UNDERSTANDING PRESCHOOLERS' PROBLEM SOLVING

IN LOGO MICROWORLDS THROUGH CRITICAL

ANALYSIS OF AUDIT TRAILS

by

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Audit trails are the captured and stored responses a learner initiates as he/she travels through a interactive learning environment. This research, through audit trail analysis, examined the decision points along the paths that individual children or groups of children from a uniquely understudied, minority preschool aged, at risk population chose as they problem solved in the interactive context of Logo.

Quantitative analysis examined the impact of the cognitive stylistic tempos of reflectivity vs. impulsivity. The mean decision making quotients (DMQs) of the reflective subjects were significantly higher than the DMQs of the impulsive subjects. The impulsive subjects were also found to have significantly higher percentages of attempted forward motion moves that resulted in prohibition of forward movement caused by internal barriers and/or the confines of the microworlds. Individual differences of selected subjects were examined qualitatively using case study formats. Unique strategies and preferences of movement throughout the microworlds were discussed.

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CHAPTER I

BACKGROUND

Computers have entered the classroom domain at all levels of the educational process. Children now have opportunities to use technology at very young ages and in a variety of ways, including practicing existing skills, exploring new concepts, and challenging their cognitive abilities through a wide variety of open-ended, decision-making, and problem-solving experiences. How children weave their paths through non-linear interactive media is a heightened area of interest within the research community.

Children may be working within the same program, achieve comparable goals, yet each have a unique experience because of the level of control an interactive instructional designer turns over to the learner. In traditional, linear instruction, whether it is media-based or not, all learners are exposed to relatively identical events because the available path through the program is fixed. The producers of such media-based instruction predetermine not only what moves can be made, but also when they can be made; therefore, learners share a common learning experience. In interactive media, each decision made by a learner has a direct impact on subsequent moves and/or decisions which are made. Therefore, individual decisions result in unique pathways through the material until some objective is met or the learner exits the program.

New technologies make it possible to capture and store all of the responses a learner initiates as he/she travels through an interactive or hypermediated learning environment. These stored data are known as audit trails and have varied application possibilities within the research domain of interactive and/or hypermediated instruction (Misanchuk & Schwier, 1991; Schwier & Misanchuk, 1990).

This research, through audit trail analysis, examined the decision points along the paths that individual children or groups of children from a uniquely understudied, minority, preschool aged, at-risk population choose as they problem solve in the interactive context of Logo. Two distinctly different problem solving contexts were created within the Logo environment. The first context, the convergent problem solving set, consisted of sixteen problems where the goal was to move the cursor (known to Logo users as the turtle) through the most direct (shortest) route from its starting point to the target. The second context, the divergent problem solving set, consisted of sixteen problems where the goal was to chart as many different paths as possible in a specified time limit.

Independent variables of interest were the children's cognitive stylistic tempos (impulsivity and reflectivity). Dependent variables were as follows: 1) the calculated decision making quotients achieved in the solution paths of the convergent problem solving set, 2) the calculated path variability quotients achieved in the solution paths of the divergent problem solving set, 3) the percentage of directional moves characterized as indecision points (where the directional heading of the cursor is changed two or more times from its existing heading before movement is initiated) in the convergent and divergent problem solving sets, and 4) the percentage of attempted forward motion moves that resulted in prohibition of forward movement caused by barriers and/or the confines of the microworlds within the convergent and divergent problem solving sets.

Theoretical Framework

This research was carried out within the framework of the information processing analysis (IPA) model which is driven by how human beings acquire, store, and retrieve information. IPA is used to reveal and/or describe the sequence of "the operations and decisions necessary to accomplish a task, to outline a competent executor's thought processes" (Jonassen, Hannum, & Tessmer, 1989, p. 59).

Information processing theory views cognitive development as a gradual process which involves the acquisition and usage of specific strategies, rules, and skills that have an impact on memory, learning, and problem solving (Klahr, 1989, 1992; Siegler, 1983, 1991). Human beings are constantly bombarded by a barrage of sensory input. Explaining how such volumes of information are processed or managed is the central focus of information processing.

Analogous to a computer operating, human beings have the capability to store vast amounts of information, to access that information as it is needed, and to analyze situations according to which problem solving strategies produce appropriate and relevant solutions. Figure 1 is a flow chart of a typical information processing system.

From an information processing perspective, it is interesting to examine not only the external nature of the stimulus - response relationship, but also the flow of information within the internal cognitive processes. Developmental changes occur within each of the processes which monitor the course of the analysis and flow of information. The control processes fulfill an executive role within a functioning system and allow for retrieval of information from the knowledge base needed for problem

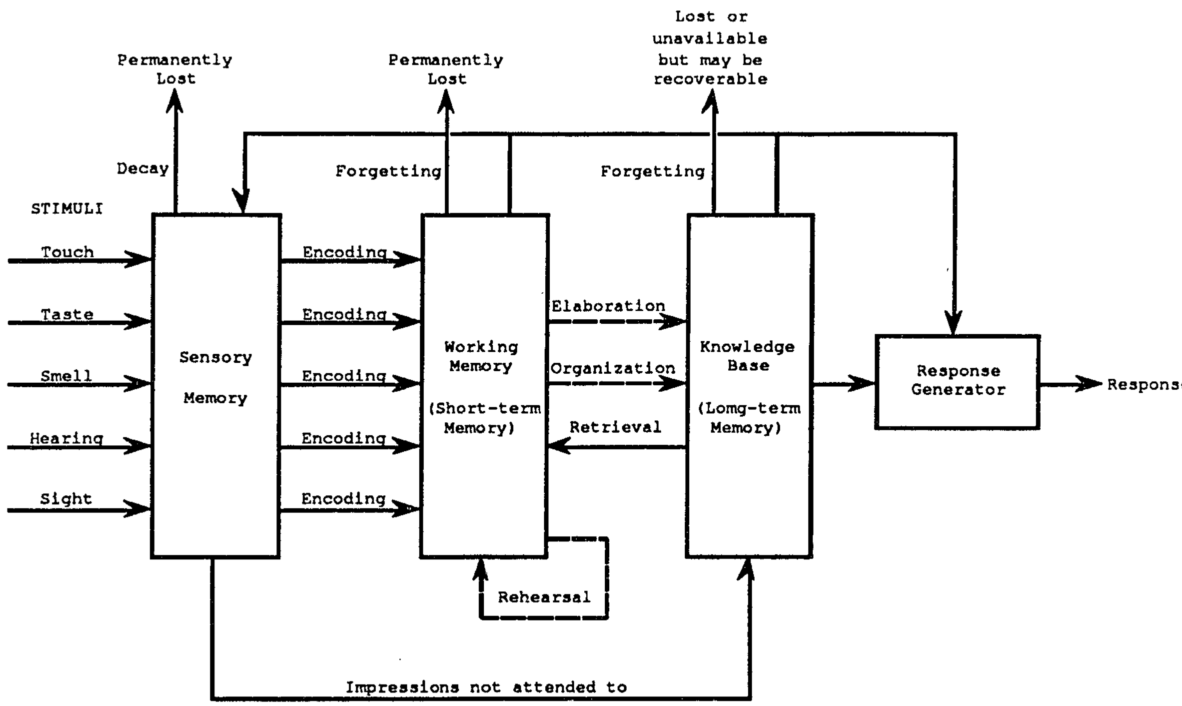

Figure 1. Information Processing Model

solving activities. These control processes are subject to noticeable changes in their levels of efficiency between preschool-age and school-age children. It is during this time that children begin to acquire some sophisticated memory and retrieval strategies, learn to employ selective attention, begin to perform automatically those mental activities that previously they were unable to perform without considerable effort, and lastly, develop and use more effective strategies for problem solving (Kuhn, 1992; Sternberg, 1988). In preschoolers these skills are generally crude and employed inconsistently, at best.

Young children also experience other developmental changes which make a contribution to age-related improvements in information processing skills (Kuhn, 1992; Flavell, 1992). Through the process of maturation, children cultivate fertile associations among their knowledge networks, which afford them the opportunities to have thoughts and ideas in one knowledge domain activate related ideas in other domains. The immature control processes of preschoolers, which allow for the attainment of information in a more piecemeal fashion, precludes these preschoolers from integrating and associating knowledge networks that enhance the depths of cognitive growth and flexibility.

Preschool-age children are also less capable than school-age children of monitoring and regulating their own thinking processes: generally they cannot yet spontaneously evaluate their performance on an intellectual task, and do not often use remedial strategies to improve their performance (Berger & Thompson, 1995).

Statement of the Problem

Working from this information processing perspective, data were analyzed at two levels, both qualitatively and quantitatively. First, a qualitative "task analysis" approach via audit trail analyses was used to determine which skills were operating as preschool-age children planned, made decisions, and tried to solve a variety of problems within different interactive Logo microworlds. Case studies were developed utilizing a microanalytic approach of the stored analytic data, with special attention being paid to the effectiveness of the decision making processes that lead to successful navigation through the microworlds, as well as to where and when errors in decision making occurred within the convergent and the divergent problem solving contexts.

The information processing model provided a framework within which the qualitative analysis proceeded. Consistent with the inductive model of thinking (see Figure 2), theory is not something to be tested, but rather it is developed and shaped through the process of the research (Creswell, 1994). It was hoped that through the information gleaned from critical analysis of the audit trails, that a "theoretical picture" of each child's thinking processes within a computer paradigm would evolve. From a basic research orientation, it wasimportant to begin to make critical inquiry into the impact of students' taking unique paths through learning environments. From an applied research orientation, questions emerged about what information could be gleaned from audit trail analyses, and how meaningful interpretations might be made from such data.

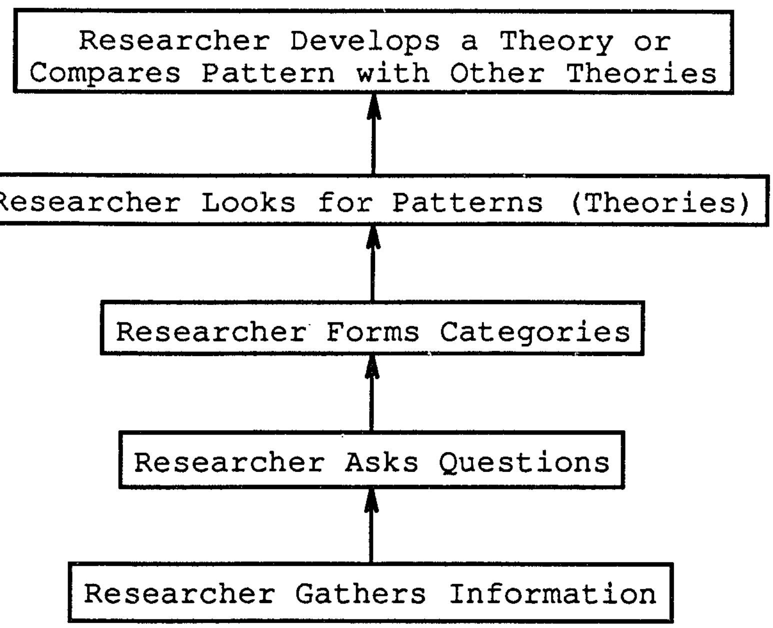

Figure 2. The Inductive Mode of Research in a Qualitative Study (Creswell, 1994, p. 96)

<u>Qualitative Questions</u>

Asking questions such as those that follow provided a starting point for the analysis. Since it was not the intent of this qualitative study to fit data into preconceived categories or to test preconceived hypotheses, the process the researcher followed and the questions that emerged during the data analysis were discussed in individual case study formats, in addition to the global interpretations of the findings.

By analyzing each decision point, can one begin to understand the logic or errors in a student's thinking? If at each decision point a child moves continually closer to his objective, can it be inferred that the preschool-age child is able to form, hold, and utilize a mental "cognitive map" of where his/her turtle needs to go? What does it tell us, if a child initially moves in the direction of the target, strays from an "on-target" direction, but then recovers at his next decision point? Would this be considered metacognitive activity -- as a young child evaluates where he needs to go, where he is at present, and what he needs to do to get back on or stay on course? How does a child's cognitive stylistic tempo impact the outcome? How does the problem solving context, whether it supports convergent or divergent thinking processes, influence the decision making processes exhibited by a preschool child as he/she problem solves in Logo microworlds?

Quantitative Questions

Quantitative analyses utilized t-tests to explore what decision making differences existed within this group of at-risk minority preschoolers. Of particular interest was how the cognitive stylistic tempos of impulsivity and reflectivity impact effective decision making within the convergent and the divergent problem solving contexts. The questions which drove the quantitative analyses were as follows:

1. Given that reflective children take the time to examine alternatives before making a decision, will they achieve

higher decision making quotients within the convergent context because the criteria for success is measured by finding the one, shortest possible path to the target? In order to achieve this goal, children must examine the microworld and avoid barriers that may interfere with any given movement.

2. Since impulsive children characteristically respond quickly, will they chart more varied routes in the time allotted in the divergent problem solving context?

3. Given that reflective children characteristically think before they act, will they have lower incidences of indecision where a directional heading is changed two or more times before movement is initiated in the convergent problem solving context?

4. Given that reflective children characteristically think before they act, will they have lower incidences of indecision where a directional heading is changed two or more times before movement is initiated in the divergent problem solving context?

5. Since impulsive children characteristically act before examining options which may be available to them in the convergent problem solving context, will they have higher incidences where continued forward movement is prohibited because of barriers within the microworld or the confines of the microworld itself?

6. Since impulsive children characteristically act before examining options which may be available to them in the divergent problem solving context, will they have higher incidences where continued forward movement is prohibited because of barriers within the microworld or the confines of the microworld itself?

Hypotheses

From these questions the following hypotheses were tested:

H_1 Children with reflective cognitive stylistic tempos will achieve significantly higher decision making quotients in the convergent problem solving set than will children with impulsive cognitive stylistic tempos.

H_2 Children with impulsive cognitive stylistic tempos will achieve significantly higher path variability quotients in the divergent problem solving set, than will children with reflective cognitive stylistic tempos.

H_3 Children with reflective cognitive stylistic tempos will have a significantly lower percentage of directional moves characterized as indecision points, where directional heading of the cursor is changed two or more times from its existing heading before movement is initiated in the convergent problem solving set.

H_4 Children with reflective cognitive stylistic tempos will have a significantly lower percentage of directional moves characterized as indecision points, where directional heading of the cursor is changed two or more times from its existing heading before movement is initiated in the divergent problem solving set.

H_5 Children with impulsive cognitive stylistic tempos will have a significantly higher percentage of attempted forward motion moves that result in prohibition of forward movement caused by barriers and/or the confines of the microworlds within the convergent problem solving set.

H_6 Children with impulsive cognitive stylistic tempos will have a significantly higher percentage of attempted forward motion moves that result in prohibition of forward movement caused by barriers and/or the confines of the microworlds within the divergent problem solving set.

Importance of the Study

A key to survival in the complex world of the 21st century will be a citizenry that has expertise in the realm of problem solving. The problems confronting the young children of today will be complex and varied, and will be solved only by those who exhibit high competence in problem solving techniques. Leaders of tomorrow will need to have a thorough understanding of cognitive problem solving approaches to confront a myriad of rapid changes in society. To be successful in a problem-oriented society, students must be flexible and utilize a variety of cognitive thinking skills.

Researchers state that children need to learn to make appropriate decisions as early as their developmental age will allow (Short, 1991). Effective problem solving comes with practice. Understanding the decision making processes that young children employ in both convergent and divergent contexts can help us to better understand how computer-based information is perceived and processed by the preschool-aged child. This line of research was important because it built on the data bases of information already in existence which explored the abilities that young children exhibit in computer-based problem solving situations. Unfortunately at-risk, minority children are vastly underrepresented in the childhood computing literature.

In 1992, a portion of the data set from which this research was based was analyzed by Allen and Watson in an attempt to answer the three fundamental questions. First, could minority preschool age children be taught to master the basic concepts needed to successfully solve on-screen Logo microworld problems? Second, would one expect to see performance differences in relation to other preschool populations that have been included in the childhood computing literature? Third, was there a "preferred learning style" as hypothesized by some Black scholars? A secondary focus of the 1992 study was to examine individual strategies as a function of the cognitive style differences of field independence and field dependence and order of training received by the subjects.

Results indicated that these children were as capable as other preschool populations at mastering the necessary concepts in order to problem solve in Logo microworlds and that no performance differences were apparent. The Hale Benson theory of a "preferred cognitive style" was not supported. No significant performance differences as a function of either cognitive style (field independence/field dependence) or order of training were supported.

Results of this research have practical applications in the field of education. By examining the audit trail data, children with ineffective general problem solving skills might be identified. Microanalysis of the audit trail can help educators of these young children plan activities that will strengthen areas in which weaknesses occur. Intervention at an early age could have positive implications as these children move into formal schooling where ability to make effective decisions in a variety of problem solving contexts is desirable.

Secondly, as the influx of information continues to grow, it is important that researchers try new and/or innovative analyses to further enhance interpretations and understanding of new and complex data sets. As the technological revolution carries us into the 21st century, we face challenges as researchers to learn to use new analytical tools and be unafraid to explore issues that, at the present time, have no answers, but only spawn new questions.

Assumptions

For this research, one must assume that each time a child stops the forward movement of the turtle and changes to another directional heading that a decision point or decision node has been reached. With this assumption, is a belief that one can characterize the thinking of a human being as an information processing system. The analysis of such a system is a belief that covert thinking and decision-making processes can be characterized, as information in the human brain is accessed and input, processed, stored, and output as some action or decision.

Limitations

The limitations of this study lie in the fact that there were no self-report data to accompany the children's movements within the microworld environments. However, given the ages of the children (between 4 years 3 months and 4 years 11 months) one could speculate that self-report data would be insufficient to illuminate the nature of the thinking processes that accompanied their choices of different directional headings and movement keys.

Definition of Terms

Audit Trail. An audit trail is described as comprising all the responses generated by a learner going through interactive or hypermediated instruction. In this study it takes the form of a string of characters (numerals and symbols) representing the choices input via the keyboard by the subjects in each problem solving activity.

Cognitive Stylistic Tempo. Cognitive stylistic tempo is defined as a characteristic way of functioning that is pervasive throughout an individual's perceptual and intellectual cognitive activities. Cognitive stylistic tempos are reflective of the cultural framework within which each individual interacts on a daily basis.

Convergent Problem Solving Context. A convergent problem solving context is one in which there is only one "correct" solution path. In this study, problems requiring convergent thinking skills asked the subject to find the shortest possible path from the turtle's starting position to the target.

Decision Making Quotient. A decision making quotient is a numerical score achieved in the convergent problem solving set by adding the score assigned at each decision point in a problem solution divided by the total number of points in that solution. The score assigned at each decision point is based on a criteria explained in Chapter III - Methods and Procedures.

Divergent Problem Solving Context. A divergent problem solving context is one in which there may be multiple "correct" solution paths. In this study, problems requiring divergent thinking asked the subject to find as many different ways to get the turtle from his starting point to the target position. Once the first path was completed the turtle instantaneously reappeared at the starting position so that another path could be charted.

Impulsivity. Impulsivity is a component of cognitive style which, in learning situations, is characterized by the tendency to respond quickly without carefully considering the various alternatives.

Indecision Point. An indecision point is characterized in an audit trail as any point at which two or more directional heading changes are made prior to the movement of the cursor.

Information Processing Analysis. Information processing analysis (IPA) is used to reveal the operations and decisions necessary to accomplish a task, to outline a competent executor's thought processes. The analysis may also be used to describe the sequence of cognitive operations accomplished to perform a task or problem.

Path Variability Quotient. A path variability quotient is a numerical score achieved in the divergent problem solving set by counting the number of unique grids passed through in completion of additional routes after the first, divided by the total number of routes charted in the time limit.

Prohibition of forward movement. Prohibition of forward movement occurs when the cursor (turtle) hits a barrier within the boundaries of the microworld and/or the confines of the microworld itself. For a more detailed description of this feature, refer to Chapter III, Methods and Procedures, NOWRAP Feature.

Reflectivity. Reflectivity is a component of cognitive style which, in learning situations, is characterized by the tendency to carefully consider various alternatives before responding.

Syntonic Learning. Syntonic learning is defined by Seymour Papert as learning which makes sense to the learner in terms of his own sense of his body and the world.

Task Analysis. Task analysis is described as a breakdown of performance into levels of specificity and/or the description of mastery performance and criteria.

Turtle. The turtle is the triangular cursor used in the Logo graphics program. It is described by Seymour Papert as an object with which to think.

CHAPTER II

REVIEW OF LITERATURE

Cutting-edge multimedia and simulation technologies of the 90's allow children to discover and explore real and/or fantasy-filled environments and to create and/or manipulate objects on the computer screen creating new and exciting foundations for learning. However, opportunities abound for young children to exercise decision-making skills in order to solve problems within the procedural programming language known as Logo, which has been in existence for the past thirty years. Logo, a tool for thinking, was developed by Seymour Papert at MIT's Artificial Intelligence Lab in the early 1960's. Because of its low threshold and high ceiling, it has been used in research with populations ranging from novice preschoolers to advanced adult programmers.

The Logo Language

Logo employs the Piagetian premise that children are the builders or "constructors" of their own knowledge as they interact with their environments. The basic structural framework of Logo is designed to facilitate the building of intricate procedures from simple ones, which is an important concept in the process of problem solving. Papert explains that in the process of breaking knowledge into "mind sized bytes" it "becomes more communicable, more assimilable, more simply constructable" (Papert, 1980, p. 171).

Papert was a student of Piaget's, and it is easy to see Piaget's influence on his conceptualization of thinking processes in young children. However, the two differ on their conceptualized timetables for cognitive development. Piaget's theory supports the premise that development unfolds as a function of nature setting up a sequence which cannot be altered by zealous parents or teachers. Piaget believed that trying to teach a child too early resulted in a child who might memorize correct answers, but would not necessarily understand underlying concepts. Papert believes that a rich computer environment (Logo) can enhance and speed up cognitive development by providing children with the materials which would make concepts simple and concrete, where "there is an intersection of cultural presence, embedded knowledge, and the possibility for personal identification" (Papert, 1980, p. 11).

While maneuvering within Logo's vast array of microworld environments, children find themselves engaged in the process of discovery learning by charting their own solution paths using a triangular cursor. This cursor is known to Logo users as the "turtle," or as Papert describes, "an object with which to think" (Papert, 1980).

Papert further states,

> ...the child, even at preschool ages is in control: the child programs the computer. As they teach the computer how to think, children embark on an exploration into how they themselves think. The experience can be heady. Thinking about thinking turns the child into an epistemology, an experience not even shared by most adults. (Krendl & Lieberman, 1988, p. 372)

Through the discovery process, children learn to control the direction and movement of the turtle. In doing so, they begin to understand cause and effect relationships. Planning their next moves and immediately seeing the results of their decisions are activities that have been reported to stimulate the thought process and also reasoning/problem solving skills (Hagen, 1984; Papert, 1980).

Turtle Graphics and Geometry

Turtle geometry was born out of Papert's desire to fit mathematics to children. First and foremost, Papert wanted it to be "appropriable," meaning that it had to have serious mathematical content while being appropriate for young learners. His premise is that "some of the most personal knowledge is also the most profoundly mathematical" (Papert, 1980, p. 54). From this line of thinking, Papert discussed the idea of syntonic learning which means that children can relate the learning process to their personal sense and knowledge about their own bodies (body syntonic); and that the learning is consistent with children's sense of themselves as individuals with intentions and goals (ego syntonic) (Papert, 1980).

The turtle was designed to be a dynamic entity that not only would have some position on the screen, but also would have some "heading," or direction. Young children can relate to and identify with the turtle being located at some point or place and facing in or pointing towards some direction, and thus bring their knowledge about their own bodies to their interactive experiences at the computer. Building on this feature, the Logo turtle has the capability to become, for the young learner, a first representative of formal knowledge and thinking.

It is within this "turtle graphics" mode that children are afforded the opportunity to make decisions, to see their decisions being carried out as the turtle moves according to their "input," and then to revise or "debug" their input in order to correct any mistakes in their preceding move. The second component feature of Logo enables preoperational children to "concretize and personalize" (Papert, 1980, p. 21) their abstract, symbolic thinking; while the third component feature allows even the youngest of users to reflect upon their previous thinking, thus building the bridge between concrete and formal understanding and facilitating metacognitive capabilities.

