>12.430</td>
<td>1</td>
<td>12.430</td>
<td>0.815</td>
<td>0.369</td>
</tr>
<tr>
<td>2-Way Interactions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex Grade</td>
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<td>2</td>
<td>0.028</td>
<td>0.002</td>
<td>0.998</td>
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<td>1</td>
<td>63.957</td>
<td>4.193</td>
<td>0.044</td>
</tr>
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<td>2</td>
<td>31.701</td>
<td>2.079</td>
<td>0.132</td>
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<tr>
<td>3-Way Interactions</td>
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<td>Sex Grade TX</td>
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<td>1.276</td>
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<td>15.252</td>
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<td>15.036</td>
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Table 12

Difference Score Means for the Four Groups Involved in the Significant Sex x Treatment Interaction (Table 11)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean Difference</th>
<th>Post - pretat</th>
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<tbody>
<tr>
<td>Male Control</td>
<td>19</td>
<td>2.000</td>
</tr>
<tr>
<td>Male Treatment</td>
<td>24</td>
<td>1.375</td>
</tr>
<tr>
<td>Female Control</td>
<td>24</td>
<td>.208</td>
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<tr>
<td>Female Treatment</td>
<td>28</td>
<td>2.178</td>
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</table>

Post Hoc Comparisons

Least Significant Difference Test (Steel and Torrie, 1980, p. 173-175).

\[
ld_t = t_{.05} \sqrt{\frac{\text{Error Mean Square} (1/N_1 + 1/N_2)}{\text{df}}}
\]

From Table 11 - Residual Source

df = 83
Mean Square = 15.252
t statistic required for significance at .05 level with 83 df = 1.293

Comparison Groups, difference scores

Male Control - Male Treatment = .625
\[
ld_{.05} = 1.293 \sqrt{15.252 (1/19 + 1/24)}
\]
= 1.556 needed for .05 significance - N.S.

Female Treatment - Female Control = 1.970
\[
ld_{.05} = 1.293 \sqrt{15.252 (1/24 + 1/29)}
\]
= 1.410 needed for .05 significance - *
Table 13
Card Rotations Test - Pre/Post-test Difference Scores in Age x Sex x Treatment ANOVA

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
<th>DF</th>
<th>MEAN SQUARE</th>
<th>F</th>
<th>SIGNIF OF F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN EFFECTS</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>AGE</td>
<td>590.108</td>
<td>6</td>
<td>98.351</td>
<td>0.396</td>
<td>0.879</td>
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<tr>
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<td>476.393</td>
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<td>119.098</td>
<td>0.480</td>
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<tr>
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<td>41.791</td>
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<td>1063.003</td>
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<td>114.998</td>
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<tr>
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<td>98.059</td>
<td>0.395</td>
<td>0.811</td>
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Table 14

Card Rotations Test – Pre/Post-test Difference Scores in Grade x Sex x Treatment ANOVA

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<th>SUM OF SQUARES</th>
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<th>SIGNIF OF F</th>
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<td>.37584</td>
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<td>174.74463</td>
<td>.832</td>
<td>.43867</td>
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Table 15

Stepwise Multiple Regression Analysis Using Standardized Test Scores to Predict Mastery Test Scores

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<th>VARIABLE</th>
<th>MULTIPLE R</th>
<th>R SQUARE</th>
<th>RSQ CHANGE</th>
<th>SIMPLE R</th>
<th>B</th>
<th>BETA</th>
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<td>0.17065</td>
<td>0.41310</td>
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<tr>
<td>CCT</td>
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<td>0.20871</td>
<td>0.03806</td>
<td>0.33000</td>
<td>0.2023044</td>
<td>0.34508</td>
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<tr>
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<td>0.03573</td>
<td>0.04527</td>
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<td>-0.25828</td>
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<tr>
<td>COM</td>
<td>0.49638</td>
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<td>0.24693</td>
<td>0.00054</td>
<td>0.20749</td>
<td>0.25790770-01</td>
<td>0.03841</td>
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<tr>
<td>(CONSTANT)</td>
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<td></td>
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<td>-1.132770</td>
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NLG = non-language
CCT = math concepts
CPU = math computation
LG = language
COM = reading comprehension
Table 16

**Significant Correlations Involving Standardized Tests, Geometry Test, Card Rotations, and Mastery Test for Treatment Group Subjects**