It is just as valuable to understand how a child arrives at a particular task performance as to know that the performance was correct or incorrect (Hunt, 1980). When young children have sufficient opportunities to view and reflect upon the correctness of or the errors in their own thinking, the primary focus of an activity becomes the process, not just the end product or the solution. One of the advantageous characteristics of Logo is how mistakes are handled. Papert believed that mistakes were a natural occurrence and should be expected. Within the Logo language errors can be easily rectified, and he believed that they could create excellent opportunities for learning (Henderson & Minner, 1991). Papert explains this concept as follows:

> . . . many children are held back in their learning because they have a model of learning in which you have either "got it" or "got it wrong." But when you learn to program a computer you almost never get it right the first time. Learning to be a master programmer is learning to become highly skilled at isolating and correcting "bugs," the parts that keep the program from working. The question to ask about the program is not whether it is right or wrong, but if it is fixable. If this way of looking at intellectual products were generalized to how the larger culture thinks about knowledge and its acquisition, we all might be less intimidated by our fears of "being wrong." (Papert, 1980, p. 23)

Logo Applications with Preschoolers

Based on Papert's philosophy, Logo becomes a means through which children can actively interact with a computer as a learning tool. As positive as this concept appears on the surface, the findings on the effectiveness of Logo have been diverse. Although research involving the preschool population is limited, studies conducted by the Children and Technology Team at the University of North Carolina at Greensboro as well as others report positive findings as to young children's success in solving problems within the Logo environment (Allen, Watson, & Howard, 1993; Brinkley & Watson, 1988; Brinkley & Watson, 1990; Brinkley & Watson, 1990/91; Clements & Gullo, 1984; Emihovich & Miller, 1986; Howard, Watson, & Allen, 1993; Papert, 1980; Pea & Kurland, 1984; Shade, Nida, Lipinski, & Watson, 1986; Watson & Brinkley, 1990/91; Watson, Lange, & Brinkley, 1991, 1992).

When special education preschoolers were given opportunities to work within the Logo environment, Lehrer, Harckman, Archer, and Pruzak (1986) reported increased general problem solving skills. Being exposed to programming opportunities has also been shown to decrease impulsivity, which is characteristic of many children diagnosed with mild cognitive delays (Maddux & Cummings, 1987).

Interest in children's spatial orientation and how that development affects performance on Logo tasks has been the focus of research for almost a decade (Brinkley & Watson, 1990; Campbell, Fein, Scholnick, Schwartz, & Frank, 1986; Easton & Watson, 1990; Fay & Mayer, 1987; Watson & Busch, 1989), however Piaget was the first to systematically study how spatial concepts develop in young children. His explanation was that the process occurred through the gradual socialization of thought from egocentrism, to socialization, to complete objectivity.

Campbell et al. (1986) described how young children navigate in the Logo environment. Kindergarten children were reported to excel in making forward moves as compared to backward or left moves, and that right turns were preferred over left turns. It was suggested in this research that children utilize a "grid" or "rectangular coordinate system" (p. 359). Some subjects, however, were able to move on a diagonal; and Campbell et al. (1986) suggested that these children did not view the computer screen as a grid pattern.

The Children and Technology Team at the University of North Carolina at Greensboro have conducted research with young children and Logo for the past decade. This line of research suggested that four and five year old children approach Logo problems using a set of strategies that include forward, right turn, and big step movements (Brinkley & Watson, 1990; Watson & Busch, 1989; Watson et al., 1990a, 1990b). The Brinkely and Watson (1990) study fornd that young children think of big steps as a more efficient way to move on-screen, as opposed to small steps, and use this method of movement more frequently in their problem solutions.

In 1987, Fay and Mayer tested Piaget's egocentric concept as children operated in a Logo environment. They described children's usage of the turtle cursor as "turtle-centric," meaning that children refer to left and right orientations in terms of the turtle's left and right and not their own. Fay and Mayer (1987) further described three changes that appeared in children's behavior as they learned to operate in a Logo environment. Children learn the syntax first, including the command keywords and their meanings. Children then begin to think semantically, which means that they have an understanding that a right turn is the turtle's right regardless of his position on the screen. Lastly, children begin to transfer skills to tasks that were not computer based. Fay and Mayer concluded that cognitive changes do occur as children operate within the Logo environment.

The proposed research focuses on examining young children's abilities to design and follow cognitive maps as a component of their problem solving activities within interactive Logo microworlds. An important facet of this endeavor is to understand the nature of the components of both the problem-solving and decision-making processes.

The Problem Solving Process

Laird and Thompson (1992) define a problem as "a question that *appears* to have an answer, a single correct answer" (p. 217). They have identified three stages that comprise the problem-solving process, which include the following:

1) formulating the problem;

2) generating a solution; and

3) checking the solution to see if it's correct (p. 217).

As a problem solver encounters each stage of the process, a variety of factors operate to influence the outcome. Before any problem can be solved, a learner must be able to define exactly what the problem is. This is an important factor because extraneous information may get in the way and distract a learner from focusing on only the pertinent facts.

The second stage in the problem-solving process is the one about which the least amount of information is known, according to Laird and Thompson, (1992), because people are not conscious of their thought processes in action. One approach to generating a solution to some problem is to use an algorithm, which is defined as a systematic procedure that produces a solution to a problem. If one follows a known algorithm step-by-step, the final result will be problem solution. If an algorithm does not work or becomes too labor intensive, a problem-solver can turn to heuristics or problem solving strategies (Laird & Thompson, 1992).

Means-end analysis is a heuristic for determining a method to reach a solution and the form that the solution should take. A learner begins this stage of the process by mentally questioning what exactly needs to be accomplished. This should be done in as concrete a form as possible. Next, the problem-solver describes the means to that end. Again, this description should be as concrete as possible. The end is the ultimate goal. The steps that one has to take to achieve the goal become sub-goals. If all of the steps are not immediately evident or clear, a learner needs to define a means to accomplish them.

One difficulty that may be encountered at this stage of the problem solving process is rigidity (Luchins, 1942), which is defined as the unwillingness to give up a problem-solving strategy that no longer works or is not as effective as a new strategy. If one strategy has proven to be successful, then there is a tendency for its user to persevere and continue its use even when it is ineffective or no longer relevant to the current situation. Rigidity interferes with creativity which is an essential element for effective problem solving (Laird & Thompson, 1992).

The final stage of the problem solving process is the testing phase. The moment a learner first recognizes that a solution to some problem is the right one and experiences the pleasurable sensation of "Aha" is known as insight. Kohler

(1927) in his research on chimpanzees described insight as an experience which links the solution-generating and solution-testing stages of problem solving.

Solutions, however, are not always correct or easily recognizable. When this is the case, then a problem-solver must test a solution to be certain that it will work. New problems can emerge during this testing phase. One of the most common is the phenomenon known as confirmation bias (Wason & Johnson-Laird, 1972). This results from an innate human weakness -- the desire to believe that we are right. Operating under this assumption can cause irregularities in the way that a problem-solver will test solutions. Generally, more attention is paid to information that may confirm hypotheses than to information that may prove them false.

The Decision Making Process

In contrast to a problem, which has some clear-cut answer, a decision does not. A decision is the choice of a course of action and may be described as "reasonable or unreasonable, better or worse, wise or foolish" (Laird & Thompson, 1992, p. 224). It is generally not defined as being clearly right or wrong, and because of this, it must be evaluated differently from a solution. In many instances, decisions can only be evaluated after some time has passed since they were made.

As mentioned previously, no discussion of problem solving and decision making would be complete without including the concept of creativity. The definition of creativity is "the ability to produce new and useful ideas or to combine information in new and useful ways" (Laird & Thompson, 1992, p. 228). The two components that are critical to the definition are 'new' and 'useful.' Creativity is dependent upon innovation, but just as important is the concept of functionality.

All of these issues are vital to an investigation of how young children will make decisions and solve problems within an interactive computer paradigm. It is also imperative that the difficulties preschool-age children encounter during problem solving, as a function of their cognitive developmental levels, be examined. If one explores cognitive development from Piaget's theoretical framework (Piaget, 1983), the preoperational child is described as having the ability to think symbolically, using mental processes that are not dependent on present experiences. Thinking symbolically is expressed in the child's ability to form mental images. This ability frees children from the here and now and allows them to think about objects when they are not actually present. More importantly, children have the ability to think about events before, during, and after their occurrence. This emerging skill allows them to integrate experiences from the past into the present and plan for the future (Krantz, 1994).

While the emergence of symbolic thought is conducive to the planning, decision making, and problem solving activities encountered in a Logo environment, other cognitive developmental characteristics present in preschool-age children serve to limit their efficiency in problem solving situations. According to Piaget, the process of centration, the tendency for young children to focus attention on minute and often inconsequential aspects of some experience lead to haphazard samplings of isolated bits of information. When preschool-age children are overwhelmed by the novelty and/or complexity of some experience, Piaget explained that their centrated perceptions merge into preconcepts which seriously limit the quality of their reasoning and problem solving abilities (Krantz, 1994). Egocentrism and irreversibility are two additional limitations that Piaget believed to be significant liabilities for young children in problem solving situations (Piaget & Inhelder, 1973).

Problem Solving Contexts

The context in which children "operate on their environments" should also be considered when assessing their skills in problem solving activities. Public schools have historically fostered convergent thinking, while they espouse to develop learners' abilities to engage in divergent thinking skills. Primary education has generally operated from the premise that one looks for the one correct solution set to a given problem or question. If one characterizes behaviors as being either "correct" or "incorrect" a binary Aristotelian world view is imposed (Steffin, 1983). Children very quickly learn to shape their problem solving processes in the direction of finding an appropriate answer in the most expedient manner possible. Steffin (1983) further believes that "this process effectively forestalls seeking either alternative routes to a response or alternative responses. In fact, alternative responses are rejected as being aversive, nonproductive contingencies for the learner" (p. 255). However, Cliatt, Shaw and Sherwood (1980) reported that very young children show dramatic increases in their use of divergent thinking skills when they have repeated exposure to divergent thinking situations.

Convergent problem solving approaches are defined as containing the following elements:

1. There is one element in the set of "correct" responses.
2. The set of "correct" responses originates from the specific subject of inquiry.
3. To attain the "correct" solution set, one must frequently employ the cognitive processes of recall and recognition memory (Steffin, 1983, pp. 255).

In contrast, divergent problem solving activities, according to Steffin (1983), include the following:

> 1. There is always more than one element in the set of "correct" responses.
>
> 2. The set of "correct" responses is a function of a set of criteria differentiating it from the set of "not correct" responses.
>
> 3. It is possible to state these criteria in clear, unambiguous operational terms so that consensus may be arrived at among multiple evaluators of the learner's response.
>
> 4. The solution set will almost always demand application skills from the learner. This involves the applying of rules to facts and concepts, rather than memory alone. (Steffin, 1983, pp. 255-256)

Opportunities to develop skills in both the convergent and divergent thinking arenas are imperative for children to meet the challenges of the 21st century. Convergent thinking skills help to provide expansive data bases of factual and conceptual knowledge that learners can bring to problem solving venues. Competence in divergent skills helps learners to utilize those data and transforms them from masses of raw materials to conglomerates of efficient and effective information that can help to meet the challenges of the future. Opportunities to work in a learning environment such as Logo, where the learner is in control, can only facilitate young users' proficiency at using divergent thinking skills. If one believes that such skills are inherent in effective problem solving then opportunities should be afforded to children at an early age "so that it becomes a natural and accepted part of children's intellectual functioning" (Cliatt, Shaw, & Sherwood, 1980).

Cognitive Stylistic Tempo

Children also bring to every learning situation their personal cognitive styles which are fostered from within the cultural framework that surrounds their day-to-day lives (Cohen, 1969). Cognitive style is known to be a influential factor in the way individuals think, understand, remember, and problem solve (Witkin, Moore, Goodenough, & Cox, 1977; Saracho, 1984, 1989). Siegel and Brodzinsky (1977) describe an individual's cognitive style as the "manner and form of cognitive performance" and a reflection of an individual's personality or preference, not as an indicator of ability or intelligence. The specific components of cognitive style that are of interest in this research are impulsivity and reflectivity.

Interest in the cognitive tempos of children, especially impulsivity, was triggered by the work of Jerome Kagan and his colleagues (Kagan, 1965, 1966; Kagan, Pearson, & Welch, 1966; Kagan, Rosman, Day, Albert, & Phillips, 1964). The extensive research that Kagan and his colleagues pursued focussed on the speed and accuracy of responses to information (Doyle & Rutherford, 1986). Kagan studied children in problem solving situations and was interested in determining whether they exhibited impulsive or reflective behavioral characteristics. He developed an assessment tool known as the Matching Familiar Figures Test to assess these behaviors. This test was a match-to-sample, individually administered test where a child was asked to find the figure that was identical to the stimulus figure. If a child responded incorrectly, he/she was asked to choose again.

Kagan obtained two measures including the average amount of time a child takes to make his/her first choice and the total number of errors made on all items. Kagan would then classify those children who scored above the median in errors and below the median in response time as impulsive. These impulsive children were the ones who responded with the first answer that occurred to them, many of which were inaccurate. The children scoring below the median in errors and above the median in response time, Kagan classified as reflective. Children classified as reflective would examine alternate hypotheses and attempt to validate their responses before answering (Kagan, 1966).

From Kagan's earlier work, in 1972 Wright developed a down-scaled version of this assessment tool which is known as the Kansas Reflection Impulsivity Scale for Preschoolers. This assessment tool follows the same format as the Matching Familiar Figures Test, except that if a child makes three incorrect responses on any one item, he/she is advanced to the next question. The KRISP does result in the same two sets of scores. Users of the KRISP are cautioned that since the stability of reflection-impulsivity at the preschool level is not as well established as it is for older populations, that using the KRISP as a predictive tool would be risky. However, it appears to be a useful tool to assist educators in identifying preschoolers who are exceptionally impulsive or reflective so that curricula may be adjusted to accommodate their needs (Kagan, 1966).

Research indicates that there is a strong tendency for the degree of reflectivity to increase with age. It is reported that after the age of eleven, when children have gained some cognitive maturity, that they perform with greater speed and accuracy (Salkind & Nelson, 1980). Also, a child's pattern of reflectivity or impulsivity can be modified in some manner through training; Salkind and Nelson (1980) report that it is feasible to teach children to become somewhat more reflective.

Audit Trail Analysis

Interactive media provide users with opportunities to chart their own courses through seas of information, thus allowing each individual to experience the material and, therefore, shape their learning experience in a unique way. One of the driving questions for instructional designers and researchers alike is "What are the effects of taking different paths through any given piece of interactive subject matter?" To explore this question, one must examine the audit trails of the users. Audit trails are described as the set of responses that a learner generates as he/she moves through interactive or hypermediated tasks (Misanchuk & Schwier, 1991). These trails can contain words, phrases, paragraphs, or any other "multiple-choice" character or numeral like responses that a user creates via the keyboard, mouse, or touch-sensitive screen.

As of this date, three unique purposes have been identified for which audit trail analysis is useful, including formative evaluation in instructional design, a tool in basic research into interactive and hypermediated instruction, and a means to audit public usage of mediated presentations (Misanchuk & Schwier, 1991). First, in formative evaluations, optimizing the performance of a product is paramount. To accomplish this, it becomes important for instructional designers to determine which paths users perceive as attractive or significant, as well as when and how errors are made.

Secondly, in research models, audit trails can help to explore such theoretical issues as cognitive styles, locus of control, and degree of learner control by tracking the performance of individuals or groups of individuals as they react to instruction differently (Higginbotham-Wheat, 1990;

Ross, Morrison, & O'Dell, 1990). In the research paradigm, both quantitative and qualitative approaches to data analysis can be considered when using audit trail analysis. If the instructional setting is linear in nature, the questions which can be explored center around "achievement/efficiency, performance, and interactions with designs and learner variables" and are quantitatively studied based on quasi-experimental designs (Misanchuk & Schwier, 1991, p. 5). When one moves into interactive/hypermedia, audit trails fit into a naturalistic observational model. Patterns of learning are not predefined, but emerge as a learner or learners move through an instructional presentation. Misanchuk and Schwier (1991) state "The learner is viewed as a part of the instructional ecosystem, simultaneously shaping and being shaped by the instruction encountered" (p. 6).

A philosophical difference which emerges when quantitative and qualitative methods are discussed centers around what can be defined as reality. In quantitative approaches, reality can be externally defined. Meanings are imposed on some context and the researcher tries to understand or uncover the reality. In qualitative inquiry, one presumes the existence of multiple realties which are born out of some context. Thus, meanings emerge from within the context (Misanchuk & Schwier, 1991).

The third usage of audit trail analysis is in monitoring the usage of hypermediated presentations being utilized by a large, heterogeneous population (for example, all visitors at an exhibit at a museum or zoo). Keeping audit trails of user pathways allows the developers to unobtrusively find out which paths are of most interest to different groups of users. Data gathered from different usage paths through interactive media can be used in formulative evaluation as well as basic research. Not only can product design be improved, but hypotheses as to why different groups of people travel specific pathways can be generated and then further explored.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Subjects in this study were sixteen minority children enrolled in the Project Uplift Child Development Center. This is a pre-kindergarten enrichment center which follows the High Scope Curriculum. Project Uplift is located adjacent to the Ray Warren Housing Community in southeast Greensboro, North Carolina and only serves those children whose families reside within Ray Warren Homes. This housing community serves low socioeconomic families and is operated by the Greensboro Housing Authority. All subjects were Black, four-year-olds (4 years/3 months - 4 years/11 months) who were considered to be developmentally and educationally "at-risk" due to economic and environmental factors. The socioeconomic status was determined by the income level and educational attainment status of each of the parents.

Of the original twenty children enrolled at the Center, three of the families moved from the housing community and one was labeled as "untestable" by the assessment team at the Developmental Evaluation Center, Greensboro, N.C. Therefore, complete data were gathered from the sixteen children remaining at the center. Ten males and six females were included in the sample population. See Table 1 for frequencies and percentages of demographic variables for all subjects.

Table 1

Frequencies and Percentages of Demographics for all Subjects

Demographic Variable	n	%
Highest Level of Custodial Parent's Education		
10th grade	1	6.25
11th grade	5	31.25
12th grade	6	37.50
1 year college	1	6.25
2 years college	2	12.50
College graduate	1	6.25
Custodial Parent's Employment Status		
Employed	8	50.00
Not Employed	8	50.00
Subject on Medicaid		
Yes	10	62.50
No	6	37.50
Custodial Parent Receives AFDC		
Yes	8	50.00
No	8	50.00
Custodial Parent Receives WIC		
Yes	6	37.50
No	10	62.50
Subject Has Sibling(s)		
Yes	12	75.00
No	4	25.00
Subject's Mother's Marital Status		
Single	10	62.50
Separated	4	25.00
Divorced	2	12.50

The principal investigator and the Project Uplift Director met with the parents of the enrolled children at a regular monthly parent meeting to explain the computer education component of the curriculum and the particulars of the proposed study. Parental consent forms were obtained at this time. Parents were advised that their children's participation in the study was strictly voluntary and would have no impact on their being involved with the regular scheduled computer education activities.

All of the subjects were pretested at the beginning of the program (September) using the Kansas Reflection Impulsivity Scale for Preschoolers (KRISP)(Wright, 1972). This is an individually administered match-to sample standardized instrument that is used to identify children who are unusually impulsive (I) or reflective (R) in their cognitive stylistic tempos (Kagan, 1966; Wright, 1972). The KRISP was initially developed as an instrument for research, but is currently used by a variety of personnel working with young children, including preschool teachers and other child care specialists without formal training in testing and measurements, as well as psychologists.

Each item of the KRISP is a match-to-sample problem requiring the child to identify from an array of similar figures the one that is an exact copy of the stimulus picture that appears above each array. There are two comparable forms of the KRISP (A & B) which allow practice on five items before the ten test items are completed. A child is allowed to advance to the next item after a third pointing error is made on any one test item. A child's total errors and the mean time to first response on the ten test items are recorded as the scores.

Interform reliability of the instrument ranged from .61 to .80 when it was used on children two years ten months to six years eight months. Test retest reliability was .581 for latencies and .746 for errors (Wright, 1972; User's Manual for the Kansas Reflection-Impulsivity Scale for Preschoolers, 1973). There is no single conclusive way of evaluating the validity of the KRISP. However, a validity indicator is the relationship between the KRISP and other variables such as a child's attention span in free play, distractibility within the preschool environment, motor impulse control, and a variety of teacher ratings (Wright, 1972; User's Manual for the Kansas Reflection-Impulsivity Scale for Preschoolers, 1973).

Children's scores on the KRISP were determined by the mean latency time to first response and the total number of errors on the ten test items. Reflective children were defined as those children who scored above the sample median in mean latency to initial response and below the sample median on total errors. Those children whose scores were below the sample median in latency time and whose error totals were above the sample median were classified as having impulsive cognitive stylistic tempos. On tasks which require more accuracy than speed, reflective children have the advantage.

Children were categorized as being Impulsive (I) or Reflective (R) by using a median split procedure. The range of scores on the KRISP for the sixteen subjects was 2.6 seconds - 9.0 seconds for mean latency to first response and 4 - 30 for total errors. Latency scores of 5.0 seconds and above and total error scores below 12 were classified as reflective. Those who scored below 5.0 seconds on mean latency scores and above 12 on total errors were classified as impulsive. This sample represented a split between the subjects of 5 (impulsive) and 6 (reflective). Of the five impulsive subjects, 4 were males and 1 was female. The reflective group was split with 4 males and 2 females. There were five children whose scores were contradictory, meaning that they had either high latency scores associated with high number of total errors or low latency scores associated with low errors. One is unable to classify these children on the basis of results of the KRISP (see Figure 3).

There is one primary disadvantage of using the median split procedure. Children's scores which fall just above or just below the median split might be classified in the

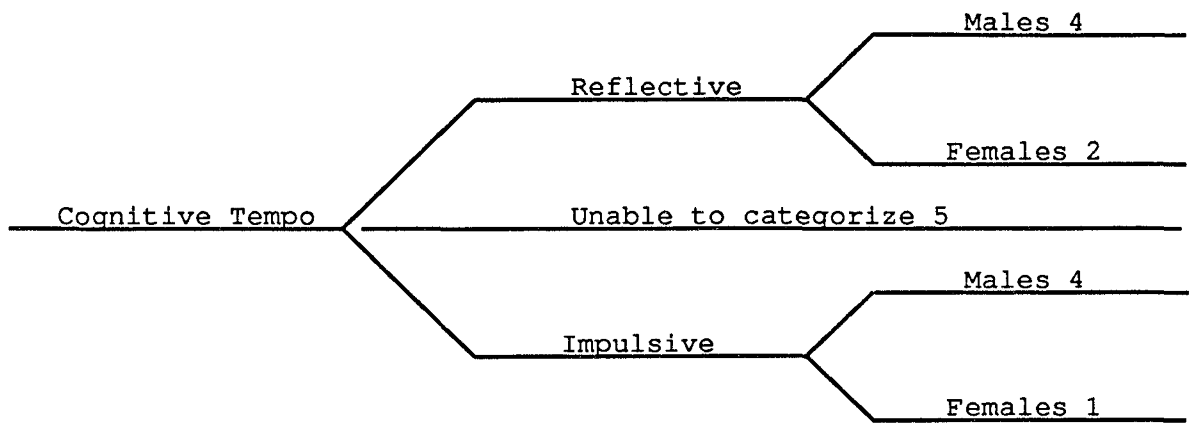

Figure 3. Breakdown of Subjects by Cognitive Stylistic Tempo and Gender Using the KRISP

alternate category if they were tested with another group of children. Since the stability of reflection and impulsivity has not been proven for preschool-age children, users of the KRISP are cautioned against using the KRISP as a predictive instrument.

It was not the intent of this study to make long-term predictions of the cognitive stylistic tempos of the children, but to identify their current level of reflectivity and impulsiveness; therefore, other measures were used to help classify those children who did not fall into Wright's (1972) classification scheme. Users of the KRISP are advised that scores can be validated by assessing the relationship between KRISP scores and other variables such as duration of attention span in free play, distractibility in the preschool environment, motor impulse control, and a variety of other teacher ratings.

In order to validate the scores for those children who could be classified as either impulsive or reflective using the KRISP and to help classify those five children who had contradictory scores, additional data were assessed using selected data from the following instruments:

1. The Kohn Social Competence Scale - Preschool (KSCS-P) (Kohn, 1971), is a classroom behavior assessment tool which is scored by a child's teacher and is designed to assess a child's mastery of a kindergarten or preschool setting. Interrater reliability (corrected) was found to range between .7 and .8. This scale has been shown to measure relatively enduring personality dispositions, such that children are stable across situations and over time (from the preschool years through early elementary years) (User's Manual for the Kohn Social Competence Scale, 1971). All statements are scored on a five point Likert scale ranging from Hardly Ever to Never (1), Seldom (2), Sometimes (3), Often (4), and Very Often or Always (5).

The following 13 statements from the 64-item instrument were chosen by a panel of experts in child development to reflect components of reflectivity and impulsivity:

3. Child easily loses interest and flits from one activity to another.

4. Child is responsible in carrying out requests and directions.

15. Child is unwilling to carry out reasonable suggestions from the teacher even when having difficulty.

19. Child can accept teacher's ideas and suggestions for play or ways of playing.

30. Child reacts negatively to teacher's ideas and suggestions for play activities.

45. Child is open to the ideas and suggestions of other children.

46. Child is responsible in following through on routines, for example: getting dressed or undressed, washing hands, etc.

51. Child can remain alert and interested in an activity.

57. Child responds well when the activity is planned and directed by the teacher.

58. Child disrupts the activities of others.

60. Child can participate actively in structured activities as well as free-play type of activities.

62. Child easily gives up when confronted with difficulty.

64. Child has trouble keeping to the rules of the game.

Once these items were selected, a Cronbach Coefficient Alpha was run using the SAS System. The resulting alpha was .92, indicating high internal consistency within these items. The range of scores on the selected items of the <u>KSCS-P</u> was 14-45 with lower scores reflecting characteristics of a reflective cognitive stylistic tempo. For those children who had been classified by the <u>KRISP</u>, their scores on the <u>KSCS-P</u> validated their placement in either the reflective or impulsive categories.

2. The <u>Classroom Behavior Inventory</u> (<u>CBI</u>) (Schaefer, Edgerton, & Aaronson, 1978) is a classroom behavior assessment tool which is scored by a child's teacher. This rating scale measures three behavior traits, including task orientation, extroversion, and hostility. From the task orientation scale five items were chosen. Interrater reliability coefficients (product-moment correlations and Spearman rank-order correlations) for the task orientation scores were .62 and .60. Internal reliability (coefficient alpha) was .72 for the task orientation scale (<u>User's Manual for the Classroom Behavior Inventory</u>, 1973). The statements are scored on a five point Likert scale ranging from Not at All Like (1), Very Little Like (2), Somewhat Like (3), Much Like (4), and Very Much Like (5). The following statements were chosen by a panel of experts in the field to reflect components of reflectivity and impulsivity:

15. Stays with a job until it is finished, even if it is difficult for him/her.
21. Keeps busy for long periods of time without my attention.
23. Works carefully and does his/her best work.
32. Pays attention to what he/she is doing and is not easily distracted.
40. Attends to the task to be done.

The Cronbach Coefficient Alpha which was computed for these variables resulted in an alpha coefficient of .83. Although .85 is desirable, it is felt that because less than ten variables were utilized that an alpha of .83 is acceptable. The range of scores on the CBI was 13-23 with the higher scores reflecting characteristics of a reflective cognitive stylistic tempo. Again scores were compared to the outcome of the KRISP and it was found that the results of the CBI validated placement. See Table 2 for a comparison of scores on the KRISP, KSCS-P, and the CBI.

Results on the KSCS-P and the CBI were used to decide the placement of the five children who were unable to be classified into the reflective or impulsive category because of conflicting scores (low latency time and low errors or high latency time and high errors) on the KRISP. The final breakdown by categories is shown in Figure 4.

Table 2

<u>Scores on the KRISP, Kohn Social Competence Scale - Preschool, and the Classroom Behavior Inventory Used to Classify Children into Reflective or Impulsive Cognitive Stylistic Tempo Categories</u>

			Kohn Social Competence Scale - Preschool (low score=reflective)		Classroom Behavior Inventory (high score=reflective)		
ID	KRISP		Score	Classification	Score	Classification	Final Classification
01	Low Latency Time, Low Errors	LL*	45	I	16	I	I
02	High Latency Time, Low Errors	R	24	R	18	R	R
04	High Latency Time, Low Errors	R	14	R	22	R	R
05	Low Latency Time, High Errors	I	29	I	17	I	I
06	Low Latency Time, High Errors	I	32	I	16	I	I
07	Low Latency Time, High Errors	I	31	I	17	I	I
08	High Latency Time, Low Errors	R	27	R	20	R	R
09	High Latency Time, Low Errors	R	15	R	20	R	R
10	Low Latency Time, Low Errors	LL*	22	R	21	R	R
13	Low Latency Time, High Errors	I	41	I	14	I	I
14	High Latency Time, High Errors	HH*	32	I	15	I	I
15	High Latency Time, High Errors	HH*	32	I	17	I	I
16	High Latency Time, Low Errors	R	26	R	19	R	R
17	Low Latency Time, High Errors	I	36	I	13	I	I
19	Low Latency Time, Low Errors	LL*	16	R	23	R	R
20	Low Latency Time, High Errors	I	35	I	15	I	I

* Unable to be classified by the KRISP

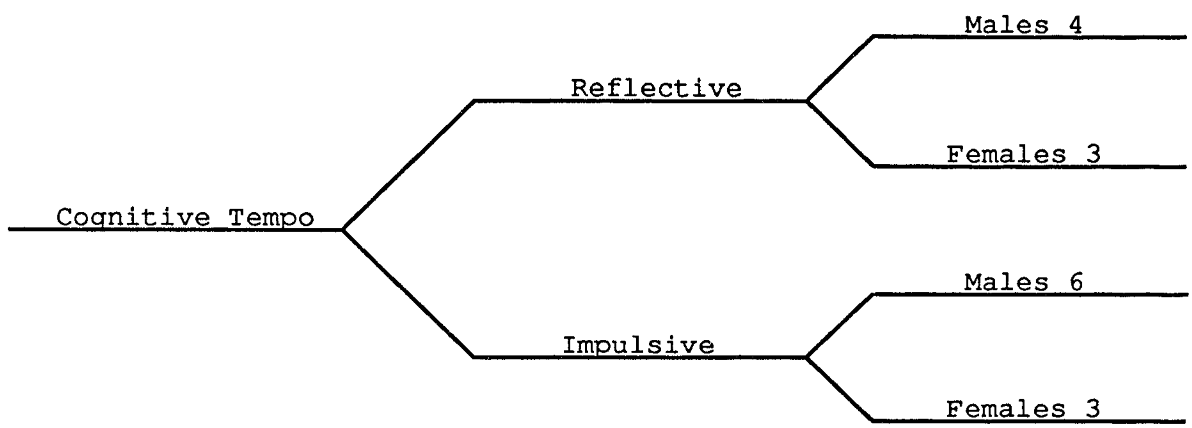

Figure 4. Breakdown of Subjects by Cognitive Stylistic Tempo and Gender Using the KRISP, the KSCS-P, and the CBI.

Design

To investigate this phenomena, the researcher utilized the data gathered through a relatively new concept of audit trail analysis (Grabinger, 1989), a procedure originally designed to track all of the responses a user makes while negotiating interactive or hypermediated instruction (Misanchuk & Schwier, 1992). Each child's stored audit trail data were qualitatively analyzed in an effort to identify patterns and/or strategies that emerged as a child made decisions and solved problems in the Logo environment. Differences between decision making and problem solving of impulsive versus reflective children were determined quantitatively. Each path charted in both the convergent and divergent problem solving sets was scored in several ways. In the convergent set, decision making quotients, percentage of directional moves characterized as indecision points, and percentages of attempted forward motion moves that resulted in prohibition of forward movement were calculated. In the divergent problem solving set, path variability quotients, percentage of directional moves characterized as indecision points, and percentages of attempted forward motion moves that resulted in prohibition of forward movement were calculated. Quantitative t-test procedures were used to compare differences between the impulsive and reflective groups.

Equipment

The equipment used in this study consisted of two Apple II GS microcomputers with 1.25 megabytes of RAM. Each computer had dual disk drives (3.5 inch and a 5.25 inch) and a 12-inch diagonal AppleColor RGB monitor. Terrapin Logo software produced by Terrapin Software, Inc. was used for designing the program contents.

The computers were introduced into the classroom setting at the beginning of the school year preceding the time of this study. By the time that data collection was begun, the computer workstations had become an integral part of the children's classroom environment and daily activities. The workstations consisted of two low tables placed across from each other. However, a partition between the tables afforded each child the freedom from distraction of another classmate while engaged in the problem solving tasks.

Experimenters

The experimenters were two doctoral students who were experienced in Logo instruction. These two experimenters were responsible for all experimental data gathered. During initial training and throughout the problem solving tasks, the experimenters provided encouraging and supportive verbal prompts to the subjects as needed.

Procedure

The Microworlds. Sixteen unique microworlds were designed and programmed with the Terrapin Logo software. The children solved two different problems in each one, for a total of thirty-two microworld experiences. The computer was pre-programmed to produce a 14 X 20 invisible grid system. Simple, multicolored block and line graphics were created which dotted each microworld landscape. A different story was written to accompany each microworld graphic. The stories varied from two to four sentences long and used simple vocabulary and objects that would be familiar to this young population (see Appendix A). Many of the stories asked the children to help the turtle find his way to some location or to find something hidden somewhere. The stories provided additional external auditory cues to help keep the children's focus and interest in the problem-solving tasks.

Syntonic Command Method. In the original Logo programs, children had to use TURTLE TALK to type in complete-word commands that could make the turtle move about the screen. Many of the children participating in this study did not know all the letters of the alphabet, were not able to recognize the letters as they appeared on the keyboard, and/or had naive and imprecise understanding of the concepts of left and right; therefore, a "syntonic command" method was conceived, and an experienced programmer used the Terrapin Logo software to reprogram the Logo command structures to be more developmentally appropriate for the pre-literate children in the study.

The Terrapin Logo software normally requires that users type in abbreviated commands such as FD (forward), BK (back), RT (right), and LT (left) accompanied by a number which instructed the turtle to move so many steps or make a turn of so many degrees. For example, FD 50 would direct the turtle to move forward 50 steps, while RT 50 would rotate the turtle 50 degrees to the right. However, using Papert's notion of syntonic learning and the pointing strategies that have been identified in earlier research, this researcher envisioned a command structure that would "make sense in the world" of the young preliterate learners.

All of the keys on the keyboard were disabled except ten of the keys on the key pad. These ten keys became known as "turtle keys." The "turtle keys" were labeled with orange and green directional stickers in the triangular shape of the on-screen turtle. Orange stickers represented the directional headings of North, South, East, and West, and were placed on the number keys 8, 2, 6, and 4, respectively. Green directional stickers were used to represent the directional headings of northeast, southeast, southwest, and northwest, and were placed on the number keys 9, 3, 1, and 7, respectively. The long zero (0) key was labeled with an orange rectangular sticker to represent a movement in a big step, while the decimal (.) key was labeled with a square green sticker representing a movement of a little step (see Appendix B).

When operating the turtle using the Syntonic Command Method, one is always moving in a forward direction, regardless of the directional heading chosen by the user. The children were able to position the turtle in one of the eight different directional headings with a single keystroke. Once a directional heading was chosen, a forward movement key could be chosen that would move the turtle along its path in big or little steps. This, too, could be accomplished by only one keystroke.

An additional design feature of the Syntonic Command Method consisted of the placement of identically shaped and colored stickers on the perimeter of the monitor screen, to correspond with the placement of the stickers on the keypad (see Appendix B). These "external environmental cues" were believed to add to the ease of maneuvering within the microworld for preschool-age users.

PENDOWN Feature. The PENDOWN feature of the Terrapin Logo Software causes the turtle to leave a trail when it moves. The software allowed the programmer to use six different colors that came up in a random order. The trail was an especially important feature of this project because it allowed the children to have instant visual feedback on the decisions that had been made regarding movement of the turtle. It was an invaluable feature for the divergent problem solving activities, because each unique path charted appeared on the screen in a different color.

NOWRAP Feature. Another feature which was programmed into the Syntonic Command Method was an invisible barrier (known as the NOWRAP procedure) along the outer perimeter of the monitor. This invisible barrier prevented the turtle from running off the edge of the screen at some point and reappearing on the other side of the screen (as if it had wrapped around the back of the monitor). The WRAP procedure as it is called, can produce interesting results, but it was felt that it would be too confusing to this novice group of children.

The children were told during their initial training session that the turtle would "bump his nose" if he ran against the side of the screen. A BEEP command was programmed in to give the children an auditory, as well as a visual cue, when the turtle could no longer proceed in a forward movement due to a barrier. The BEEP system was helpful to the children; it was a consistent cue that served to remind them that it was time to make a decision, since the turtle could move no farther in that particular direction. This BEEP system was also programmed into all visible barriers within the microworlds (walls, trees, lakes, etc.).

Data Collection

Each subject had a personal disk where all data were stored for each microworld activity session. Hard copies of data were printed out to be used in data analyses.

Training

Before the study began each child received four 15-minute training sessions on how to maneuver in the Logo microworld. There was a daily agenda for training that was followed by each of the trainers (see Appendix C). Children were trained individually and on Day 5, following the one-hour of accumulated training time, each child was tested on their mastery of the ten maneuvering keys, with a 16-item instrument designed by the principal investigator.

Subjects were shown one 5 X 8 card at a time and were asked to duplicate the drawing on the screen. Each of the stimulus drawings required the use of one or more of the ten maneuvering keys. The degree of difficulty was varied throughout the sixteen cards. A poster with written and graphic "move reminders" was positioned by each computer at the child's eye level for any subjects who chose to use it. The poster was provided to alleviate anxiety and frustration that might be experienced by some of the subjects, as they worked to perform the operations on the cards. The criterion for an acceptable level of mastery was the successful completion of eight cards, or 50% of the basic moves.

Once mastery of the maneuvering keys was met, all subjects received an additional four weeks of training either in convergent problem solving followed by divergent problem solving practices or practices in the reverse order (see Appendix D). After the first two weeks the subjects were presented with sixteen microworld activities, half of the problems were in convergent contexts, and the other half were divergent. The order of presentation of the two different microworld contexts was randomly chosen. When all subjects completed the first sixteen activities, another two weeks of training was provided in the alternate problem solving context. At the end of the two week practice time, another sixteen microworld activities were presented. Again, the contexts of the problems were randomly ordered.

Problem Solving Contexts

Convergent Thinking. Half of the thirty-two microworld experiences were programmed within a convergent thinking context. For these problems, the subjects were asked to find the shortest possible path to get the turtle from his starting position to some destination within the microworld. As the graphics materialized on the monitor, the subject was read a short story about some situation in which the turtle found himself. The computer was programmed to compute the most efficient route and hold in memory the number of invisible grids passed through from starting point to target. As each subject charted a path, the computer recorded each directional and movement key input until the target was reached. Once the target was reached the microworld graphic dissolved and the screen cleared. The stored record of the charted path is the audit trail (see Appendix E).

Divergent Thinking. The other half of the microworlds were programmed in a divergent thinking context. For these problems the subjects were asked to chart as many different routes as they could in two minutes. It was emphasized to the subjects, that in these problems there was no "one best way" to get the turtle to the target. As in the convergent problem solving activities a story was read to accompany the graphic microworld. Once a successful path had been charted, the turtle instantaneously reappeared at the starting point so a different path could be charted. Each successful path was charted in a different color and remained on the screen until the two-minute time limit ran out. This feature allowed each subject to view previously charted courses; and therefore make decisions as to how each successive course could be altered to achieve as many different solution paths as possible within the two-minute time limit. The computer stored the audit trails for each complete path charted within the time limit (see Appendix F).

Task Analysis Models

Using the Information Processing Analysis Model as a guide, a task analysis model was designed for each of the problem solving contexts. The models show each step in the problem solving process, what questions must be asked, and the points in the process where decisions must be made as a child navigates the turtle through the microworlds to reach the target. Figure 5 shows the model for the convergent problem solving context.

Figure 6 illustrates the task analysis process for the divergent problem solving contexts. The models are very similar, except for the last decision point where additional paths may be charted, if time permits.

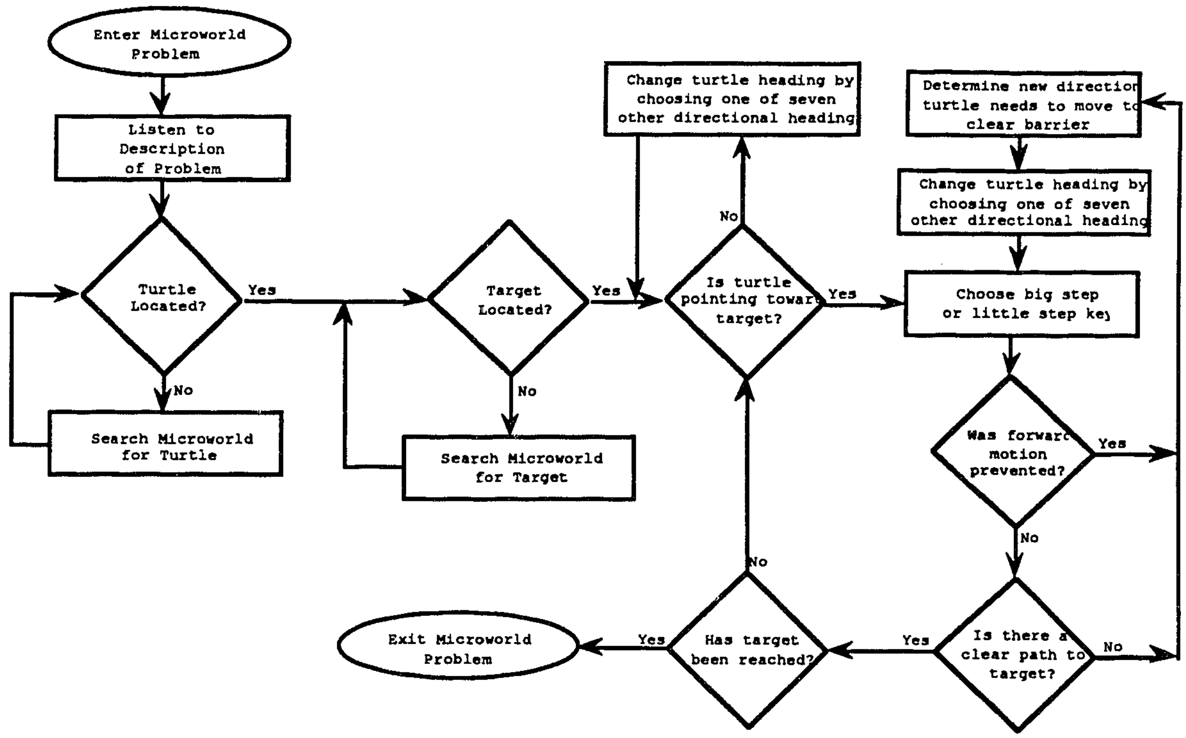

Figure 5. Model of Task Analysis for Convergent Logo Problem Solving Tasks

Once the models were constructed, the criteria for scoring the effectiveness of a child's decision at each decision point were determined. To determine the scores on effectiveness of decision making in the Convergent Problem Solving Loop, the following steps will be followed:

1. When a child begins the problem he/she leaves the turtle in the original position or changes the turtle's position

or

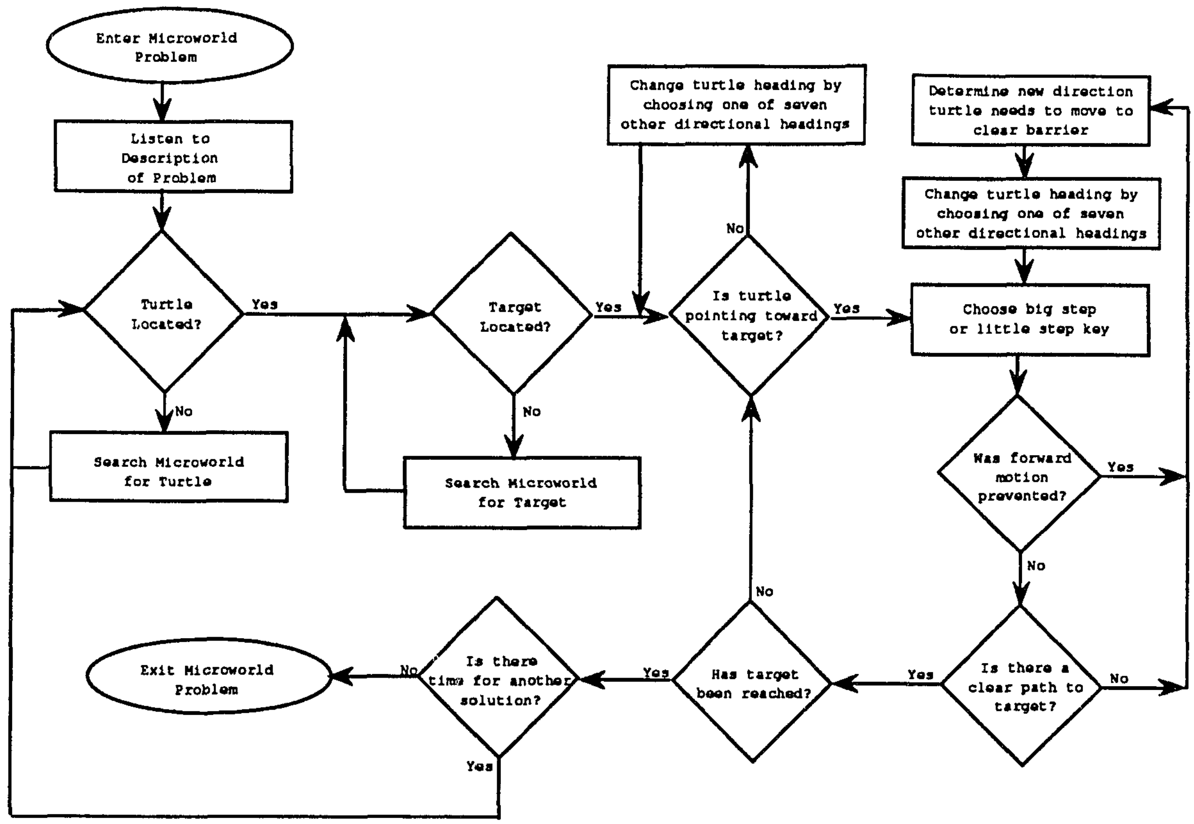

Figure 6. Model of Task Analysis for Divergent Logo Problem Solving Tasks

2. As a child moves through the problem, each time forward movement is stopped and the child changes the directional heading of the turtle, the effectiveness of the decisions will be scored as follows:

5 - Extremely effective - directional heading allows for forward movement which is not obstructed in any way and moves the turtle directly towards the target

3 - Moderately effective - directional heading allows for forward movement which is not obstructed in any way, but moves the turtle indirectly towards the turtle

1 - Ineffective - directional heading moves turtle away from the target or forward motion is prohibited by the edge of screen barrier (no-wrap feature) or by some on-screen obstacle

The decision making quotient will be computed by summing scores of all decision points and then dividing by the total number of decision points.

From a subloop within the larger task analysis model, points of indecision were located and quantified as a percentage of directional moves where the directional heading of the cursor (turtle) is changed two or more times from its existing heading before movement is initiated. Another subloop within the larger model allowed the researcher to examine incidences where forward movement was prohibited by barriers and/or the confines of the microworlds. These incidences will be reported as a percentage of the total attempted forward moves.

Data Analysis

Data were analyzed both qualitatively and quantitatively. This dissertation explored the utility of a new methodology, audit trail analysis, in analyzing data gathered from Logo microworld experiences.

Qualitative Analysis. Audit trail information for each problem was obtained from the original raw data sheets that were printed out after each child's problem solving session was completed. The audit trails for the convergent problem solving tasks consisted of the one route that was charted by the child. The audit trails from the divergent problem solving tasks included every completed path that was charted within the two-minute time limit. If a child had only partially completed a path when his/her time had run out, the computer would automatically delete the information on that path. Therefore, the data represent only successfully completed paths (meaning that the turtle's course had been charted from starting point to target).