<table>
<thead>
<tr>
<th>Correlations with Mastery Test</th>
<th>Correlation</th>
<th>Significance level</th>
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<td>Non-language</td>
<td>.41</td>
<td>.003</td>
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<td>Total (language &amp; non-language</td>
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<td>.02</td>
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<td>Math concepts</td>
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<td>.02</td>
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<tr>
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<td>.008</td>
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<td>Card Rotations post-test</td>
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<td>.08 NS</td>
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<td>.009</td>
</tr>
<tr>
<td>Geometry post-test</td>
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<td>.001</td>
</tr>
<tr>
<td>Math Applications</td>
<td>.21</td>
<td>.10 NS</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlations with Card Rotations pretest</th>
<th>Correlation</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry pretest</td>
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<td>.001</td>
</tr>
<tr>
<td>Geometry post-test</td>
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<td>.02</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlations with Card Rotations post-test</th>
<th>Correlation</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry pretest</td>
<td>.47</td>
<td>.000</td>
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<tr>
<td>Geometry post-test</td>
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<td>.05</td>
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</table>
Table 17
Geometry Test - Pre/Post-test Difference Scores in an Age x Sex x Treatment ANOVA
with 11 and 15 Year Old Subjects Only

<table>
<thead>
<tr>
<th>SOURCE OF VARIATION</th>
<th>SUM OF SQUARES</th>
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<th>F</th>
<th>SIGNIF OF F</th>
</tr>
</thead>
<tbody>
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<td>MAIN EFFECTS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>AGE</td>
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CHAPTER V
DISCUSSION

A major strength of the present study is its ecological relevance. The research was conducted under circumstances that ideally fostered "... a convergence of both the naturalistic and the experimental approaches ..." (Bronfenbrenner, 1977 p.514). The setting was a naturally occurring situation in which a large number of computer naive subjects of various ages were located in a school that had just installed a computer laboratory. There were no regular computer classes being taught at the time, and the school administration was eager to get the computers into immediate use. The laboratory was too small to accommodate an entire class at once, so almost any use of the computers would require the division of classes.

There were only three mild experimental interventions. Pre and post-testing was conducted, using pencil and paper school-type tests. The subjects were trained in graphics programming, using instructional materials similar to those that might have eventually been
selected for use by the teachers. The classes were randomly divided into treatment and control groups, as opposed to the teachers' selection of students to go to the laboratory. The students also had an unfamiliar teacher for the computer classes. In many schools, however, a different teacher is hired to run computer programming classes, so this was not a departure from what might normally occur.

It is widely recognized that research with ecological relevance is often difficult to conduct (Gibbs, 1979; Bronfenbrenner, 1977). That being the case, this study was run under unusually fortunate circumstances. It seems clear, however, that almost anytime a new teaching technique or technology is introduced into the classroom a "natural experiment" is provided.

Hypothesis I predicted transfer of training to the mastery test, the geometry test, and to the test of spatial orientation. It also predicted that the amount of transfer would be ranked in the order just listed. The ANOVA's for the mastery test, as expected, showed a large treatment effect (Tables 8 and 9). For the geometry test, there was a treatment effect for females (Table 11), and for Card Rotations, there were no treatment effects (Tables 13 & 14). The prediction of
the differential amount of transfer was thus confirmed. The correlations between the mastery test and the geometry test, and between the mastery test and the Card Rotations test (Table 16) indicate that the skills required for the geometry test may be more closely related to computer programming skills than are spatial orientation abilities.

The lack of transfer to Card Rotations and the low correlation between this test and the mastery test support Pea and Kurland's (1984) suggestion that transfer from computer programming to broad cognitive abilities is unlikely. More success with transfer is to be expected when using tests that measure abilities closely related to programming skills. The Card Rotations test of spatial orientation was included partly because the past research on generalization of computer programming training was limited and not yet convincing. The present study, however, adds further evidence to the likelihood that no remarkable wide ranging transfer of training will result from subjects' learning to program computers.

The main treatment effect of interest in this study is the treatment by sex interaction reported in Table 11 and graphed in Figures 3–8. The difference between treatment and control group
improvement is only significant for the females. This is an overall improvement of 2.2 points on a test with a mean for all subjects of 23.3 and a standard deviation of 4.6. The highest possible score on this test is 38. Though significant, this is a small effect. Sex by treatment ANOVA's were run on all 17 items to determine if this improvement for females was generalized or only reflected improvement on specific items. The results indicated that the advantage for females was not restricted to any particular set of items.