Initially, a coding sheet was designed onto which were transferred all audit trails from the original data sheets. Because of multiple paths per problem in the divergent data, separate coding sheets for the divergent and convergent problem sets were devised. Since the original audit trails contained strings of information containing numbers and characters (1,2,3,4,6,7,8,9,0, and .), it was thought that visual examination of the data might be more easily accomplished if it were color coded. The color blue was used for the numbers representing direction headings, yellow for the number of little steps used, and red for the number of big steps used. An example of an original audit trail and a re-coded audit trail is shown below (Yellow numbers representing little steps are <u>underlined</u>, while red numbers representing big steps are shown in **outline**:

06.8..70006..200040

1 6 <u>1</u> 8 <u>2</u> 7 **3** 6 <u>2</u> 2 **3** 4 **1**

The information that can be derived from this is as follows:

1. Initial move consisted of one big step in a northerly direction (the equivalent of three grids on the microworld map). The child did not have to enter a directional heading if he/she wanted to move in the original heading of the turtle in his starting position.
2. The position was changed to an easterly direction (6) and movement was made via one small step (<u>1</u>) (the equivalent of one grid on the microworld map).
3. The position was changed to a northerly position (8) and two small steps (<u>2</u>) were taken.
4. The position was changed so the turtle was facing in a northeasterly direction (9), and the child programmed the computer to move the turtle three big steps (**3**)
5. The turtle was then pointed in a easterly direction (4) and moved two small steps (<u>2</u>).
6. Direction of the turtle was changed to face the south (2), and movement consisted of three big steps (**3**).

7. The final directional heading was to the east (6), and the movement of one big step (**1**) brought the turtle to the target.

This audit trail represents seven decision points in the problem solution. Following the task analysis model for convergent problems, these seven actions can be placed on one of the decision making points in the model. Although the young child is not consciously aware of asking each of the decision-making questions, these are the processes which need to be accomplished if successful solutions are to result.

The process of looking at the data and examining them to see what could be found was exciting. The more the data were scrutinized, the more questions and ideas came to mind. A note-pad was kept, so that each question or idea could be recorded as it surfaced. Sometimes the questions were about some aspect of the thinking processes; sometimes ideas would occur about how these data could be coded on the computer to afford the same ease of "visualizing the process" as the color-coded sheet seemed to be doing. The audit trails proved to be an excellent source of information regarding the thinking processes that were involved in Logo microworld problem solving.

A qualitative case study approach was used to determine the nature of information that audit trail analysis could provide to this researcher about the decision-making processes of the sixteen, young, novice subjects working in a Logo microworld environment. These case studies provided the researcher with information about unique, individual problem solving strategies.

Quantitative Analysis. The quantitative analyses utilized t-test procedures to determine what, if any, differences existed between the effectiveness of decision making processes as a function of cognitive stylistic tempos (reflectivity - impulsivity) by comparing the following variables: decision making quotients in the convergent problem solving set; path variability quotients in the divergent problem solving set; the percentage of directional moves characterized as indecision points within the convergent and divergent problem solving sets; and the percentage of attempted forward motion moves that resulted in prohibition of forward movement caused by barriers and/or the confines of the microworlds within the convergent and divergent problem solving sets.

CHAPTER IV

RESULTS

This study was designed to investigate the problem solving techniques of a sample of minority at-risk preschoolers as a function of their reflectivity/impulsivity within a computer paradigm using Logo microworlds as the context. Children were involved in 16 convergent and 16 divergent problem solving situations. By employing quantitative data analyses of the audit trail data, group differences were examined. Qualitative analyses of the audit trails in the form of randomly selected case studies examined individual preferences and looked to see what strategies were employed in solving both convergent and divergent thinking problem sets.

Quantitative Data Analysis

Hypothesis 1. It was hypothesized that children with reflective cognitive stylistic tempos would achieve significantly higher decision making quotients (DMQs) in the convergent problem solving set than would children with impulsive stylistic tempos. See Table 3 for means and standard deviations of decision making quotients by problem for the convergent problem solving set by learning style.

The reflective children had a mean DMQ of 3.65, as compared to the impulsive children who had a mean DMQ of 3.32.

Table 3

Frequencies, Means, and Standard Deviations of Decision Making Quotient by Problem for the Convergent Problem Solving Set by Learning Style

	Learning Style					
	Impulsive			Reflective		
Problem Number	n	$\bar{X}$	SD	n	$\bar{X}$	SD
1	9	2.911	0.528	7	3.571	0.531
4	9	2.644	0.428	7	3.171	0.670
6	9	3.178	0.897	7	4.586	0.708
7	9	3.156	0.361	7	3.171	0.330
9	9	2.989	0.660	7	3.243	0.378
11	9	3.089	0.533	7	3.386	0.406
12	9	3.678	0.663	7	3.686	0.324
15	9	5.000	0.000	7	5.000	0.000
17	9	2.933	0.738	7	3.486	0.313
20	9	3.233	0.775	7	3.257	0.496
21	9	3.367	0.581	7	3.614	0.430
25	9	3.167	0.899	7	3.400	0.968
27	9	2.689	0.382	7	3.243	0.655
28	9	5.000	0.000	7	5.000	0.000
30	9	3.278	0.360	7	3.186	0.376
32	9	2.944	0.548	7	3.443	0.608

A *t*-test was used to test for significant differences between the mean decision making quotients of the reflective versus the impulsive groups. The *t*-test showed that the difference between the mean DMQ of the two groups was significant (T=-2.727, *p*=0.016). The hypothesis was supported (see Table 4).

Table 4

Frequencies, Means, Standard Deviations, and t-test for Decision Making Quotient (DMQ) By Learning Style

Learning Style	*n*	$\bar{X}$	SD	*T*	DF	*p*
Impulsive	9	3.328	0.241	-2.727	14.0	0.016
Reflective	7	3.653	0.229			

Hypothesis 2. It was hypothesized that children with impulsive cognitive stylistic tempos would achieve significantly higher path variability quotients in the divergent problem solving set, than would children with reflective cognitive stylistic tempos. See Table 5 for means and standard deviations of the path variability quotient by problem for the divergent problem solving set by learning style.

Table 5

Frequencies, Means, and Standard Deviations of Path Variability Quotient by Problem for the Divergent Problem Solving Set by Learning Style

	Learning Style					
	Impulsive			Reflective		
Problem Number	n	$\bar{X}$	SD	n	$\bar{X}$	SD
2	7	7.500	5.488	6	8.917	4.652
3	8	4.239	3.089	6	6.820	1.441
5	6	5.417	6.469	6	5.500	6.512
8	6	8.500	7.232	6	2.500	6.124
10	9	4.722	6.190	7	4.953	6.710
13	6	5.695	7.508	6	5.750	7.237
14	9	4.278	7.738	7	8.429	8.853
16	8	6.458	5.376	7	11.357	3.966
18	8	8.625	9.701	7	6.906	7.567
19	8	6.000	6.671	7	5.929	6.133
22	8	9.688	10.621	7	6.024	5.813
23	8	7.510	4.829	7	7.786	4.475
24	8	6.343	4.004	7	9.273	6.240
26	9	11.056	6.488	7	13.893	6.678
29	9	9.712	5.644	7	11.643	1.909
31	9	8.713	5.713	7	10.417	6.409

A *t*-test was used to test for a significant difference in the mean path variability quotient of the impulsive group versus the reflective group. The *t*-test revealed that the difference was not significant between the two groups ($T=-0.712$, $p=0.488$). The hypothesis was not supported (see Table 6).

Table 6

Frequencies, Means, Standard Deviations, and t-test for Path Variability Quotient (PVQ) By Learning Style

Learning Style	*n*	$\bar{X}$	SD	*T*	DF	*p*
Impulsive	9	6.301	3.844	-0.712	14.0	0.488
Reflective	7	7.618	3.419			

Hypothesis 3. It was hypothesized that children with reflective cognitive stylistic tempos would have a significantly lower percentage of directional moves characterized as indecision points, when directional heading of the cursor is changed two or more times from its existing heading before movement is initiated in the convergent problem solving set. See Table 7 for means and standard deviations of the indecision points for the convergent problem solving set by learning style. The mean indecision point (IP) in the convergent problem solving set for the reflective group of children was lower ($\bar{X}=0.219$) than the

Table 7

<u>Frequencies, Means, and Standard Deviations of Indecision Points (IP) for the Convergent and Divergent Problem Solving Sets by Learning Style</u>

	Learning Style					
	Impulsive			Reflective		
Problem Solving Set	*n*	$\bar{X}$	SD	*n*	$\bar{X}$	SD
Convergent	9	0.270	0.150	7	0.219	0.123
Divergent	9	0.236	0.121	7	0.245	0.092

mean for the impulsive group of children ($\bar{X}$=0.270). However, the *t*-test revealed that the difference was not significant (T=0.729, *p*=0.478). Therefore, hypothesis 3 was not supported (see Table 8).

<u>Hypothesis 4</u>. It was hypothesized that children with reflective cognitive stylistic tempos would have a significantly lower percentage of directional moves characterized as indecision points, when directional heading of the cursor is changed two or more times from its existing heading before movement is initiated in the divergent problem solving set. See Table 7 for the means and standard deviations of the indecision points for the divergent problem solving set by learning style.

Table 8

Frequencies, Means, Standard Deviations, and t-test for Indecison Points (IP) on the Convergent Problem Solving Set By Learning Style

Learning Style	*n*	$\bar{X}$	SD	*T*	DF	*p*
Impulsive	9	0.270	0.150	0.7285	14	0.4783
Reflective	7	0.219	0.123			

Results of the *t*-test showed that the difference was not significant (T=-0.154, *p*=0.880). Therefore, hypothesis 4 was not supported (see Table 9).

Hypothesis 5. It was hypothesized that children with impulsive cognitive stylistic tempos would have a significantly higher percentage of attempted forward motion moves that resulted in prohibition of forward movement (PFM) caused by the barriers and/or confines of the microworlds within the convergent problem solving set. See Table 10 for means and standard deviations for prohibition of forward movement by problem for the convergent problem solving set by learning style.

The mean PFM for the impulsive children in the convergent problem solving set was 0.209, compared with a mean PFM for the reflective children of 0.120. The *t*-test

Table 9

Frequencies, Means, Standard Deviations, and t-test for Indecison Points (IP) on the Divergent Problem Solving Set By Learning Style

Learning Style	n	$\bar{X}$	SD	T	DF	p
Impulsive	9	0.236	0.120	-0.154	14	0.880
Reflective	7	0.245	0.092			

revealed that the difference was significant (T=2.752, p=0.016). Hypothesis 5 was supported (see Table 11).

Hypothesis 6. It was hypothesized that children with impulsive cognitive stylistic tempos would have a significantly higher percentage of attempted forward motion moves that resulted in prohibition of forward movement (PFM) caused by the barriers and/or confines of the microworlds within the divergent problem solving set. See Table 12 for means and standard deviations for prohibition of forward movement by problem for the divergent problem solving set by learning style.

The mean PFM for the impulsive children in the divergent problem solving set was 0.243, compared with a mean PFM for the reflective children of 0.196. The t-test revealed that

Table 10

Frequencies, Means, and Standard Deviations for Prohibition of Forward Movement by Problem for the Convergent Problem Solving Set by Learning Style

	Learning Style					
	Impulsive			Reflective		
Problem Number	n	$\bar{X}$	SD	n	$\bar{X}$	SD
1	9	0.341	0.141	7	0.156	0.149
4	9	0.438	0.171	7	0.196	0.143
6	9	0.139	0.125	7	0.000	0.000
7	9	0.255	0.141	7	0.042	0.102
9	9	0.237	0.169	7	0.140	0.165
11	9	0.206	0.205	7	0.057	0.098
12	9	0.028	0.083	7	0.036	0.094
15	9	0.000	0.000	7	0.000	0.000
17	9	0.282	0.236	7	0.203	0.107
20	9	0.134	0.179	7	0.232	0.085
21	9	0.155	0.185	7	0.000	0.000
25	9	0.300	0.195	7	0.310	0.296
27	8	0.368	0.140	7	0.210	0.169
28	9	0.000	0.000	7	0.000	0.000
30	9	0.111	0.144	7	0.119	0.120
32	9	0.355	0.170	7	0.269	0.199

Table 11

<u>Frequencies, Means, Standard Deviations, and t-test for Prohibition of Forward Movement (PFM) on the Convergent Problem Solving Set By Learning Style</u>

Learning Style	n	$\bar{X}$	SD	T	DF	p
Impulsive	9	0.209	0.064	2.752	14	0.016
Reflective	7	0.120	0.066			

the difference was not significant (T=1.212, p=0.246). Hypothesis 6 was not supported (see Table 13).

To summarize the results of the quantitative analysis from the audit trails of the sixteen, minority, preschool-age subjects the following table was constructed (see Table 14). The more reflective children did score higher DMQs in the convergent problem solving set (Hypothesis 1), meaning that their movement decisions consistently were directed toward the target and avoided barriers along the perimeter of the microworld and within the microworld. The more reflective children also had lower percentages of prohibition of forward movement in the convergent problem set (Hypothesis 5), meaning that they were more successful at avoiding "bumping the turtle's nose" as they solved problems which required them to find the shortest, quickest path to the target. The

Table 12

Frequencies, Means, and Standard Deviations for Prohibition of Forward Movement by Problem for the Divergent Problem Solving Set by Learning Style

	Learning Style					
	Impulsive			Reflective		
Problem Number	n	$\bar{X}$	SD	n	$\bar{X}$	SD
2	7	0.230	0.147	6	0.147	0.123
3	8	0.259	0.177	6	0.101	0.085
5	6	0.427	0.219	6	0.301	0.227
8	6	0.346	0.105	6	0.225	0.208
10	9	0.212	0.120	7	0.187	0.086
13	6	0.377	0.230	6	0.323	0.061
14	9	0.322	0.167	7	0.252	0.225
16	8	0.261	0.145	7	0.222	0.172
18	8	0.320	0.199	6	0.173	0.081
19	8	0.285	0.231	6	0.223	0.109
22	7	0.347	0.116	7	0.243	0.166
23	8	0.234	0.111	7	0.133	0.124
24	8	0.326	0.140	7	0.274	0.060
26	8	0.264	0.093	7	0.157	0.152
29	8	0.123	0.069	7	0.156	0.098
31	9	0.295	0.154	7	0.226	0.218

Table 13

Frequencies, Means, Standard Deviations, and t-test for Prohibition of Forward Movement (PFM) on the Divergent Problem Solving Set By Learning Style

Learning Style	n	$\bar{X}$	SD	T	DF	p
Impulsive	9	0.243	0.182	1.212	14.0	0.246
Reflective	7	0.196	0.071			

Table 14

Summary of Quantitative Results for Hypotheses 1-6

Hypothesis	Variable of Interest	Problem Solving Set	t-test	p
1*	Decision Making Quotient (DMQ)	Convergent	-2.727	0.02
2	Path Variability Quotient (PVQ)	Divergent	-0.712	0.49
3	Indecision Points (IP)	Convergent	0.729	0.47
4	Indecision Points (IP)	Divergent	-0.154	0.88
5*	Prohibition of Forward Movement (PFM)	Convergent	2.752	0.02
6	Prohibition of Forward Movement (PFM)	Divergent	1.212	0.24

* Supported Hypothesis

results of Hypothesis 6 (PFM in the divergent problem solving set) were moving towards significance (p=0.24) and had the sample size been larger, significant differences may also have been realized in the divergent problem solving set.

Qualitative Data Analysis

The audit trails of each child as he/she solved the convergent and divergent problems were analyzed and then written up in a case study format. See Appendix G for sample case studies of four of the study participants. Two children were chosen at random from each cognitive stylistic tempo category (impulsive/reflective) to be included. Each of the children's names were changed in the case studies to ensure confidentiality.

The case studies allowed for individual differences to be identified and discussed. Preferences by different children for using particular strategies were described and discussed in the context of other research findings. Two of the case studies include graphics of the 32 on-screen Logo problems that were solved in the convergent and divergent problem solving sets. These graphics allowed the researcher to examine route strategy and patterns of movement that were unique to individual children. The graphics also allowed for "visual analysis" of how children negotiated barriers as they moved through the microworlds. The graphics permitted the researcher to "see" the directness or indirectness of each charted path. The strengths of individual children, as well as areas where children experienced difficulties could be identified. See Tables 15-16 for summaries of data gleaned from microanalytic analysis of the audit trail data.

Table 15

Summary of Audit Trail Analyses for the Convergent Problem Solving Set

	Subject ID															
	Impulsive									Reflective						
Parameter	01	05	06	07	13	14	15	17	20	02	04	08	09	10	16	19
Mean Decision Making Quotient	3.5	3.1	3.2	3.5	2.9	3.6	3.3	3.2	3.6	3.8	4.0	3.6	3.8	3.6	3.3	3.6
Total Directional Decision Points	67	131	110	87	229	75	88	109	76	88	82	91	64	93	130	55
Total Problems Solved	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Decisions to use Little Steps	16	18	45	59	40	66	67	64	16	34	15	40	60	59	47	24
Decisions to use Big Steps	46	99	52	22	79	3	12	44	58	47	66	36	7	31	60	33
Number of Diagonal Moves Made	1	28	9	15	19	10	11	6	13	19	12	5	0	5	24	0
Incidences of Indecision	7	16	13	7	29	5	10	12	4	11	4	11	3	9	19	1
Number of Directional Changes Involved in Incidences of Indecision	7	19	22	11	116	6	12	19	5	14	6	18	4	16	30	2
Number of Problems Involving Indecision	7	6	7	6	12	3	7	5	3	7	3	8	3	5	11	1

Table 16

Summary of Audit Trail Analyses for the Divergent Problem Solving Set

	Subject ID																
	Impulsive									Reflective							
Parameter	01	05	06	07	13	14	15	17	20	02	04	08	09	10	16	19
Toral Number of Charted Paths	30	37	32	33	18	12	18	34	46	37	46	27	31	28	27	19
Total Directional Decision Points	242	259	286	221	168	62	91	266	299	247	303	205	216	165	168	160
Decisions to use Little Steps	41	44	117	134	37	57	66	157	58	90	44	99	67	121	93	82
Decisions to use Big Steps	170	202	120	57	79	7	20	102	242	128	261	74	21	40	68	54
Number of Diagonal Moves Made	15	40	27	20	17	9	10	8	35	52	66	14	7	21	49	5
Incidences of Indecision	33	20	34	19	16	1	9	22	21	28	18	26	26	7	18	19
Number of Directional Changes Involved in Incidences of Indecision	38	27	65	32	61	1	11	34	25	40	20	46	42	12	22	28
Number of Problems Involving Indecision	12	10	13	9	11	1	6	12	10	12	10	15	11	5	10	9

Specific results and interpretation for the selected individual children are included within each case study (see Appendix G).

Table 15 summarizes the qualitative data which were compiled from the subjects' audit trails in the convergent problem solving set. The mean decision making quotients of the children with the more impulsive cognitive stylistic tempos ranged from 2.9 to 3.6. The more reflective children had mean decision making quotients which ranged from 3.3 to 4.0. The range of total directional decision points made by the more impulsive children in the problem solutions of the 16 convergent problems was 67 to 229. The range was much narrower for the more reflective children, 55 to 130. All of the subjects, regardless of the cognitive stylistic tempo, were successful at completing each of the 16 convergent problems.

When comparing children's preferences for how they moved the turtle through the microworlds, it was interesting that the range of decisions to use little steps for both groups were very similar with the impulsive group ranging from 16 to 67 and the reflective group ranging from 15 to 60. The more impulsive group had a range of 3 to 99 for their decisions to use big steps to move the turtle. The more reflective group had a more narrow range of 7 to 66. It was interesting, however, that two children in the impulsive group (#14 and

#15) and one child in the reflective group (#9) had a clear preference for using little steps over big steps. Preferences for using big steps over little steps were exhibited by subject #5 in the more impulsive group and subject #4 in the more reflective group.

When the audit trails were examined for the children's use of diagonal moves in their problem solutions, it was noted that two children from the more reflective group did not use any diagonal moves in any of the problem solutions. Of the five subjects from the reflective group who did use diagonal moves, the range was 5-24. The range of diagonal moves utilized by the nine children in the more impulsive group ranged from 1 to 28.

Analysis of the audit trails for incidences of indecision revealed higher incidences for the more impulsive group, which had a range of 4 to 29, with a mean of 11.4 points of indecision. Points of indecision were characterized as any time two or more directional keys were pressed before a movement decision was made. It was also possible to count the number of directional changes involved in incidences of indecision through audit trail analysis. The range for the impulsive group was 5 to 116. One of the children in the more impulsive group (#13) was particular noteworthy. This child had the highest number of incidences of indecision (29) and the highest number of directional changes involved in incidences of indecision (116). The range of incidences of indecision for the more reflective group was 1 to 19, with a mean of 8.2. The number of directional changes involved in incidences of indecision ranged from 2 to 30.

Table 16 summarizes the qualitative data which were compiled from the 16 subjects' audit trails in the divergent problem solving set. In this problem solving set children were asked to solve the problems using as many different routes as they could chart in a two-minute time limit. The total number of paths charted in the solution of the 16 divergent problems ranged from a low of 12 paths to a high of 46 unique paths. One of the children in more impulsive group (#14) only completed a total of 12 solution paths which means that on some of the divergent problems, no path was completed in the two minute time limit. The child who completed the most uniquely different paths was in the reflective group (subject #4). The range of total directional decision points made by the more impulsive children in the divergent problem solving set was 62 to 299. The range for the more reflective children was 160 to 303.

The children's preferences for using little steps over big steps was also compared in the divergent problem solving set. The usage of little steps ranged from 41 to 134 for the impulsive group compared to 44 to 121 for the more reflective group. The usage of big steps ranged from 7 to 242 for the more impulsive group and 21 to 128 for the more reflective group. Again, certain children preferences for one movement style over the other was visible. The same children who showed a preference for little step usage over big step usage (#14 and #15 for the impulsive group and #9 for the reflective group) in the convergent problem solving set also demonstrated this preference in the divergent problem solving set. When the data were examined for preferences for big step usage over little step usage, it was evident that three of the more impulsive children (#1, #5, and #20) and one of the more reflective children (#4) utilized big steps much more frequently than little steps in their problem solutions. All of the 16 subjects utilized diagonal moves in some of their problem solutions in the divergent problem solving set. The range of usage for the more impulsive group was 8 to 35, as compared to the more reflective group who ranged from 5 to 66.

The more impulsive group had a wider range of incidences of indecision in the divergent problem solving set, from a low of 1 to a high of 34. The range for the more reflective group was much more narrow, ranging from 7 to 28. When the range of directional changes involved in incidences of indecision were compared, it was again noted that the more reflective group had a lower number and a more narrow range.

The more impulsive children had a range of 1 to 65 directional changes involved in incidences of indecision compared to a range of 12 to 46 for the more reflective group.

There was a wide range of problems in which indecision occurred. In the more impulsive group of children, the range was from 1 to 13 problems in which indecision occurred. For the more reflective group, this range was from 5 to 15 problems.

As case studies were completed, additional data were compiled to examine the problems in which children had points of indecision. Sixty-nine percent of the children (n=11) experienced more points of indecision in the divergent problem solving set. Twenty-five percent (n=4) had more indecision points in the convergent problems, and one child (6%) had an equal number of incidences of indecision in the convergent and divergent problem solving sets. There were two problems (#15 and #28) in the convergent problem solving set in which none of the children had any points of indecision. These data are shown in tabulated form in Table 17 and Table 18.

Table 17

Problems Where Indecision Occurred in the Convergent and Divergent Problem Solving Sets

	Problem Number																															
	Convergent																Divergent															
ID	1	4	6	7	9	11	12	15	17	20	21	25	27	28	30	32	2	3	5	8	10	13	14	16	18	19	22	23	24	26	29	31
01					X				X	X	X	X	X								X	X	X	X	X	X	X	X	X	X	X	X
02	X	X		X	X	X						X	X				X	X	X	X	X		X		X	X	X	X			X	X
04		X				X					X									X	X				X	X	X	X	X	X	X	X
05		X	X	X					X	X		X							X	X	X	X			X			X	X	X		X
06	X		X		X				X		X		X			X	X	X			X		X	X	X	X	X	X	X	X	X	X
07	X		X			X			X				X		X		X	X		X	X		X		X	X	X			X		
08	X	X	X		X	X				X			X		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
09		X							X		X						X	X		X	X		X	X	X		X	X			X	X
10		X		X	X				X		X								X		X	X							X	X		
13	X	X	X	X	X	X			X	X	X	X	X			X		X			X		X		X	X	X	X	X	X	X	X
14	X			X					X																							X
15	X	X	X	X	X		X						X				X			X	X			X			X	X				
16	X	X		X	X	X	X		X		X	X	X		X		X	X		X	X	X				X		X	X		X	X
17	X	X			X				X								X	X		X	X	X	X	X	X	X		X	X		X	X
19					X																X	X	X	X		X	X	X	X		X	
20			X				X		X								X		X	X	X			X	X	X	X	X	X	X		

Table 18

Percentage of Problems in Which Indecision Occurred for the Convergent, Divergent, and Total Problem Solving Sets for all Subjects by Learning Style

Subject ID	Percentage of Convergent Problems	Percentage of Divergent Problems	Percentage of Total Problems
Impulsive			
01	37.5	75.0	56.3
05	37.5	56.3	46.9
06	43.8	81.3	62.5
07	37.5	56.3	46.9
13	75.0	68.8	71.9
14	18.8	6.3	12.5
15	43.8	37.5	40.6
17	25.0	81.3	53.1
20	18.8	68.8	43.8
Reflective			
02	43.8	75.0	59.4
04	18.8	62.5	40.6
08	50.0	93.8	71.9
09	18.8	68.8	43.8
10	31.3	31.3	31.3
16	68.8	62.5	65.6
19	6.3	56.3	62.5

CHAPTER V

DISCUSSION

No longer is a question such as, "Can preschool-age children learn to program in Logo?" appropriate to ask. Empirical data gathered over the past decade has continually documented young children's success in maneuvering the "turtle" cursor in Logo environments, as well as explored the concepts of spatial orientation, mode of movement, barrier effects, quadrant effects, and training effects on young children's performance in a computer paradigm using Logo (Allen, Watson, & Howard, 1993; Brinkley & Watson, 1988; Brinkley & Watson, 1990; Brinkley & Watson, 1990/91; Clements & Gullo, 1984; Emihovich & Miller, 1986; Howard, Watson, & Allen, 1993; Papert, 1980; Pea & Kurland, 1984; Shade, Nida, Lipinski, & Watson, 1986; Watson & Brinkley, 1990/91; Watson, Lange, & Brinkley, 1991, 1992).

This research utilized both quantitative and qualitative techniques to expand the body of childhood computing literature by analyzing stored audit trail data from the Logo problem solving activities of sixteen minority, at-risk preschoolers. Quantitative analyses allowed this researcher to examine group differences in problem solving techniques and decision making processes as a function of the cognitive stylistic tempos of impulsivity and reflectivity. Qualitative analyses allowed the researcher to explore, through microanalytic case studies, the decision making processes that are unique to individual children. Using qualitative and quantitative techniques simultaneously gave a rich, in-depth picture of a sample of young children's decision making skills and problem solving endeavors in a variety of Logo microworlds.

Quantitative Analysis

Hypothesis 1. Results of the t-test between the mean decision making quotients (DMQ) of the reflective and the impulsive group of children in the convergent problem solving set showed that the difference was significant. Higher decision making scores were awarded to those children who consistently moved the "turtle" cursor towards the target and who avoided barriers that would interfere with that forward movement.

Reflective children characteristically take more time to "reflect" on alternate options before making a decision (Kagan, 1966; Wright, 1972), and since the criteria for success was measured by finding the one, shortest path to the goal, it is reasonable to expect that the reflective children would be more successful. Even though the difference in the mean DMQ's was significant, with the reflective group achieving a higher DMQ, one cannot say that the impulsive group was not successful.

Each of the children, regardless of his/her cognitive stylistic tempo was successful at charting a path from the starting point to the target in the convergent problem solving set. The fact that all of the children were able to chart solution paths to the targets may be explained by the age-appropriate syntonic command method and the features that were included in the program which made moving the turtle easy for these novice problem solvers.

The feature which may have accounted for the impulsive children's success at this task was the use of the PENDOWN feature. The colored trail that was left by the turtle as he moved across the screen allowed the children to have instant visual feedback on the decisions that had been made regarding the movement of the turtle.

Another feature of using the syntonic command method which may have proven to be a salient variable of the children's success rates was the placement of the colored "turtle" stickers on the perimeter of the monitor screen that corresponded with the placement of the stickers on the keypad. These stickers provided constant "external environmental cues" which added to the ease with which the children could move the turtle about within the different microworlds.

Hypothesis 2. Results for hypothesis 2 showed that the difference between the mean path variability quotients of the reflective and impulsive groups achieved in the divergent problem solving set was not significant. Further, it was predicted that impulsive children would have greater path variability quotients. In fact, the results showed that the children in the reflective group and the impulsive group achieved almost equal PVQs. The explanation for these results is multi-faceted.

Since a fast response time is characteristic of impulsive children (Kagan, 1966), it was reasonable to predict that they would be able to chart a greater number of paths (thus passing through more grids) in the allotted time. One reason that could be posited for the result is that the impulsive children became impatient after charting one path and wanted to move on to another problem. If this occurred and they failed to complete additional paths then their PVQ would be zero, since the score is computed by counting the number of unique grids passed through in completion of additional routes after the first and then divided by the total number of routes charted in the time limit.

Another possible explanation for the unsupported results of this hypothesis could lie in the nature of the directions themselves. The directions given to the children during the divergent problem solving activities were that there was "no one correct path" and that they were to chart as many different paths as they possibly could in the time allotted (two minutes) for each problem. It is plausible to think that the impulsive children, eager to begin the task, did not process the directions as thoroughly as the more reflective children.

By the young age of four, many children have become more familiar with answering questions to which there is a single correct response. Telling the children that there was "no one correct answer" to the question may have confounded their processing of what was expected of them.

An additional factor that could have impacted the more impulsive children's performance was the characteristic which Piaget described as "centration." Preschool children are generally unable to focus on more than one aspect of a task at a time, which inhibits their ability to problem solve. The more impulsive children may have become "focussed" on the time limit and were hesitant to begin additional paths for fear that time would run out before their new paths could be completed.

Hypotheses 3 and 4. Results of hypotheses 3 and 4 both showed that there was no significant difference between the reflective and impulsive groups' percentage of directional moves characterized as indecision points in the convergent and divergent problem solving sets. Indecision points were defined as any point in a solution path where a directional heading was changed two or more times from its existing heading before forward movement was initiated. It was predicted that the reflective group would have significantly lower percentages than the impulsive group in both problem solving contexts.

The data from the t-test showed that the mean percentage of indecision points of the reflective group was lower in the convergent problem solving set, but not low enough to be statistically significant. The results of the t-test from the divergent problem solving set data however, showed no significant differences between the reflective group and the impulsive group in the mean percentages of moves characterized as indecision points.

Since reflective children are characterized by their ability to "think before they act" and to take into account various alternatives that may be available to them (Kagan, 1966; Wright, 1972), it is reasonable to expect they would have fewer instances where multiple directional keys would be pressed before a decision to move was made. One could surmise that a reflective child would assess the turtle's relation to the target by using syntonic reasoning (Papert, 1980; Brinkley & Watson, 1990) and choose a directional heading that would enable the turtle to continually move towards that target.

One could also reason that reflective children are more likely to take the time to assess the layout of the microworld and therefore, the turtle's position in relation to the target and would thus demonstrate higher levels of perspective taking, an activity discussed by Piaget and Inhelder (1966) in a discussion of the emergence of projective space. Taking the time to reflect on the situation before making a decision would enable the reflective children to choose an appropriate directional heading with a minimum of confusion about which directional heading to choose; hence, having fewer points of indecision.

It is just as likely to imagine that the more impulsive children would press a direction key without first determining which was the best direction in which to proceed, and then press another key without paying attention to where on the keypad their fingers were placed. If this second directional heading was also incorrect, the same scenario would be played out multiple times before the correct heading was chosen and then movement was initiated.

The overall success of both groups of children as they problem solved in the convergent and divergent contexts may be explained through the examination of the program features that allowed for ease of movement throughout the microworlds. The directional keys with their color-coded stickers along with the accompanying color-coded "turtle" stickers around the perimeter of the monitor screen may have provided a level of support or "external cueing" that assisted the children in attending to the directional heading that would be needed for problem solutions.

Another program feature that may have accounted for the more impulsive children's greater degree of success in the divergent problem solving set was the fact that each path charted remained on the screen as the turtle cursor reappeared at the starting point. Since each unique route was charted in a different color, the children could make decisions for new path solutions using previously charted paths as a reference.

Hypothesis 5. Results of the t-test between the mean percentages of attempted moves that resulted in prohibition of forward movement (PFM) of the reflective and the impulsive group of children in the convergent problem solving set showed that the difference was significant. Frequencies were tallied when the turtle's forward movement was prohibited by a barrier in the microworld or the confines of the microworld due to the NOWRAP feature, and then compared to the total number of attempted forward moves in the problem solution to compute a percentage score. It was hypothesized that the reflective group would have a lower percentage of these types of moves because they characteristically have a slower response time (Kagan, 1966; Wright, 1972), and therefore could plan their movements more carefully to avoid barriers.

An important program feature to be considered in an explanation of the above results is the auditory warning cue (BEEP), where the children were told that the turtle would "bump his nose" if he ran against the edge of the screen or into any of the barriers. This added feature of the program served to give the children an auditory as well as a visual cue that it was time to make a directional decision, because the turtle could no longer proceed in the current direction.

Children could have responded in two ways to this feature by either avoiding making the turtle bump his nose causing the BEEP, or by seeing how many times they could make the turtle cause the BEEP. Since the results in the convergent problem solving set showed that the group of children with more impulsive tendencies had a mean percentage of prohibition of forward moves that was almost double that of the more reflective children, it cannot be discounted that these children may have been purposefully making the turtle "bump his nose." If this is true, then the differences do not necessarily reflect differences in their understanding of spatial concepts or motor abilities, but may indeed be a reflection sensory input processing.

Hypothesis 6. Results for hypothesis 6 showed that the difference between the mean percentages of attempted moves that resulted in prohibition of forward movement (PFM) of the reflective and the impulsive group of children in the divergent problem solving set was not significant. Although the reflective group had a lower mean than the impulsive group, the margin between the two became much more narrow. Both groups had higher incidences of PFMs in the divergent problem solving set.

One explanation for the higher means in the divergent set may lie in the fact that all of the children were charting more paths per problem in the divergent problem solving set, and thus had more opportunities to "bump the turtle's nose. For those children who experienced more prohibition of forward movement in paths charted after the first, one might reason that because they were in a hurry to finish the additional paths before the time limit ran out, they did not attend as closely to the movements they were making, and thus ran the turtle into more barriers accidentally.

Another explanation may lie in the fact that the children became bored with the problem and because of loss of interest found it entertaining to make the turtle "bump his nose" causing the auditory cue to BEEP.

Qualitative Analyses

Although no generalizations can be made from the case studies of this group of novice problem solvers, results on the unique strategies and patterns of movement that emerged as the audit trails were examined microanalytically are no less valuable. Much of the information gleaned from this study would have been undiscovered if a case by case approach had not been undertaken. In fact, from the microanalytic analysis of individual audit trails evolved the questions which drove the quantitative analyses. The quantitative hypothesis tested certain variables and answered discrete questions for this researcher; the qualitative studies helped this researcher to appreciate the uniqueness of each child's problem solving style. In quantitative analysis a researcher is concerned with how the outliers may skew the results, from a qualitative approach, studying the outliers may provide the most interesting results.

From the case studies, unique preferences and trends were examined. For example, subject #4 described in Case Study 1 demonstrated the use of a definite strategy in both the convergent and divergent problem solving sets. In 91% of the convergent problem solutions and 92.5% of the divergent problem solutions, he utilized little steps in the move prior to problem solution. This pattern seems to indicate that this child had a good approach to the target before his last move.

The subject described in Case Study 2 highlighted an individual preference to use little steps as a preferred method of moving the turtle through the microworlds. This preference for little step usage is contrary to previous research which reported that young children have a preference for utilizing big steps. Her use of little steps to big steps was consistent across problem solving contexts. The ratio of little steps to big steps in the convergent problem solving set was 2.6:1, compared to 2.4:1 in the divergent problem solving set. Although this young child did use some big step movements, she used little steps exclusively in the solution of the 16 convergent problems and in 12 of the 33 paths she charted in the divergent problem solving set.

The subject described in Case Study 3 also demonstrated a preference for little steps. This preference did not appear to thwart his ability to chart multiple paths in the divergent problem solving set. More than 80% of all of this child's movement decisions resulted in the use of little steps in both the convergent and divergent problem solving sets. It did not seem to matter in what position the cursor or target were in or whether or not there were barriers in the microworld. Since the child was classified as one of the more reflective children, the use of this little step strategy helped her to feel more in control of the turtle and gave her more time to "reflect" on what directional decisions would be needed to get the turtle cursor to the target.

From Case Study 4 a characteristic of impulsiveness seemed to emerge. This child demonstrated multiple incidences of indecision in both sets of problems. The number of directional keys that were pressed before movement was initiated ranged from 10 to 38. In all incidences this child had runs of hitting "4" and "6" keys. It appeared that he would lose focus and "get stuck" for some time period before he could continue with a problem solution.

Although this researcher had no intentions to generalize any of the findings from these case studies to other preschool-age children working in a computer paradigm with Logo, certain impressions were gathered from this small sample. As Short (1991) stated, children need to learn to make appropriate decisions as early as their developmental age will allow. Since these young children had not been exposed to computers prior to their introduction into the preschool classroom, their overall success in the 32 Logo problems provides evidence that young children can be taught to utilize the computer as an aid to problem solving and even short-term exposure seems to encourage and promote sophisticated thinking processes. Papert (1980) proposed that Logo's rich environment can speed up cognitive development through the provision of materials which help to make concepts simpler and more concrete. These problem solving activities provided young problem solvers a variety of opportunities to enhance their understanding of cause and effect relationships and the importance of planning the problem solving process, as well as providing immediate feedback as a result of decisions. Hagen (1984) and Papert (1980) have reported that opportunities such as these stimulate the thought processes and also reasoning and problem solving skills.

It appears that all of the children in this group of 16 demonstrated at least one strategy, and in several cases, multiple strategies in their problem solutions. Some of the strategies were simply a distinct preference for either big or little step. Some children also demonstrated strategic use of diagonal moves in problem solutions. The use of diagonal moves is indicative of viewing the screen as a series of concentric circles, rather than a coordinate grid system (Fay & Mayer, 1987; Watson & Busch, 1989), and represents higher order thinking skills.

Limitations of the Study

Although the qualitative analyses yielded interesting findings in the strategic nature of young children working in a computer paradigm using Logo, there were definite limitations which must be considered. The small sample size limited significant findings. The use of multiple *t*-tests with a small sample was risky. There were also no data on the status of the children's motor skills or on their information processing styles. An understanding of how important visual and/or auditory input was to these children could have been helpful in determining what import the environmental cues of the program had on the children's problem solving abilities.

Implications for Training

This study provided information that should be useful to professionals who are planning curricula and activities for preschool-age children. First, it is important that young children are given opportunities in which to test and evaluate their emerging problem solving skills. It is obvious that children of this age can be taught to use the computer as a problem solving device. Working in a computer-based paradigm within the context of Logo provides children with excellent opportunities to be engaged in the process of discussing learning. It is important that young children be exposed to opportunities that allow for reflection in the decisions which have been made. Opportunities to work in a program such as Logo help to build the bridge between concrete and formal understanding of concepts and facilitates metacognitive abilities. Second, giving children adequate opportunities to work in a divergent thinking context is also beneficial. The creativity of young children should be encouraged in problem solving settings across the preschool curricula. Third, it is not too early (at age four) to begin to teach children how using strategies in their thinking will be beneficial to them in academic settings. If children are taught what a strategy is and how it can be helpful to them before they enter a formal school system, their probability of success in the classroom setting is enhanced.

Conclusions

There has been much debate over the soundness of mixing methods and designs, but Greene, Caracelli, and Graham (1989) postulated five sound purposes for the combining of quantitative and qualitative methods in a single study. This piece of research utilized the two approaches to add scope and breadth to the study of sixteen minority, at-risk preschoolers' decision making and problem solving processes in a computer-based paradigm using Logo. The quantitative analyses allowed for testing of differences as a function of the cognitive stylistic tempos - impulsivity and reflectivity. The qualitative portion of the study allowed the researcher to explore the distinctive characteristics of individual children as they worked through the same problem sets (convergent and divergent), arrived at the same result (getting the "turtle" cursor to the target), yet had uniquely different experiences in the process.

This research has answered a set of questions and has spawned many more. One of the initial questions that was posed was whether or not evaluation of audit trail data can be useful in understanding a cognitive process. To this question, the researcher replies a definite "Yes." Although the process is time-consuming, for children who may be identified as at-risk educationally, studying the audit trails of their work in a problem solving computer-based environment can illuminate certain patterns or strategies that may need to be encouraged and strengthened, remediated, revised, or eliminated to enhance individual decision making and problem solving skills.

This study lead this researcher to question whether or not cognitive style or tempo is the most salient variable to be used as a means of categorization of young subjects in this type of research. Perhaps using a measure of learning style or sensory processing preferences (auditory, visual, or kinesthetic) could lead to better understanding of performance differences. The quest for understanding the cognitive processes of young children from an information processing theoretical perspective will carry researchers into the 21st century.

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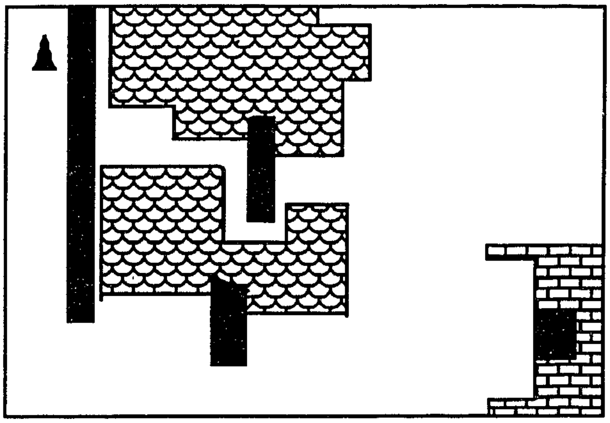
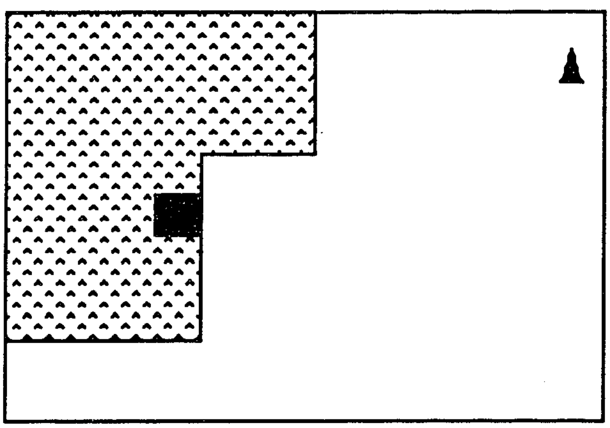
APPENDIX A

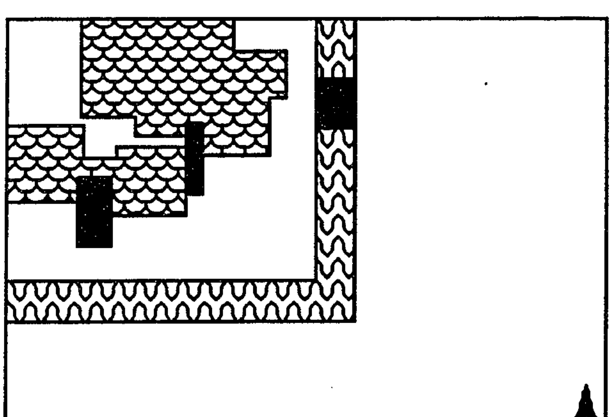
LOGO PROBLEM SOLVING TEST



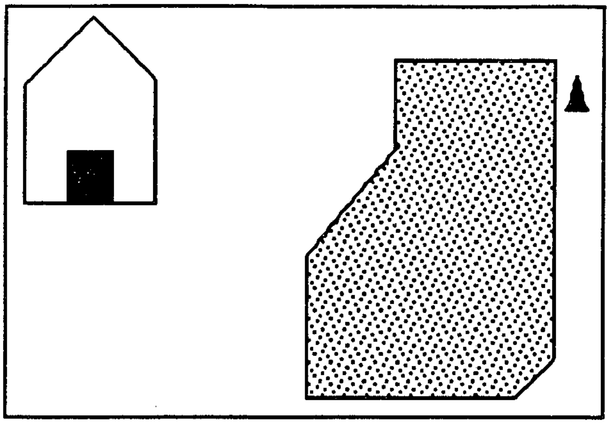
1-C. Mr. Turtle needs to get to school as fast as he can so he can be the first person in line. He cannot climb over the fence or cut through the trees. Help Mr. Turtle get to school so he can be the line leader at school today.



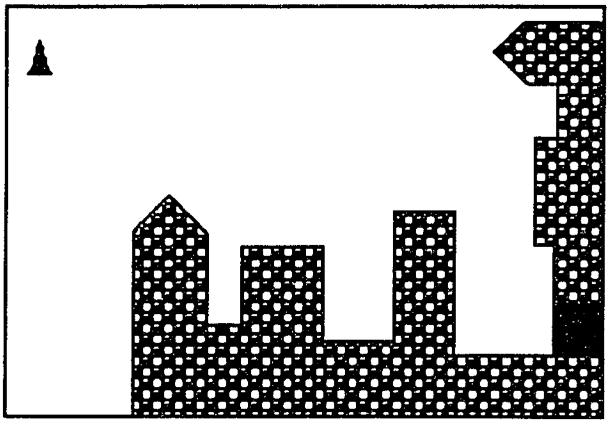
2-D. Mr. Turtle has found a magic box hidden at the edge of the field. Help him get to the box in as many different ways as you possibly can. Once he reaches the box, he will start over again. Each time he finds a new way to get to the box, there is a prize inside for him. See how many prizes you can help Mr. Turtle get.



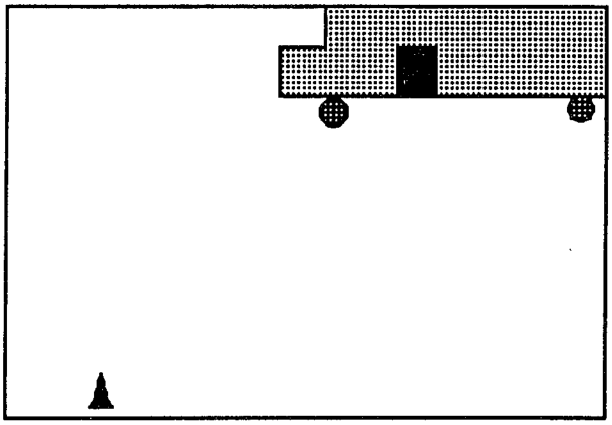
3-D. Mr. Turtle is playing a game. He has to run to the gate that goes into the park. If he finds the most paths that lead to the gate, he will win the blue ribbon. Mr. Turtle needs your help so he can find lots of different ways to get to the gate and be the winner.



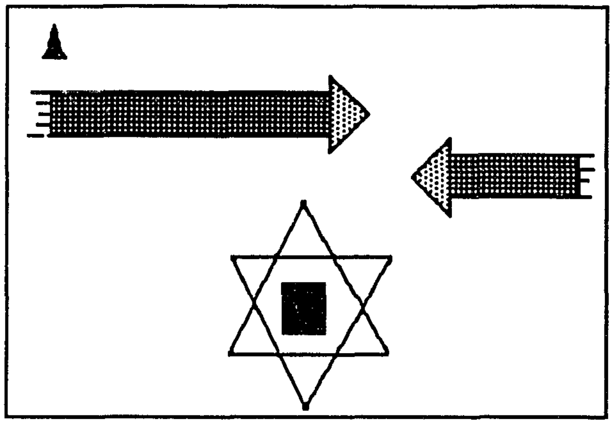
4-C. Mr. Turtle is taking a walk around the lake next to his house and he hears the phone start to ring. Help him run to the house so he he can answer the phone before it stops ringing. He cannot swim across the lake. Help him get to the house as fast as you can because he does not want to miss the phone call from his Grandma.



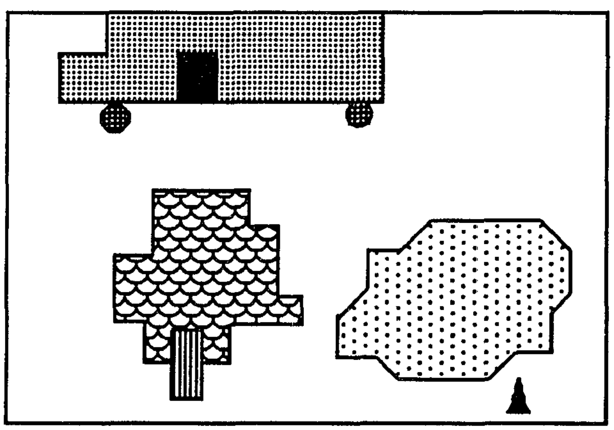
5-D. Mr. Turtle is trying to save all the princesses in the pink castle. He must get to the black door to rescue each one. Once he gets the first princess, he must start all over again. See how many princesses you can help Mr. Turtle save.