This treatment by sex interaction is very similar to the results reported by Gagnon (1984). That study involved transfer from videogames to spatial visualization. Recall that here too there was a pretest/post-test improvement for females, and no improvement for males. These two studies considered together may indicate some special relation between females and computer graphics that cannot be accounted for by reference to standard sex differences in spatial abilities.

There are several possible explanations for this treatment by sex interaction. The first relates to a distinction between spatial abilities and training in spatial abilities. Studies involving assessment of
spatial abilities following puberty consistently report an advantage for males. Research concerning instruction in spatial abilities, however, is not quite as definitive. Most of the studies find no sex differences in improvement following training. There are only a small number of studies in which greater improvement for males is reported (McGee, 1979 review; Smith and Litman, 1979).

Another possible reason for the inaccurate hypothesis concerns the pubertal status of the subjects. Reviews of sex differences in spatial abilities usually indicate that the greater advantage for males occurs after puberty (Nyborg, 1983). In the present study, 86% of the subjects were aged 12 to 14, right at puberty. If hormones are an important factor in elevated spatial abilities in males, then predictions based on hormones would be less accurate in situations like the present study where there is an uncertain mixture of pre and post-pubertal hormonal levels for both sexes.

Careful reflection on the behavior of the subjects' during training and testing suggests, however, that the most plausible explanation of the sex difference in treatment effect rests on various social and motivational factors. Although difficult to unravel, situational and "intrapersonal" contexts must be considered whenever educational measurements are taken to evaluate learning and transfer (Messick, 1984).
The interpersonal behaviors of the males in the subject pool suggest that there was an interaction occurring between the peer group and the instructional setting.

The pretest and post-test graphs for males clearly demonstrate that, while the treatment group improved only slightly, the control group males improved significantly. (This was not the case for females.) What would cause the male control group to perform so much better on the post-test? Informal observations indicated that the males in this school were very competitive, and that most of them really wanted to be chosen to go down to the computer laboratory. I occasionally noticed males in the treatment group bragging to control group males about their programming successes. It is my hypothesis that, at the time of post-testing, many of the control group males believed that their future access to the computers depended on their performance on the tests. As a result, they were very motivated. The female control group, on the other hand, did not seem very interested in taking the computer class, and their pre and post-test scores are similar.

The other major factor contributing to the lack of a significant improvement for males was the behavior
of the treatment group. The same competition that inspired the control group worked to distract the treatment group males from their programming tasks. Many of these subjects were easily excited and easily frustrated. There were occasional discipline problems, and several males often seemed more interested in the activities of other students than in their own programming. As a result, the males spent considerably less time on task than did the females. It is believed that this combination of an unusually motivated control group and a distracted treatment group caused the scores of the males in the treatment group to be generally lower than expected, and the control group scores to be higher than expected, thus eliminating a significant treatment effect for males.

Hypothesis III predicted an increase in test scores, and an increase in improvement with age. There were no significant results for hypothesis III. This may be because the age range in the present study is fairly limited, and age is confounded with grade. As a result, there are subjects of the same age with different amounts of educational experience, and subjects of different ages with the same amount of educational experience.
There is one analysis, however, that is somewhat surprising and is related to age. Table 17 is an age x sex x treatment ANOVA of scores on the geometry test for 11 and 15 year old subjects only, (the extreme groups). Cronbach and Snow (1977) recommend using extreme groups in such a case, "Measuring an aptitude, dropping cases from the middle of the distribution, and randomly dividing cases in each of the tails to form treatment groups produces a comparatively powerful design." (p. 59) In this analysis, there is a significant main effect for treatment, $p < .01$. This analysis must be considered exploratory, and the effect interpreted cautiously, however, because there are only 13 subjects included.

If it can be assumed that this result may be meaningful, there are probably two different processes at work here. The 11 year old subjects could have benefited from the training because they may be more intelligent than their 12 year old classmates. They have managed to keep up with older children and not be retained in a grade. The 15 year old subjects, although, they may have been held back a grade, probably benefit by being older.
Hypothesis IV predicted test score increases with grade and increases in improvement with grade. Although there was a hint of score increases by grade on the mastery and geometry tests, there were no significant results for hypothesis IV.