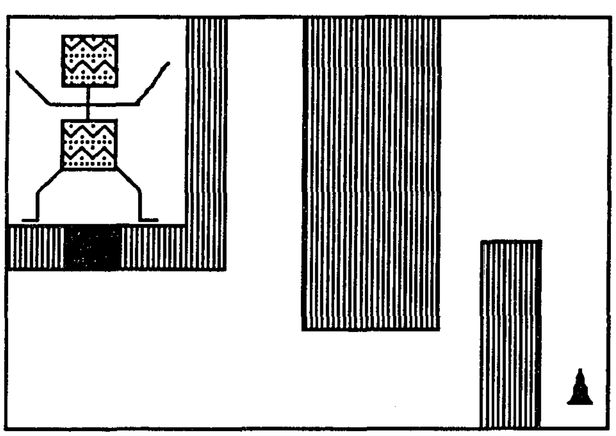
6-C. Mr. Turtle wants to be the first turtle to get on the school bus. If he gets to the bus before anyone else he can sit in the front seat next to the driver. Help Mr. Turtle get to the bus as fast as he can.



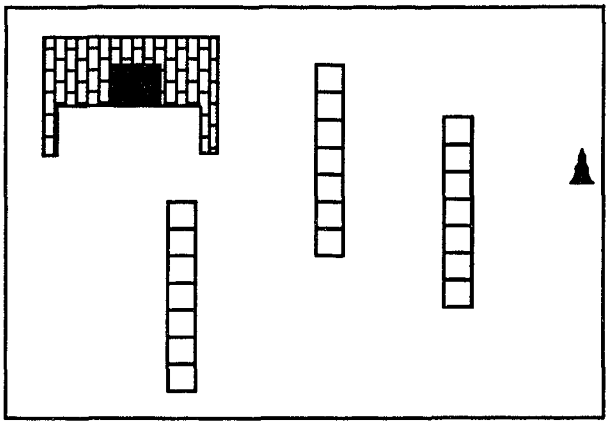
7-C. Mr. Turtle is an astronaut. He is out taking a walk in space. Help him to be the first turtle to stand in the middle of a star. He cannot walk over his rocket ship. Get him to the star the fastest way you can.



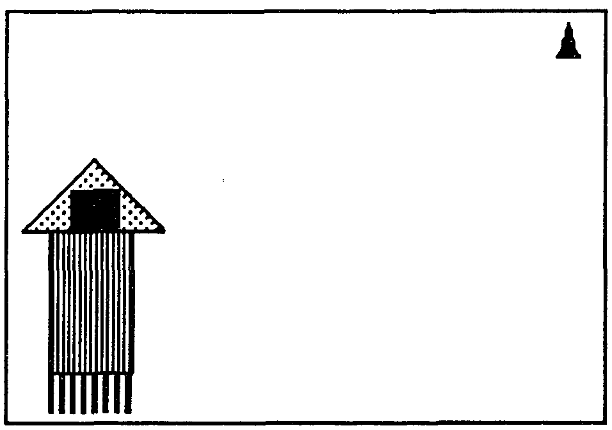
8-D. Mr. Turtle is at the park. He wants to see how many different ways he can find to get back to his school bus. He cannot swim across the lake or go through the trees to get to the bus. Help him figure out as many ways as you can to get back to his bus.



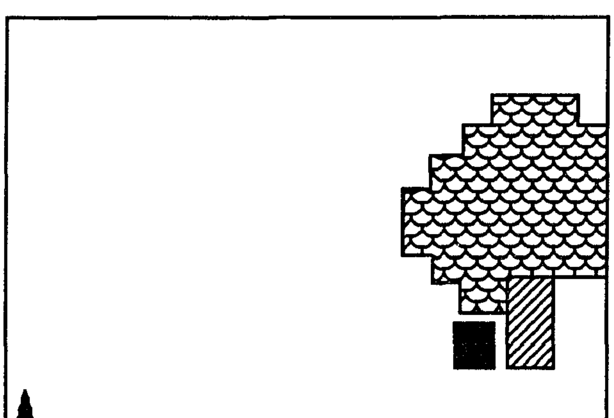
9-C. Mr. Turtle's robot "Harry" has run away. He is hiding in Mr. Turtle's library behind some shelves of books. Help Mr. Turtle find Harry and push the orange button at Harry's feet so he will stay still. Help Mr. Turtle get to Harry before he can run away again!



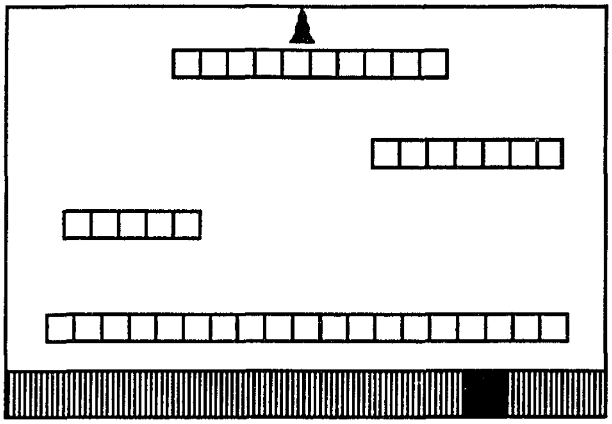
10-D. The Teenage Mutant Ninja Turtles are going to be at Mr. Turtle's school today. Everytime Mr. Turtle finds a new way to get to the front door of his school he gets to meet a different turtle. Mr. Turtle cannot walk through the flower beds in front of the school to get to the front door. Help Mr. Turtle find as many different ways as he can to get to the door so he can meet all the turtles today.



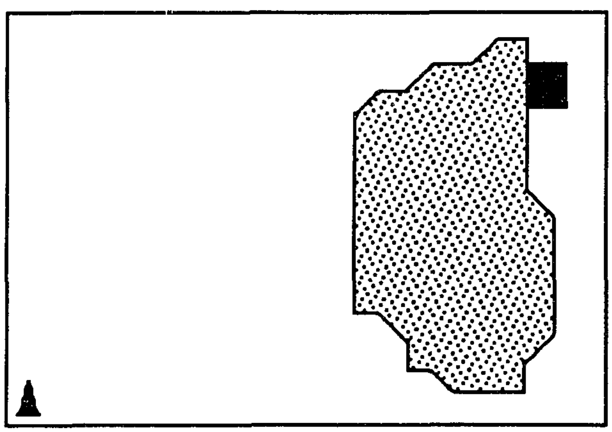
11-C. Mr. Turtle is an astronaut. He has been taking a walk in space and has gotten very hungry. It's time for lunch, and Mr. Turtle must hurry to get back to the spaceship. Help Mr. Turtle get back inside the door of his spaceship as fast as he can so his food will not get cold.



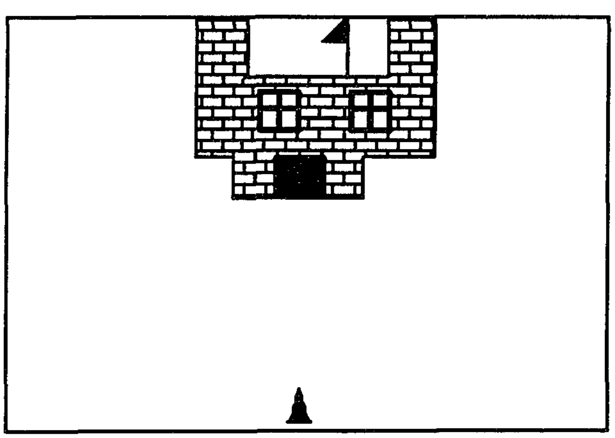
12-C. Today is Mr. Turtle's birthday. His birthday present is underneath the tree. He is very excited to find out what is inside of the box. Help him run to the box as fast as he can so he can find out what his birthday surprise is.



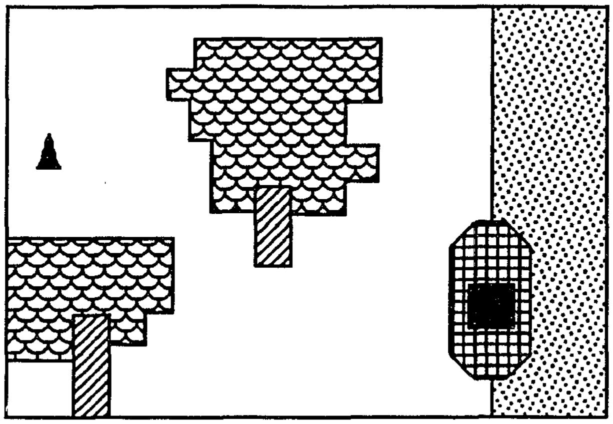
13-D. Mr. Turtle is on a walk to the park. Someone has put up several fences that Mr. Turtle must walk around before he can get to the gate at the park. Help Mr. Turtle find as many different ways as he can to get to the gate. Remember: Mr. Turtle must walk around the fences; he cannot climb over them.



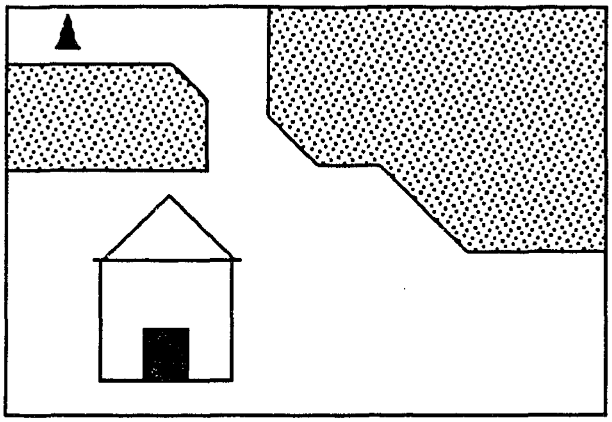
14-D. Mr. Turtle likes to go fishing at the lake. Each time he goes to the fishing pier he likes to take a different path. Mr. Turtle wants you to help him find some new ways to walk to the fishing pier. Help him find as many new ways to walk around the lake to the pier as you can.



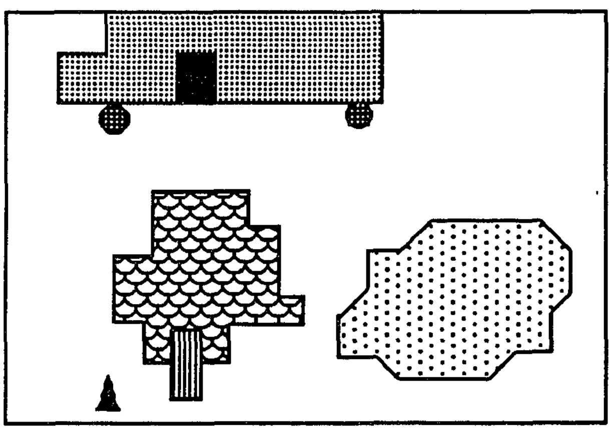
15-C. Mr. Turtle has over-slept and is late for school. Help him get inside the door before his teacher gets angry with him.



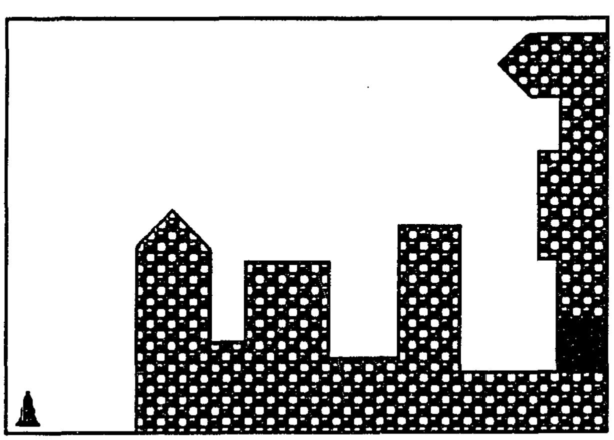
16-D. Mr. Turtle wants to take a ride on the lake in the big boat. Every time he finds a new way to get into the boat he gets another ride. Help Mr. Turtle find as many ways to get to the boat as he can so he can get lots of boat rides.



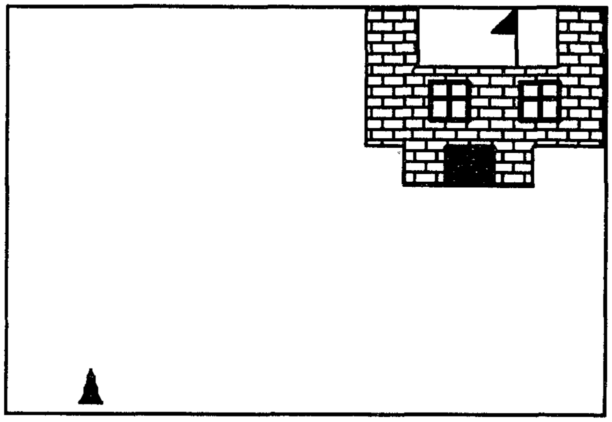
17-C. Mr. Turtle is camping. He needs to find the park ranger's cabin as fast as he can. He cannot swim across the lakes. Help Mr. Turtle see if the park ranger is home.



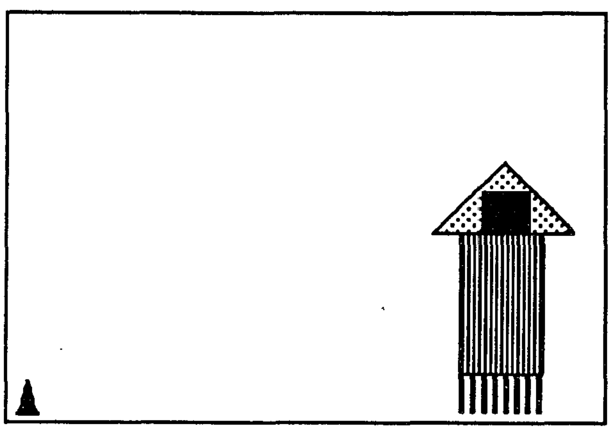
18-D. Mr. Turtle is at the park. He wants to see how many different ways he can find to get back to school bus. He cannot swim across the lake or go through the trees to get to the bus. Help him figure out as many ways as you can to get back to to his bus.



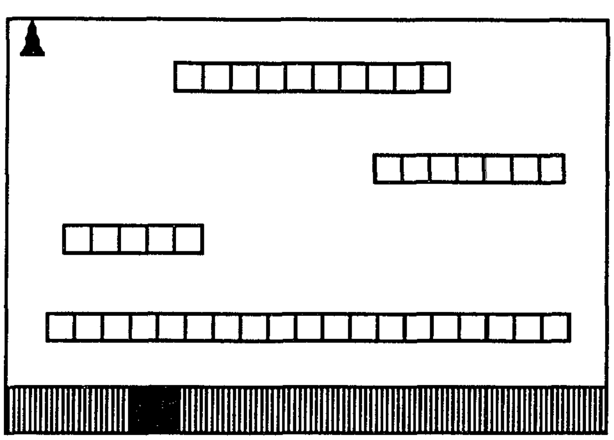
19-D. Mr. Turtle is trying to save all of the princesses in the pink castle. He must get to the black door to rescue each one. Once he gets the first princess, he must start all over again. See how many princesses you can help Mr. Turtle save.



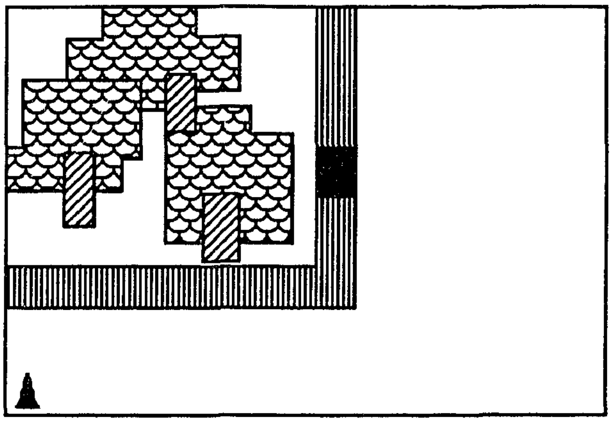
20-C. Mr. Turtle is out on the playground next to his school. It is time to come inside now. Help Mr. Turtle be the first turtle to reach the school door.



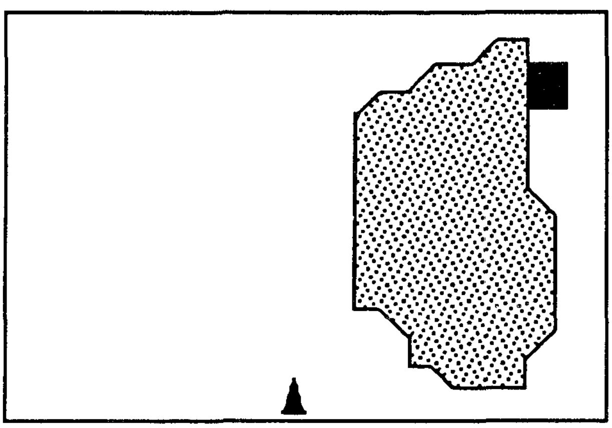
21-C. Mr. Turtle is an astronaut. He is taking a walk on the moon, but he needs to get back to his spaceship right away. Help him find the shortest path back to his spaceship.



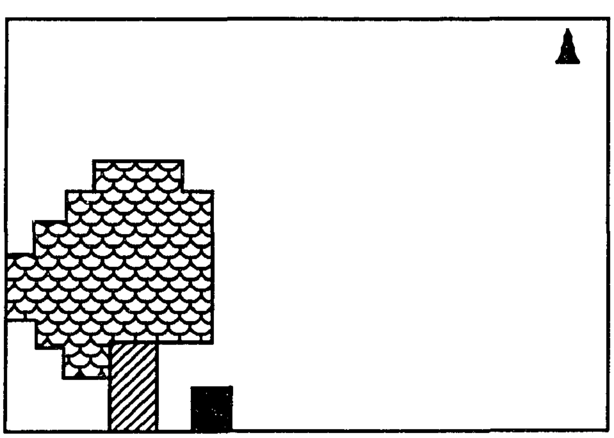
22-D. Mr. Turtle is on a walk to the park. Someone has put up several fences that Mr. Turtle must walk around before he can get to the gate of the park. Help Mr. Turtle find as many different ways as he can to get to the gate. Remember: Mr. Turtle must walk around the fences; he cannot climb over them.



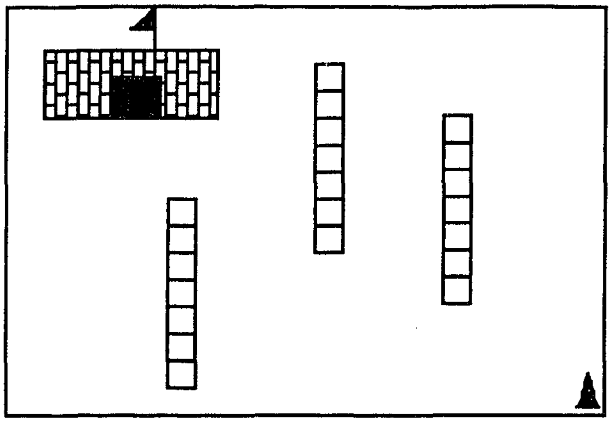
23-D. Mr. Turtle is playing a game. He has to run to the black gate that goes into the park. If he finds the most paths that lead to the gate, he will win a blue ribbon. Mr. Turtle needs your help so he can find lots of different ways to get to the gate and be the winner!



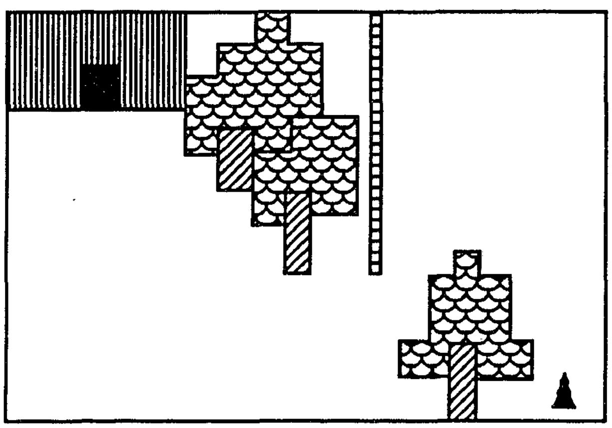
24-D. Mr. Turtle is out for an afternoon swim in the lake. He likes to jump off the pier and then swim to the other side of the lake. See how many different ways you can help him to run to the pier so he can jump into the water.



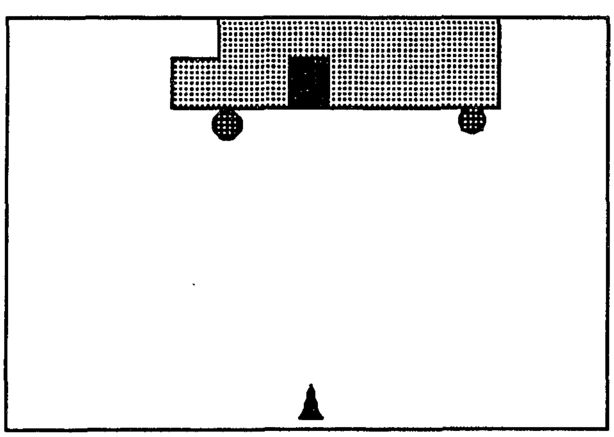
25-C. Mr. Turtle sees that there is a puppy in the box under the tree. Help Mr. Turtle get over to the box to let the puppy out so they can play.



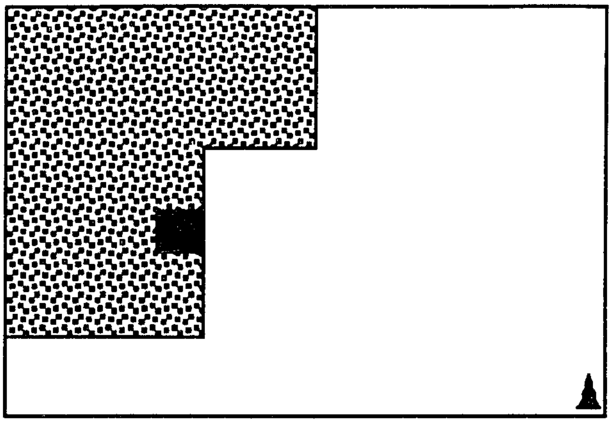
26-D. Mr. Turtle wants to see how many different ways he can get to the door of the school. Each time he wants to go around the flower beds in a different way. See how many times you can help Mr. Turtle get at the school door.



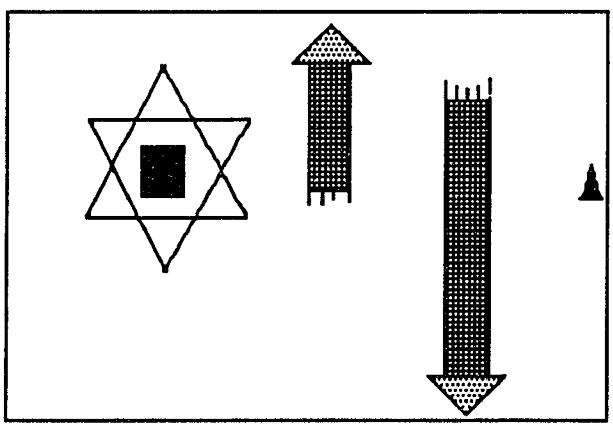
27-C. Mr. Turtle is taking a walk in the park, but it starts to rain. Help Mr. Turtle run to the picnic shelter as fast as he can so he will not get wet.



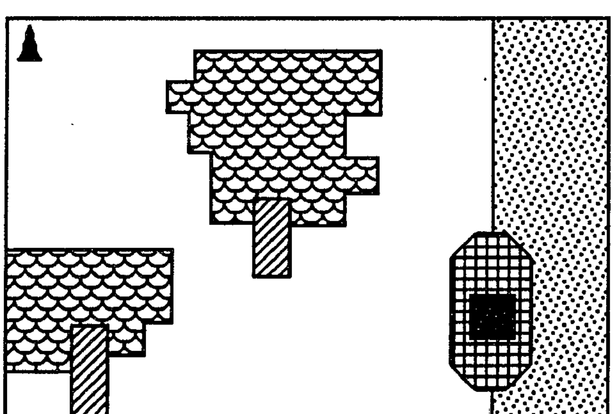
28-C. Mr. Turtle over-slept and he is about to miss the bus. Help Mr. Turtle get out to the bus before the bus driver leaves him behind.