It is important to keep in mind that the mastery test, geometry test, and spatial orientation test were all assessing abilities that had not been formally taught to the subjects. The mathematics teachers all indicated that they had not covered any of the concepts reflected in the test items. Therefore, even though it might be expected that subjects in higher grades would have better general learning and analysis skills, in this case, an increase in grade level does not imply increased exposure to the relevant geometric concepts.

Hypothesis V predicted that the applied mathematics scale of the California Test of Basic Skills would be the best predictor of scores on the mastery test. This was not the case. The best predictor was the non-language scale. This scale was also the best predictor in regression analyses for the geometry level test and for the Card Rotations test.

Superficially, this may not seem like an unusual result. Non-language scales, however, are generally categorized with general intelligence and aptitude
tests (Cronbach, 1984). Measures of intelligence and aptitude do not normally correlate as well with tests of specific abilities as do applied tests in areas related to the specific ability. It may be that graphics programming, spatial orientation, and van Hiele levels of geometric thought are all related more to general intelligence than to specifically trained abilities.

In retrospect, it is felt that the original design of this study should have included more consideration of the intrapersonal and situational contexts that probably explain the most notable result, the sex by treatment interaction. It would have been beneficial if some of these factors could have been measured and separated out from the variance due to treatment effects. In conducting a similar study in the future, it may be advisable to obtain eg. ratings from teachers of discipline problems with individual students. A questionnaire about the subjects' attitudes toward computers might also be given. This might include a measure of frustration level following a programming course, a measure of motivation during the class, or some items concerning perceived peer pressure to perform.
Such data could then be analyzed using an analysis of covariance. The importance of the various contextual factors could then be more closely examined.

This kind of analysis of covariance technique is compatible with an ecological approach to research. Situational variables, such as peer pressure, are taken into account, and there is minimal disruption induced by the researcher.

It is common that research in the field, in this case in the schools, often produces data that is the result of many subtle influences, and main effects are frequently difficult to obtain. The results of the present study seem to support Bronfenbrenner's (1977) related comment - "To corrupt, only slightly, the terminology of experimental design: 'In ecological research, the principal main effects are likely to be interactions". (p. 518)
FOOTNOTES


2. Exact correlations and ANOVA statistics were not available. For more information see reference for D. Gagnon.

3. Anticipated ages of subjects to be used in the present study are 11 to 15 years.
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Appendix A

Sample Items from Burger (1981)
Activity 2: Identifying and Defining Triangles

Part A.
Purpose: To determine whether the student can identify certain triangles.

Script: Put a T on each triangle on this sheet.

Part B.
Purpose: To determine the properties that the student focuses on when identifying triangles.

Script: 1. Why did you put a T on ? (Pick out at least 3/4 of those marked.) Be sure to include all "unusual" responses.
2. Are there any triangles in ? If so, "how many do you see?"
3. Are there any triangles in ? If so, "how many do you see?"
4. Pick out at least 4 (if possible) not marked as triangles. Ask, Why did you not put a T on ? (for each one)

Part C.
Purpose: To elicit properties the student perceives as necessary for a figure to be a triangle.

Script: What would you tell someone to look for to pick out all the triangles on a sheet of figures?

Part D.
Purpose: To elicit properties the student perceives as necessary and sufficient for a figure to be a triangle.

Script: What is the shortest list of things you could tell someone to look for to pick out all the triangle in a sheet of figures?
Activity 3: Sorting Triangles

Part A.
Purpose: To determine what properties the student focuses on when comparing triangles.

Script: (Place cutouts on the table.)
1. Put some of these together that are alike in some way. (Record the grouping.)
   How are they alike?
2. (Put the cutouts back together.) Can you put some together that are alike in another way? (Record the grouping.)
   How are they alike?
3. (Repeat as long as sortings appear useful. Remind students, if necessary, that they can reuse figures.)

Part B.
Purpose: To determine the student's ability to distinguish common properties of preselected triangles.

Script:
1. (Interviewer selects a set of triangles that have some common property: all isosceles, all right triangles, all obtuse, etc.). All of these shapes are alike in some way. How are they alike?
   (The student may find a property that the shapes share, but which does not distinguish them from the others. If this happens, praise can be given, and the student can be told, "There is another way -- can you find it?"
2. Repeat part 1 with a different sorting rule. (Make sure at least one of the sortings contains more than two shapes.)
3. Include at least one sorting using a group that the student had formed in part A.
Appendix B

Pretests and Post-tests
Test Instructions

Subjects were asked to examine the first practice item in the Card Rotations test. A cardboard cut-out of the first shape was placed against the blackboard and rotated or flipped to match each shape to the right of the comparison shape. The class was asked to verbalize whether or not the cardboard shape, in each particular position, was a rotation or a flip. Subjects were then instructed to circle all the rotations and leave flipped shapes alone. The subjects then were asked to complete the second practice item on their own. Subjects were told that the test is timed for 3 minutes. They began and ended on a verbal signal.