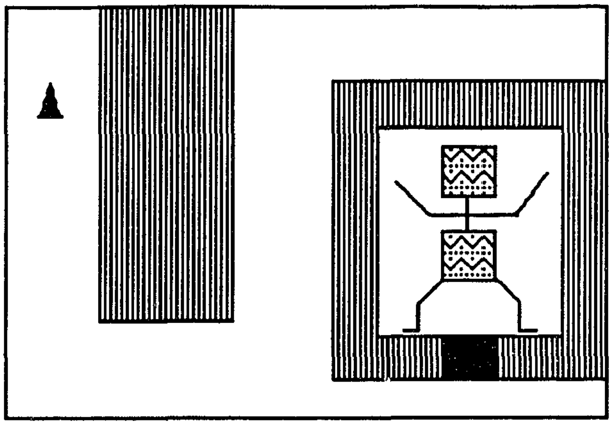
29-D. Mr. Turtle has found a magic black box at the edge of the field. Help him get to the box in as many different ways as he possibly can. Once he reaches the box, he will start over again. Each time he finds a new path to the box there is a prize inside for him. See how many prizes you can help Mr. Turtle get.



30-C. Mr. Turtle is an astronaut. He is out taking a walk in space. Help him to be the first turtle to stand in the middle of the star. He cannot walk over his rocket ship. Help him get to the star the fastest way he can.



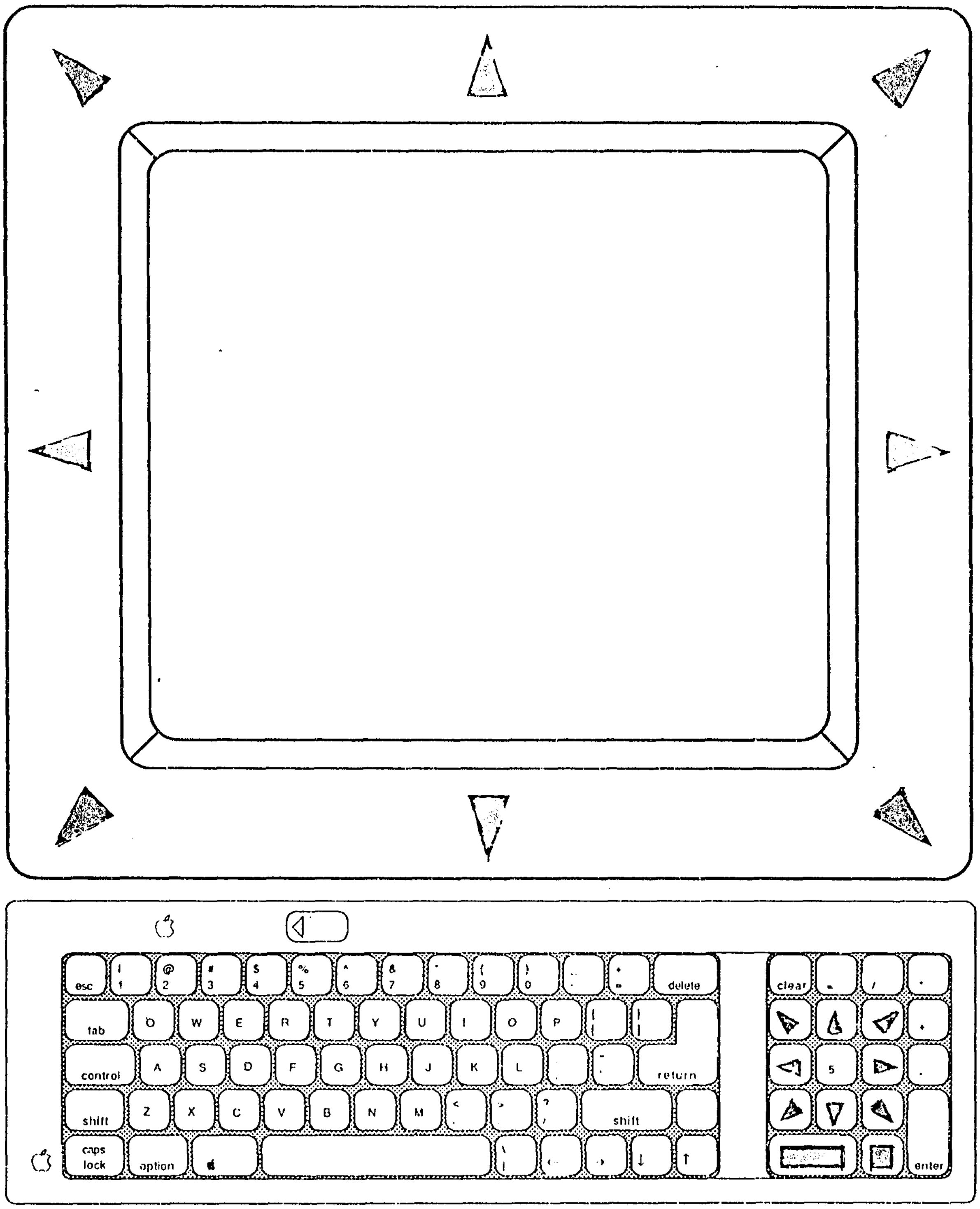
31-D. Mr. Turtle wants to take a ride on the lake in the big boat. Every time he finds a new way to get into the boat he gets another ride. Help Mr. Turtle find as many ways to get to the boat as he can so he gets lots of boat rides.



32-C. Harry the robot has run away again and has locked himself in the closet. Help Mr. Turtle find Harry as fast as he can and open the door to the closet so Harry can get out.

APPENDIX B

SYNTONIC COMMAND KEYBOARD AND MONITOR


esc
delete
tab
Q W E R T Y U I O P
control
A S D F G H J K L
return
shift
Z X C V B N M
shift
caps lock
option
clear
5
enter

APPENDIX C

LOGO LESSON PLANS

LOGO LESSON PLANS

WEEK 1 RESEARCH PROJECT

DAY 1:

Task 1:

Explain that cursor will be called a "turtle" and the child may point the turtle in the direction that he/she wants to move.

Task 2:

Demonstrate that touching the orange "turtle keys" will make the turtle point up, down, right side, and left side.

Task 3:

Show the child the "green little step" key and "orange big step" key and explain that once the turtle points in the correct direction, the turtle can move forward in big or small steps.

Practice 1:

Ask child to point to top of screen.
Ask child to point turtle towards top of the screen..
Ask child to move turtle a little step.
Clear screen.
Ask child to move turtle a big step.
Clear screen.

Practice 2:

Ask child to point to bottom of screen.
Ask child to point turtle towards bottom of the screen and then move turtle 2 little steps.
Clear screen. Repeat first question.
Ask child to move turtle 2 big steps.
Clear screen.

Practice 3:

Ask child to point to right side of the screen.
Ask child to point turtle towards right side of the screen and then move turtle 1 little step and 1 big step.
Clear screen. Repeat first question.
Ask child to point turtle towards right side of the screen and then move turtle 1 big step and 1 little step.

Clear screen.

<u>Practice 4</u>:

Ask child to point to <u>left side</u> of the screen.
Ask child to point turtle towards left side of the screen and then move turtle <u>2 little steps and 2 big steps</u>.
Clear screen. Repeat first question.
Ask child to point turtle towards <u>left side</u> of the screen and then move turtle <u>2 big steps and 2 little steps</u>.
Clear screen.

Give assistance as needed anytime during any of the practice sessions.

If a child has difficulty deciding which key to press, point to the direction of the screen where he/she is to point the cursor, then point to the correct cursor key.

If a child still seems uncertain, have the child point to top, bottom, right side, and left side of the screen and repeat the directions after the instructor.

Repeat. Have child point to appropriate cursor keys and name them.

If a child seems to understand what is being asked of him/her, allow the child to repeat Practices 1-4 for the remainder of the session.

LOGO LESSON PLANS

WEEK 1 RESEARCH PROJECT

DAY 2:

Task 1:

Review orange direction keys and the greem little step and orange big step keys.

Task 2:

Explain that today the child will learn to point to the corners of the screen. (Instructor points to corners of the screen - top right, bottom right, bottom left, and top left.)

Point to green cursor direction keys and repeat the directions

Task 3:

Explain that little step and big step keys will work just as they did the day before.

Practice 1:

Ask child to point to top right corner of screen.
Ask child to point turtle towards top right corner of the screen and move turtle one litle step.
Clear screen. Repeat first question.
Ask child to point turtle towards top right corner of the screen and move turtle one big step.
Clear screen.

Practice 2:

Ask child to point to bottom right corner of screen.
Ask child to point turtle to bottom right corner move turtle 2 little steps.
Clear screen. Repeat first question.
Ask child to point turtle to bottom right corner move turtle 2 big steps.
Clear screen.

Practice 3:

Ask child to point to bottom left corner of screen.
Ask child to point turtle to bottom left corner and move turtle 2 little steps and 1 big step.

Clear screen. Repeat first question.
Ask child to point turtle to <u>bottom right corner</u> and move turtle <u>2 big steps and 1 little step</u>.
Clear screen.

<u>Practice 4</u>:

Ask child to point to <u>top left corner</u> of the screen.
Ask child to point turtle to top left corner and move turtle <u>1 little step and 2 big steps</u>.
Clear screen. Repeat first question.
Ask child to point turtle to <u>top right corner</u> and move turtle <u>1 big step and 2 little steps</u>.
Clear screen.

Give assistance as needed anytime during any of the practice sessions.

Repeat as directed in Day 1.

LOGO LESSON PLANS

WEEK 1 RESEARCH PROJECT

DAY 3:

Task 1:

Review "green corner direction keys" and the green little step and orange big step keys.

Task 2:

Explain that today the child will practice making the turtle move in all different and take both big and little steps.

Practice 1:

Ask child to point turtle to bottom of the screen.
Ask child to move turtle 2 big steps.
Clear screen.

Practice 2:

Ask child to point turtle to left side of the screen.
Ask child to move turtle 3 little steps.
Clear screen.

Practice 3:

Ask child to point turtle to bottom right corner of the screen.
Ask child to move turtle 2 big steps and 3 little steps.
Clear screen.

Practice 4:

Ask child to point turtle to top left corner of the screen.
Ask child to move turtle 3 little steps and 2 big steps.
Clear screen.

Practice 5:

Ask child to point turtle to top of the screen.
Ask child to move 2 big steps.
Ask child to point turtle to bottom of the screen.
Ask child to move 3 big steps and 3 little steps.
Clear screen.

Practice 6:

Ask child to point turtle to right side of the screen.
Ask child to move 1 little step and 3 big steps.
Ask child to point turtle to bottom left corner of the screen.
Ask child to move 3 little steps and 2 big steps.
Clear screen.

Give assistance as needed anytime during any of the practice sessions.

Repeat as directed on Day 1.

LOGO LESSON PLANS

WEEK 1 RESEARCH PROJECT

DAY 4:

Repeat practice sessions for Day 3.

DAY 5:

See index cards 1-12.

APPENDIX D

CONVERGENT AND DIVERGENT TRAINING

Convergent Problem Solving Training

Weeks 2 and 3

Explain to child that there is only one shortest, quickest path that will take the turtle to the target box. Demonstrate on Practice 1 Screen the correct path that will give the only correct answer to the problem.

Explain to the child that for each problem there is only one correct path that can be taken. Emphasize that the child is to find the shortest, quickest path to get the turtle into the target box.

Explain to the child that youy want him to draw the one path that he thinks is the shortest, quickest way to the target box. After the child charts a path, the next practice screen will appear.

When the child has completed all six practice screens, the series of screens will repeat themselves. The child may go through the series as many times as he/she can during the training session. When the 15-minute session is complete, press Q. You will get the "Enter child's name" prompt. You are now ready for the next child to begin Convergent Problem Solving Training.

After the last child has had training and "Q" has been pressed, you will get another "Enter child's name" prompt. At this point press "Enter." This will take you to "Welcome to Logo" and the disk can be removed.

Divergent Problem Solving Training

Weeks 2 & 3

Explain to child that the turtle can get into the target box by taking any number of different paths. Demonstrate on the Practice 1 Screen several different paths that might be chosen.

Explain to the child that every path he chooses that will allow the turtle to get into the target box will be correct.

Explain to the child that you want him to draw as many different paths to the target box as he/she can. Each time the child charts a successful path the "turtle cursor" will return to the initial starting position.

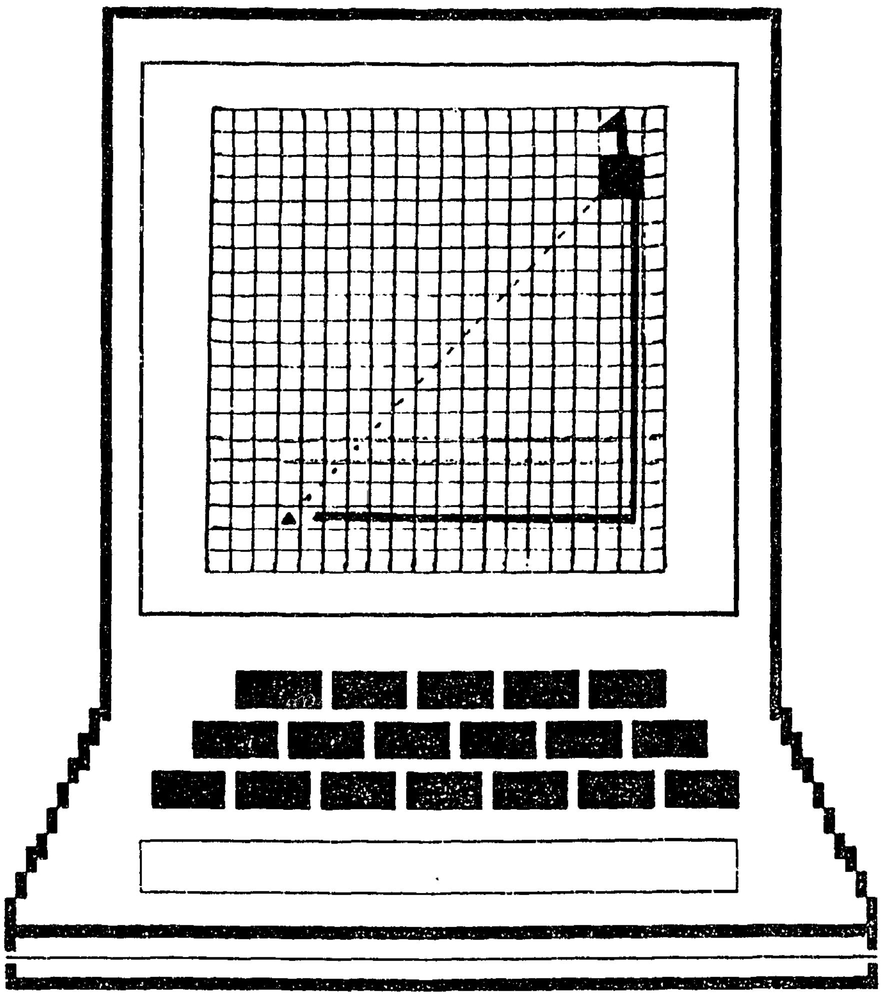
Time the child for 2 minutes. At the end of two minutes, press E. The screen will move to Practice Screen 2. Repeat Procedure. At the end of Practice Screen 6, press Q. You will get the "Enter child's name" prompt. You are now ready for the next child to begin Divergent Problem Solving Training.

After the last child has had training and "Q" has been pressed, you will get another "Enter the child's name" prompt. At this point press "Enter." This will take you to "Welcome to Logo" and the disk can be removed.

APPENDIX E

EXAMPLE OF A PROBLEM IN THE CONVERGENT LOGO PROBLEM SOLVING SET

Example of a problem in the Convergent Logo Problem Solving Set



Subject saw the computer screen as shown above; however, the grid system was invisible. Directions were given that the turtle needs to get from his home to Turtle School. He needs to take the shortest route or he will be late. Subject was asked to find the one route that would get the turtle to school on time.

The computer was programmed to calculate the most direct path and to record the number of grids that were passed through if that route was taken. As the subject chose a solution, the computer kept a record of the route (the audit trail) utilized in solving each problem.

.... Most direct path calculated by the computer
_____ Path chosen by subject

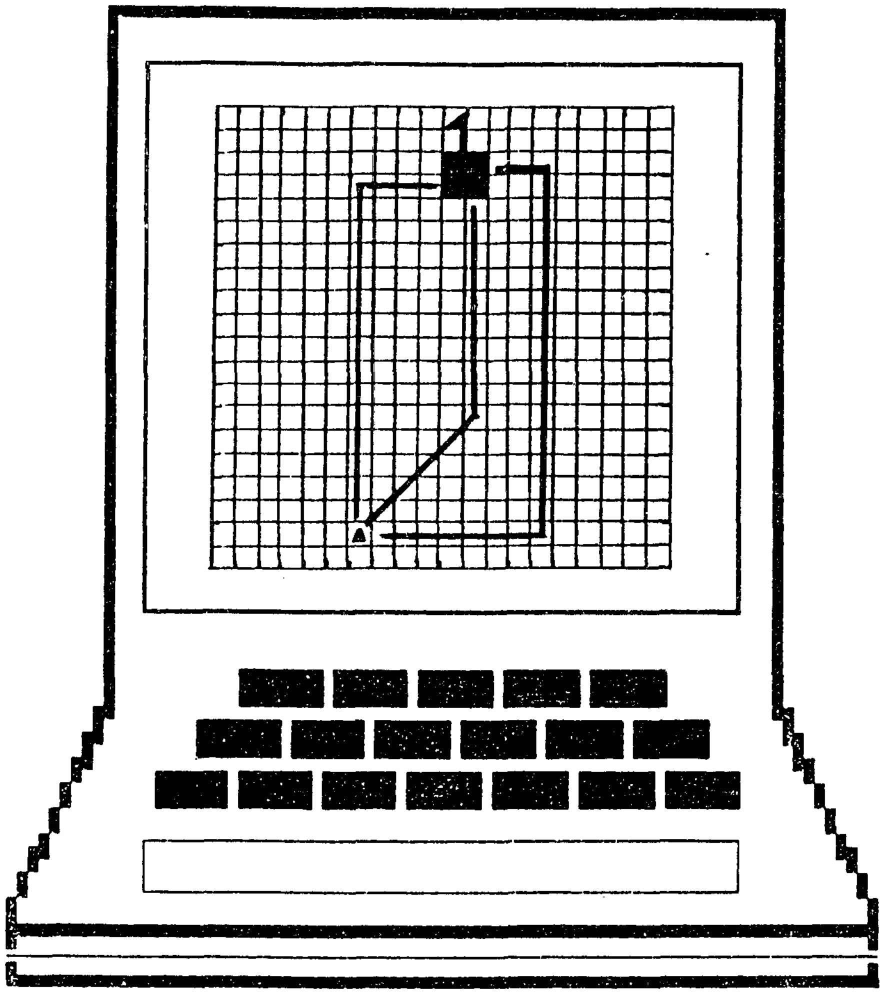
Stored path audit trails for this problem might look like the following:

60000080000.. or 6...............800........

APPENDIX F

EXAMPLE OF A PROBLEM IN THE DIVERGENT LOGO PROBLEM SOLVING SET

<u>Example of a problem in the Divergent Logo Problem Solving Set</u>



Subject saw the computer screen as shown above; however, the grid system was invisible. Directions were given that the turtle needs to get from his home to Turtle School. He can choose any number of ways to get there since there is no 'one best way.' Subject was asked to find as many routes as possible (in two minutes) that the turtle could take that would get him to school.

The computer was programmed to record each different route chosen by the subject (the audit trail) in solving each problem.

____ Paths chosen by subject (each path was charted on screen in a different color and all charted paths remained on the screen during the two minute time limit.

Stored path audit trails for the three routes charted above might look like the following:

80000060. 9.....800.... 6..008.000004...

APPENDIX G

CASE STUDIES

CASE STUDY 1

Results

Terrell was characterized as having reflective characteristics according to his KRISP score. Scores achieved on the Classroom Behavior Inventory and the Kohn Social Competence Scale - Preschoolers validated categorizing Terrell as reflective.

Convergent thinking problems. Examination of the audit trails from his problem solving experiences yielded interesting results. First, he utilized 82 directional moves in solving the sixteen convergent thinking problems. This represents a mean of 5.1 decision points per solution path. Of the 82 moves, 12, or 14.6% were diagonal moves. Diagonal moves were employed in 6 of the 16 problem solutions. Six of the twelve diagonal moves (50%) were made as the initial move in a problem solving solution. The other diagonal moves were made as second, third, or fourth moves; but none were utilized in the final move to get the turtle to the target.

Research has also documented that children solve problems more easily from a left to right perspective, and also, from a bottom to top perspective. The problems in which Terrell utilized diagonal moves represents all four orientations, including top-to-bottom, bottom-to top, right-to-left, and left-to-right. Table 1 shows the frequencies and percentages of diagonal moves in both convergent and divergent contexts.

Table 1

Frequencies of Diagonal Moves in Convergent and Divergent Problem Solving

	Directional Heading				
Test Type	Top-right to Bottom-left (1)	Top-left to Bottom-right (3)	Bottom-right to Top-left (7)	Bottom-left to Top-right (9)	Percentage of all Directions
Convergent	4	2	2	4	14.6
Divergent	14	16	22	12	22.4
Total	18	18	24	16	20.7

Researchers have consistently reported that children use more big steps than little steps, and Terrell's performance did not challenge those findings. He made 67 decisions to use big steps and only 15 decisions to use little steps in convergent problem solutions. This represents 81.7% and 18.3% of the total movement steps, respectively. Little steps were used in eleven of the sixteen problem solutions (68.8%); and in ten of these eleven solutions, little steps were used as the move just prior to problem solution.

From audit trail analysis one can view the number of instances in which Terrell was indecisive about which directional heading to take in order to proceed with the problem solving process. Terrell had only four instances of indecision in all 82 directional decisions he made while solving the sixteen convergent problems, representing an indecision point percentage of 4.8%. All four of the indecision points occurred in three problems. One of the instances involved four successive directional heading changes before a movement key was selected. Two of the three problems in which indecision occurred were barrier free, meaning there were no obstacles in the microworld that would interfere with or block the path of the turtle. In the one problem that contained a barrier, the indecision point occurred after the barrier had been negotiated, and the turtle was approaching the target. This also represented the only time in the convergent problem solving set that an indecision point resulted in a choice of a diagonal move. In one of the barrier-free problems, Terrell had difficulty deciding in which direction to proceed before his initial move was made. The three problems in which indecision occurred also represented a variety of starting point cursor positions and target positions, including bottom-to-top, top-to-bottom, and top-to-top, as well as left-to-right and right-to-left orientations.

Divergent thinking problems. Terrell completed 47 solution paths in the 16 divergent problems, an average of

2.9 completed routes per problem in the two-minute time limit. A breakdown of his success includes five problems in which he completed two uniquely different paths, seven problems where his completion rate was three paths; and four problems in which he charted four different paths within the time limit. In the first eight divergent problems, Terrell charted twenty solution paths; in the last eight divergent problems, his solution rate increased to twenty-seven.

He made a total of 286 directional moves in the 47 solution paths. This represents a mean of 6.6 decision points per solution. Of the 286 moves, 66, or 23.1% were diagonal moves. He utilized diagonal moves in thirteen of the sixteen divergent problems (81.2%), for a total of twenty-nine paths or 61.7% of all paths charted in the divergent problem-solving set.

The data in Table 1 show how Terrell utilized more diagonal moves (22) in the right-to-left, bottom-to-top spatial orientation than in the other three problem orientations. Eight of the problems in which diagonals were used contained barriers of some type, while five of the problems were barrier free.

In four of the problems (#2 solution 1, #18, solution 3, #31 solution 1, and #31, solution 3) Terrell used diagonals five or six different times in his solution paths. In two of these problem solutions, all four possible diagonals were utilized in reaching the target. Diagonals were used in the initial moves in nineteen (40.4%) of the divergent problem solutions, and differing from the convergent problems, they were utilized as final moves to the target in six (12.7%) of the solutions.