Subjects were then instructed not to go back to the Card Rotations test but to "forget about it and concentrate on the next set of puzzles." The instructions for the first two items on the geometry test were reviewed, then the subjects were left to complete the geometry test at their own pace. Subjects were permitted to ask questions about items they did not understand.

When the first few subjects neared the end of the geometry test, the subjects were briefly interrupted and informed that the mastery test was to find out if
anyone knew how to program those particular BASIC graphics. Subjects were told not to worry if they could not answer any of these questions.

Total allotted testing time was 45 minutes. All subjects appeared to finish within this time.
Pretest

NAME

Age _______ Birthdate ________

Grade _______ Period ________

Boy / Girl (circle)

Today’s Date ___________________
PLEASE NOTE:

Copyrighted materials in this document have not been filmed at the request of the author. They are available for consultation, however, in the author's university library.

These consist of pages:

Appendix B, pages 112-136 (Pre-tests and Post-tests)
Appendix C

Instructional Materials
You probably wouldn't be very excited, or even want to spend the time, if you were asked to print a list of names 100 times. A computer can do simple jobs like this lots and lots of times, and can do them very fast!

Using FOR...NEXT statements in a program can make the computer do all kinds of work for you. The words FOR and NEXT are always a pair. Some people call this a FOR-NEXT loop. The computer does a job or performs an action over and over again -- it keeps looping back to find out what to do, and does the job again until a counter lets it know it has finished doing the job the correct number of times.
Let's tell the computer to do the job of printing your name 12 times. Type what is in the box into the computer. Press the RETURN key when you finish typing each line.

```
10 FOR X = 1 TO 12
20 PRINT * " Type your name in the space."
20 PRINT " Don't forget the quotation marks!
30 NEXT X
```

^ RUN

Type what is in the box into the computer. Remember to press the RETURN key when you finish typing a line.

```
NEW
10 FOR N = 1 TO 20
20 PRINT N
30 NEXT N
```

RUN
Type what is in the box into the computer.

```
NEW
10 FOR N = 1 TO 20
20 PRINT N
30 NEXT N
RUN
```

Change line 110 by typing:

```
10 FOR N = 1 TO 30
```

What happened? ____________________________

Try changing line 110 again. You fill in the second number. Run the program each time you change the line to see what happens.

```
10 FOR N = 1 TO ___
```

```
10 FOR N = 1 TO ___
```

Which one printed the most numbers? ______________
Type what is in the box into the computer.
In line 20 put your name inside the quotation marks.

```
NEW
10 FOR K = 1 TO 5
20 PRINT "
30 NEXT K
RUN
```

What happened?

Make the program print your name 20 times.
What did you change?

6

Type what is in the box into the computer.

```
NEW
10 FOR S = 1 TO 20
20 PRINT S; "*****"
30 PRINT "STARS"
40 NEXT S
RUN
```

What does the S in line 20 do?
How can you make it print more stars in each row?

Try it!
Type what is in the box into the computer.

```
NEW
10 FOR Z = 1 TO 15
20 PRINT Z,Z+Z
30 NEXT Z
RUN
```

What is happening in this program? ______________

Retype line #20.

```
20 PRINT Z,Z*Z
```

How did "*" change the program? ______________

Try writing a program that gives the following output:

```
0*0 = 0
1*1 = 1
2*2 = 4
3*3 = 9
4*4 = 16
5*5 = 25
6*6 = 36
7*7 = 49
8*8 = 64
9*9 = 81
10*10 = 100
11*11 = 121
```

RUN
Graphics are things like lines, colors, shapes, and pictures.

You can program the computer to produce graphics on the TV screen or monitor.
To set the computer know you want to work in the graphics mode, you need to type GR into the computer. (GR stands for graphics.)

In the graphics mode, only the bottom 4 lines of the screen can be used to show text (letters or numbers), and the rest of the screen will be used to show graphics.

Little dots or squares of light are used to make graphics on the screen. You have to tell the computer which squares you want to light up, and what color you want them to be.

Before you tell the computer which squares to light, you need to choose a color. You have 16 colors to choose from and each has its own color number.
When you are choosing colors, keep in mind that the background color is usually black. And, if you don't tell the computer your color choice, the computer chooses for you -- it always chooses color number 0 -- black! Will a black line or square show up on a black background?

COLOR CODES

Here are the colors you have to choose from and their color numbers:

0 black
1 magenta
2 dark blue
3 purple
4 dark green
5 grey
6 medium blue
7 light blue
8 brown
9 orange
10 grey
11 pink
12 green
13 yellow
14 aqua
15 white
To tell the computer your color choice, you simply type:

```
COLOR = <----- type the color number
```

What color have I chosen if I typed this into the computer?

```
COLOR = 12
```

How would you tell the computer you have chosen orange?

```

```

The graphics screen is divided into a lot of little squares -- 40 across and 40 down.

You have to give the exact location when telling the computer which square to light up -- how many squares over and how many squares down.

To light up a square, you type PLOT and the location of the square.

```
PLOT 10,5
```

This tells the computer to light up the square that is 10 squares over, 5 squares down.
Try this graphics program:

```
NEW
10 GR
20 COLOR = 14
30 PLOT 0,9
40 PLOT 1,9
50 PLOT 2,9
60 PLOT 3,9
70 PLOT 4,9
80 PLOT 5,9
90 PLOT 6,9
100 PLOT 7,9
RUN
```
LIST your program.

Oops! You can see only the bottom 4 lines (that happens in graphics model).

Type the word TEXT. This tells the computer to show letters and numbers on the screen instead of pictures, and will allow you to look at your program. (Hint: Remember, HOME clears garbage off the screen.)

Now, try LIST. Let's do a little more with this program.

Add some more PLOT statements to make the colored line longer. Try changing the color of the line. Add some more PLOT statements to make another line on the screen.

It sure takes a lot of PLOT statements to make one line across the screen or down the screen.

How many PLOT statements do you think it would take to light up every single little square on the screen? TOO MANY!

Yes — to your rescue — there is an easier way.
VLIN (stands for vertical line) tells the computer to light up squares down the screen, or vertically. You tell it where to start and where to stop.

VLIN 0,12 AT 2

This statement tells the computer to light up the squares down the screen, beginning at 0 and ending at 12; "AT 2" squares across the screen.

The line marked here starts at 0 and stops at 12; AT 2 squares across the screen.

This is the line the computer would light up if you told it VLIN 0,12 AT 2.

Mark the vertical lines that the computer would light up for:

VLIN 5,15 AT 6
VLIN 12,39 AT 38
VLIN 2,20 AT 10
VLIN 0,39 AT 20
Here's the start of a program using VLIN. You add more VLIN statements. Just experiment -- try to make appear on the screen lines that are different lengths and at different locations:

```
NEW
10 GD
20 COLOR = 1
30 VLIN 0,20 AT 5
40 VLIN 8,39 AT 7
50
60
70
80
90
RUN
```

Not only can you easily make vertical lines -- horizontal lines can be done almost the same way. HLIN (stands for horizontal line) tells the computer to light up squares across the screen. You tell it where to start and where to stop.

```
HLIN 0,10 AT 5
```

This statement tells the computer to light up the squares across the screen, starting at 0, stopping at 10, AT 5 squares down from the top of the screen.
The next two programs are graphics programs for you to experiment with.

```
NEW
10 GR
20 COLOR = 9
30 HLIN 0,39 AT 0
40 VLIN 0,39 AT 0
50 HLIN 0,39 AT 39
60 VLIN 0,39 AT 39
70 GOTO 10
RUN
```

```
NEW
10 PRINT "I CAN COLOR THE SCREEN 16 DIFFERENT COLORS"
20 PRINT "TYPE A NUMBER BETWEEN 0 AND 15"
30 INPUT A
40 GR
50 COLOR = A
60 FOR X = 0 TO 39
70 HLIN 0,39 AT X
80 NEXT X
90 GOTO 10
RUN
```
Here are some ideas that you might want to try writing a graphics program for:

- Make your name appear in colors -- yes, in graphics!
- Create an original design.
- Create a symmetrical pattern.
- Get some blinking colors going on the screen -- anywhere you want them!
- Make a perfect square, or a triangle, or even a circle -- in color!