Divergent audit trail data are consistent with the convergent data in respect to big and little steps. Terrell used 261 big steps and 44 little steps in completing the solution paths. This represents 85.6% and 14.4% of the total movement decisions, respectively. Little steps were used more frequently at or near the end of the problem solutions, rather than at the beginning. A total of 49.8% of all little-step-moves were made as the move just prior to problem solution. This strategy occurred in 24 problem solutions. However, out of the last four divergent problems, which represented fifteen solution paths and 89 decisions about movement, Terrell only used little steps three times. Of these three times, two of them were used as the move prior to problem solution.

There were eighteen instances of indecision about directional heading, which represents a 6.5% indecision point percentage. The indecision points were located in fifteen of the 47 solution paths and involved ten of the problems. Five of the microworlds which appeared to cause some difficulty for Terrell were barrier-free, while the remaining five did contain at least one obstacle or barrier that had to be negotiated before the target could be reached. In four of the problem solutions, the indecision point occurred prior to the first movement decision. Table 2 shows in which solution paths the points of indecision occurred.

Table 2

Divergent Solution Paths in Which One or More Points of Indecision Occurred

Problem Number	Barrier/ No Barrier	First Solution	Second Solution	Third Solution	Fourth Solution	Total Solutions
8	Barrier	√	-			2
10	Barrier	-	√	-		3
18	Barrier	√	-	-		3
19	No Barrier	-	-	√		3
22	Barrier	√	√	√		3
23	No Barrier	-	-	√		3
24	Barrier	-	-	√	-	4
26	Barrier	-	√	-	√	4
29	No Barrier	-	-	√		3
31	Barrier	-	√	√	√	4

It is apparent from Table 2 that indecisions occurred more frequently in the paths succeeding the completion of the initial solution. Twelve of the fifteen points of indecision occurred in the second, third, and fourth solution paths. The data also indicate that indecisions about directional heading occurred more frequently in the problems that contained some type of barrier. Problems 22 and 31 seemed to be most problematic, with three instances of indecision in problem 22 and four instances in problem 31. Only two times did indecision about directional heading result in Terrell's use of a diagonal move. Both of these occurred in problem 31.

Discussion

Diagonal moves usually are executed more easily when children learn to view the computer screen as a concentric circle system of angle rotations, rather than as a grid system based on coordinates. This conceptualization represents what Campbell et al. (1986), referred to as a stage that occurs later developmentally and to what Watson and Bush (1989) referred to as Level IV of the spatial thinking model within the Logo microworld. The ability to maneuver in the microworld using a system of angles is representative of higher order thinking skills on the "chain sequence of cognitive achievements" (Watson & Busch, 1989, p. 14).

Only six of the thirty-two microworlds in which diagonals were employed in both the convergent and divergent problem-solving sets had any visual cues which might have influenced the use of diagonal moves in maneuvering the turtle towards the target. Other microworld problems also had visual cues that were created using diagonal lines, but Terrell did not appear to be influenced by their presence in the field and operated using forward and right angle turns in his problem solutions. His ability to overcome the influence of the visual cues within the contextual field of the microworlds may be attributable to his field independent strength. This allowed him to be free of the contextual clues, to not become distracted by the barriers, and to concentrate on the task of moving the turtle from his starting point to the target.

The examination of the divergent data revealed that once a choice had been made to utilize diagonal moves in the first or second solution path, it was highly likely that a diagonal would be used somewhere in succeeding routes. Therefore, it may not have been contextual clues from within the microworld that influenced Terrell's use of diagonal moves, but the presence of his previous routes on the screen that were influencing his continued use of diagonals. It could be that Terrell was also enjoying the freedom to create a variety of shapes on the screen in the divergent problems that impacted his use of diagonal moves.

It was apparent, however, that in some of the microworlds, the visual cues might have influenced Terrell's choice of directional moves. Rectangular barriers seemed to be most influential in both the convergent and divergent problem solving sets. Terrell would usually follow along a perimeter path around the rectangular barrier, and then proceed toward the target.

In reviewing the data from Table 1, it appears that Terrell was equally comfortable using all four diagonal perspectives in his problem solutions. This was further confirmed by the fact that only four times in all of the problem solutions did Terrell exhibit some indecision about directional heading prior to choosing a diagonal move. The Syntonic Command System with its color coding "turtle" stickers on the keyboard and also on the perimeter of the monitor may be responsible for the comfort level of this student using all 8 directional headings from a variety of spatial orientations.

In examining the problems in which Terrell experienced some indecision points, it was important to keep in mind that he was successfully able to chart paths in other microworlds with these same spatial layout orientations. It will be interesting to examine the data after all case studies are complete to determine if certain problems posed difficulties to a majority of the students. At this time it is difficult to speculate about what features of the problems caused the difficulties.

One of the most interesting findings from audit trail analysis on Terrell's convergent problem-solving data was the appearance of a definite strategy. His initial moves were always made in big steps. However, Terrell utilized little step moves in eleven of the sixteen problems; and each time they were used when he was close to reaching the target.

In ten of the eleven convergent problems, little steps were made just prior to the last move which would solve the problem. It appears that Terrell used little steps to ensure a correct heading before making his final move to reach the target. In only one of the sixteen problems (6.2 %) did Terrell utilize a little step to move the turtle onto the target. After using the little steps to get close, Terrell solved the other fifteen problems by choosing a directional heading and using big steps to carry the turtle to the target.

The divergent problem-solving data revealed a continued use of this strategy. In 92.5% of the routes that utilized little steps in the solution, they were used as the move prior to problem solution. This strategy occurs frequently enough not to be random, or haphazard in nature. As in the convergent tasks, it appears that Terrell would utilize the little steps to ensure he had a good approach to the target before his last move.

The "bump the nose" audio cuing feature of the program, also helps to explain how Terrell knew he did not have to be precise with all of the turtle's movements. If he moved the turtle too far using big steps which caused him to "bump" into a barrier or the perimeter wall, Terrell learned quickly that the turtle would simply stop and beep. This signal cued him that he needed to change directions, because forward motion in the current direction was prohibited. This may explain why he only utilized little steps when he was in close proximity to the target.

Overall, it appears that Terrell found no particular difficulties with the barriers in the problems. Although he did "bump the nose" of the turtle on the barriers in a variety of problems, he almost always recovered his sense of where he needed to be going on the following move. It also appears from the visual inspection of the audit trail data and the microworlds that were created from those data, that Terrell was able to make a mental map and work his way to the target with a great deal of success.

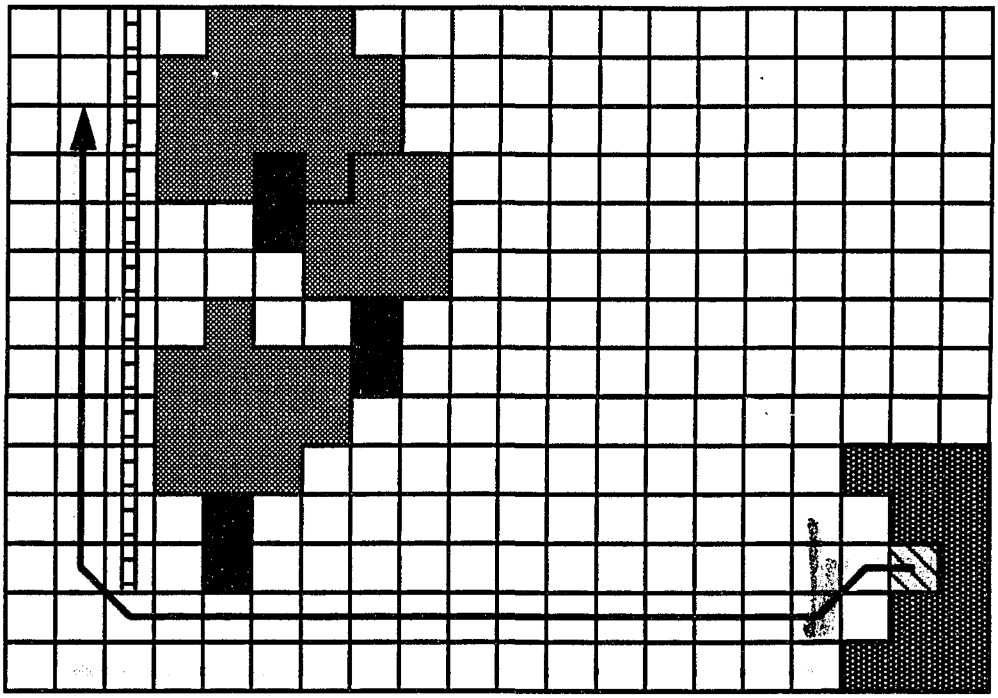
Convergent Problem Solving Set

Orange lines represent big steps
Green lines represent little steps
Bold black line represents shortest possible path

<u>Convergent Problem Solving Set</u>

Orange Lines Represent Big Steps
Green Lines Represent Little Steps
Solid Black Line Represents Shortest Possible Path

Test 1A - Problem 1



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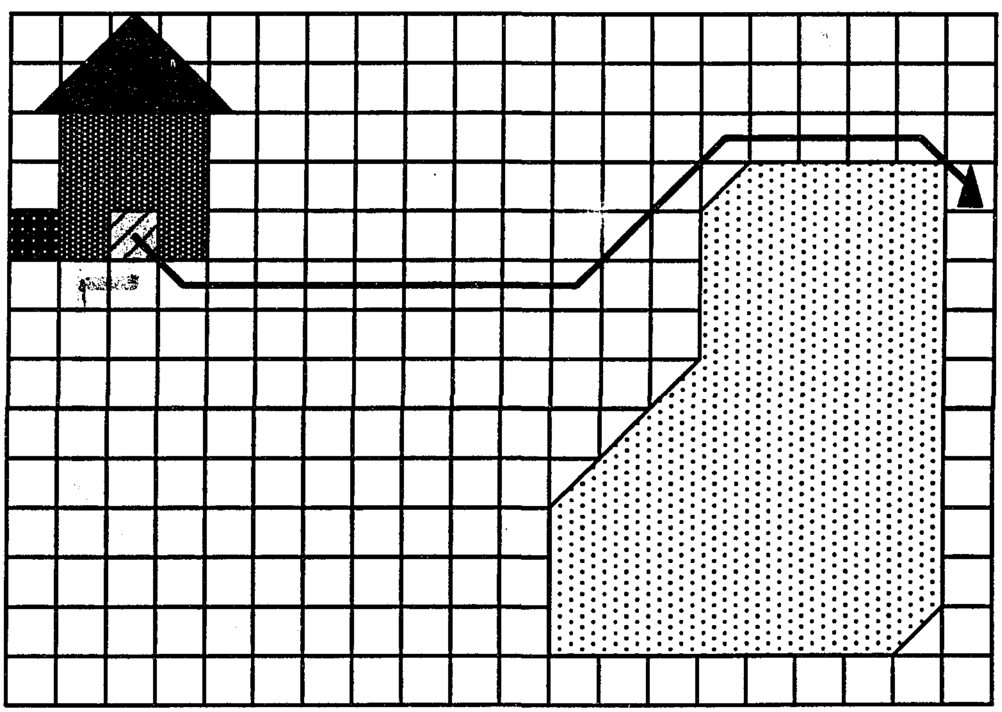

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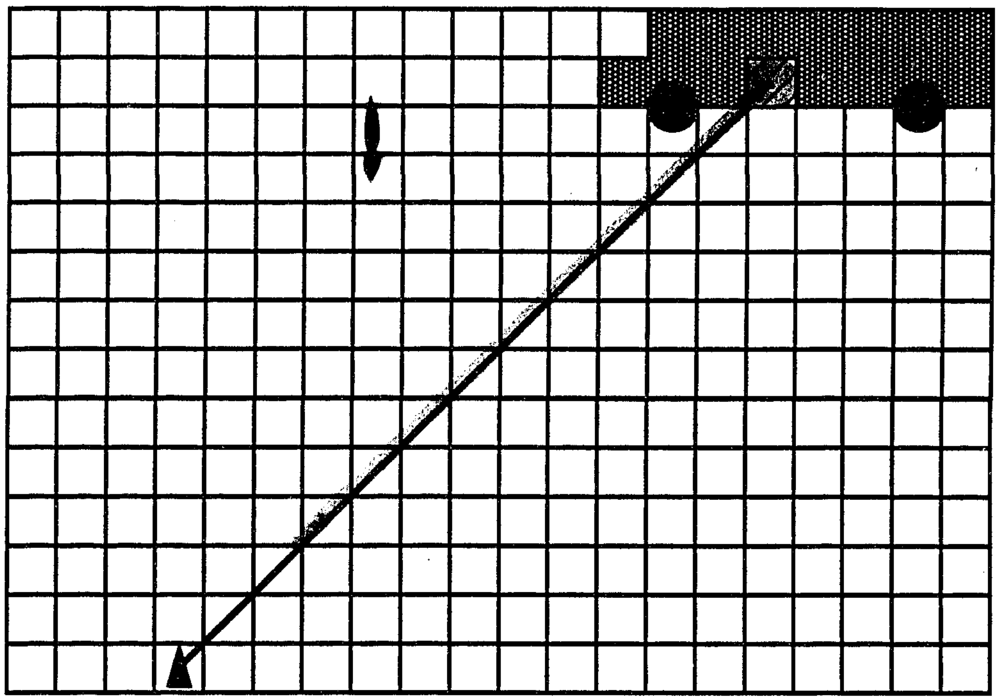

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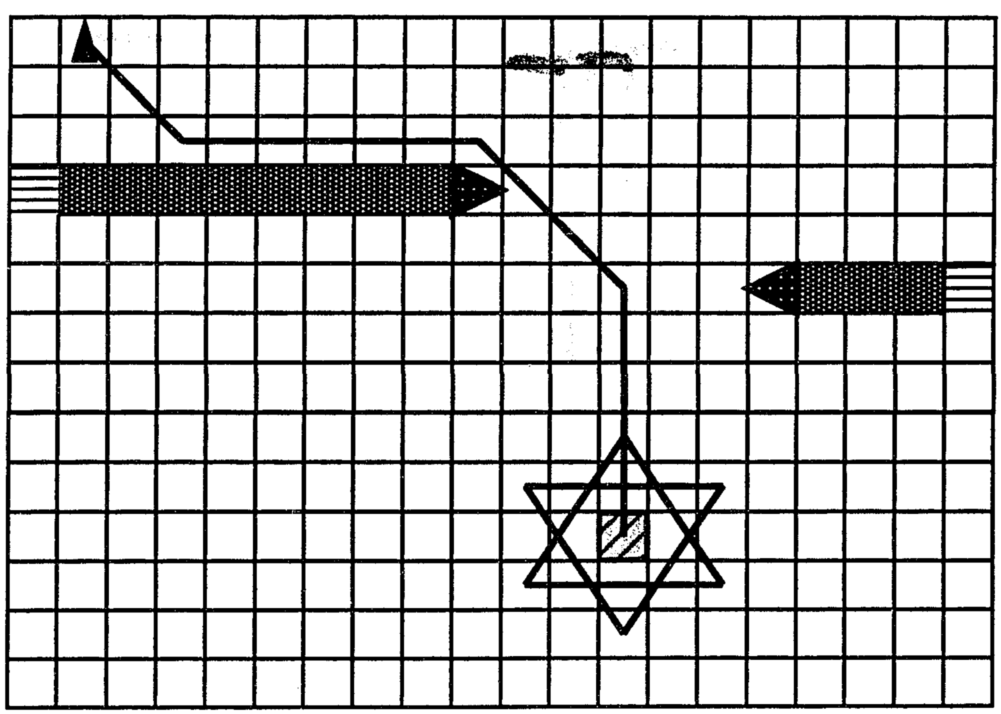
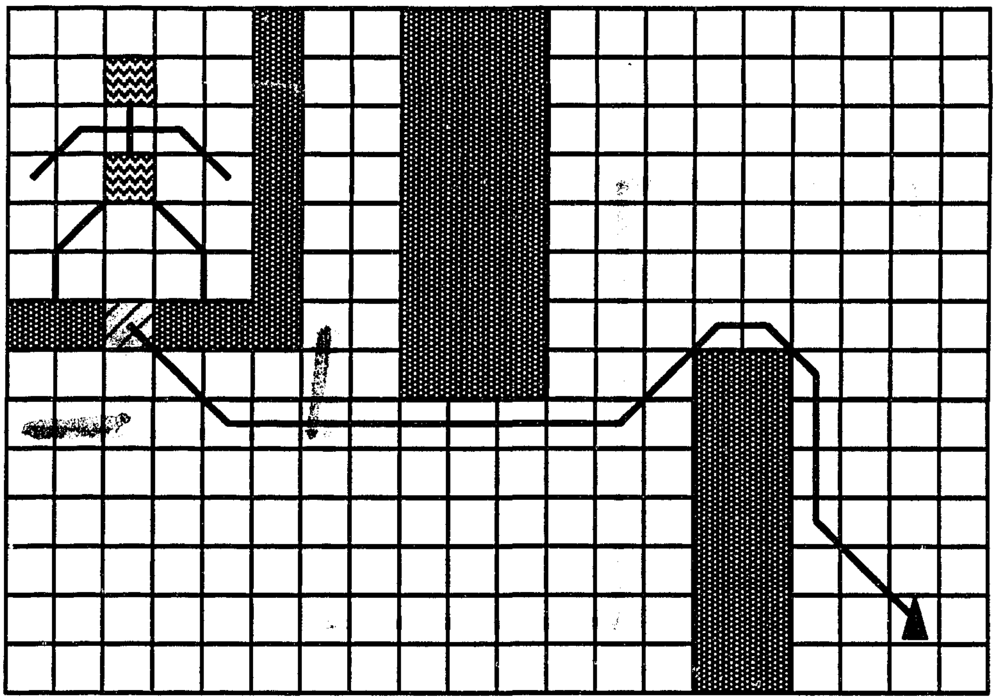


Test 1B - Problem 9



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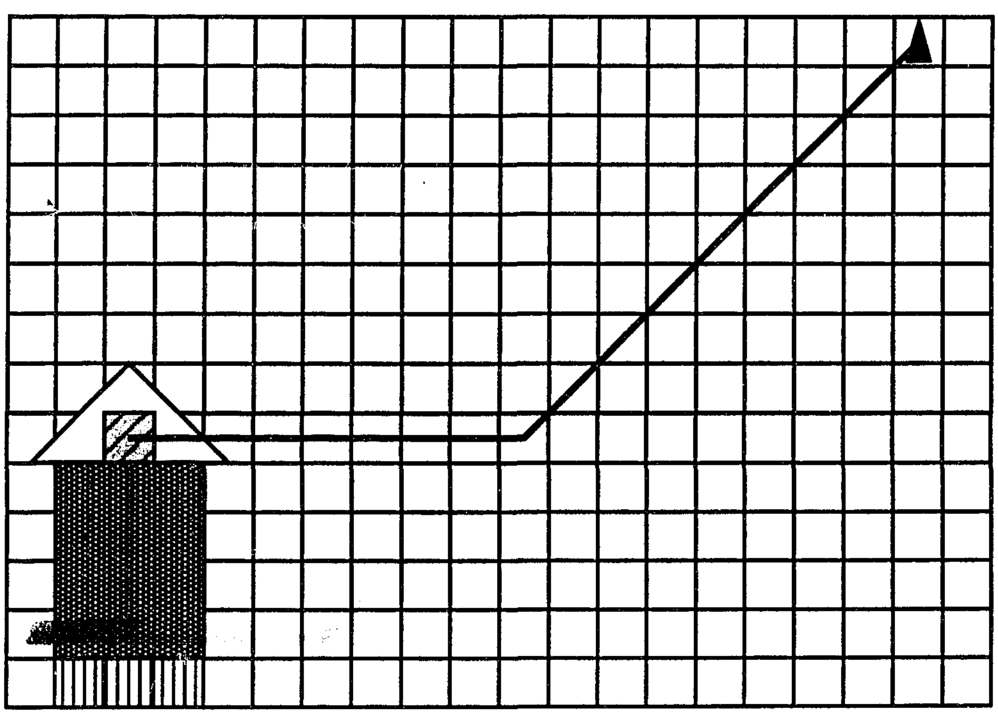

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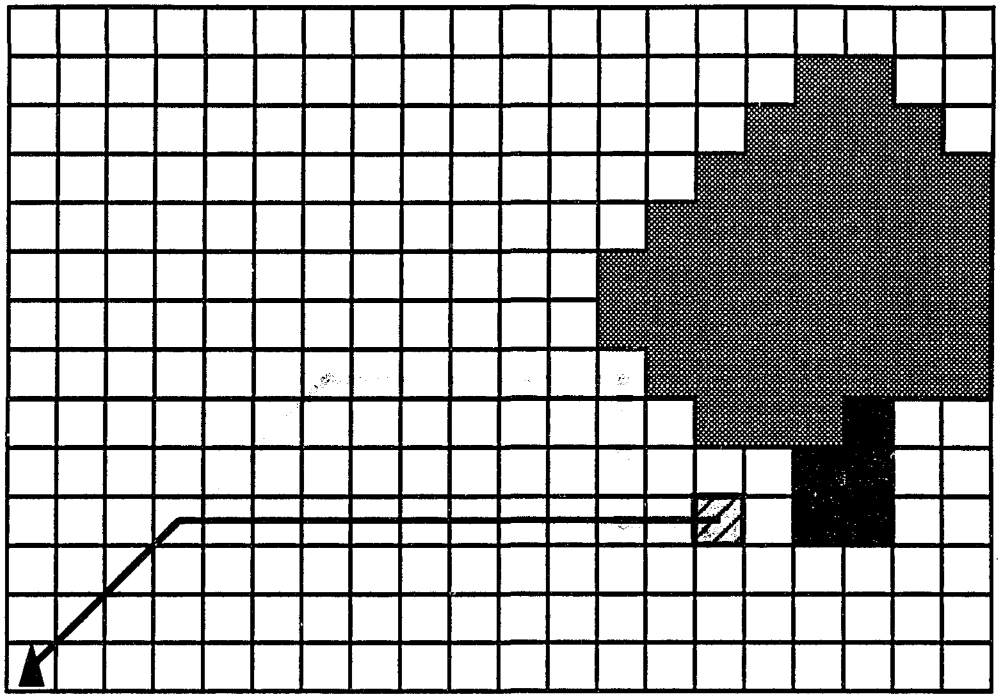

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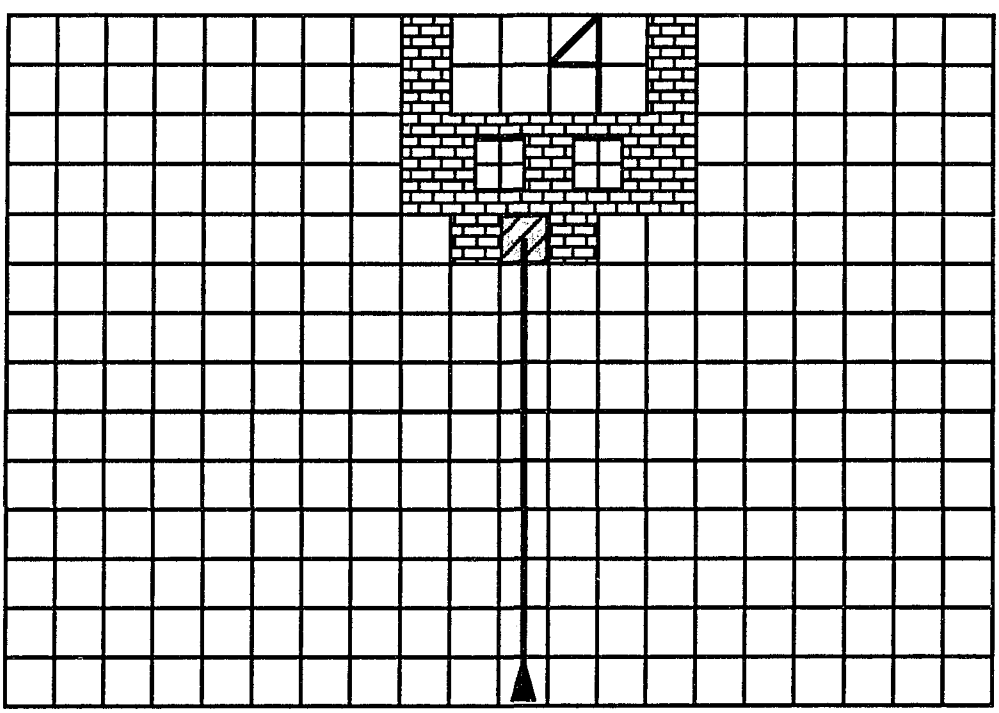
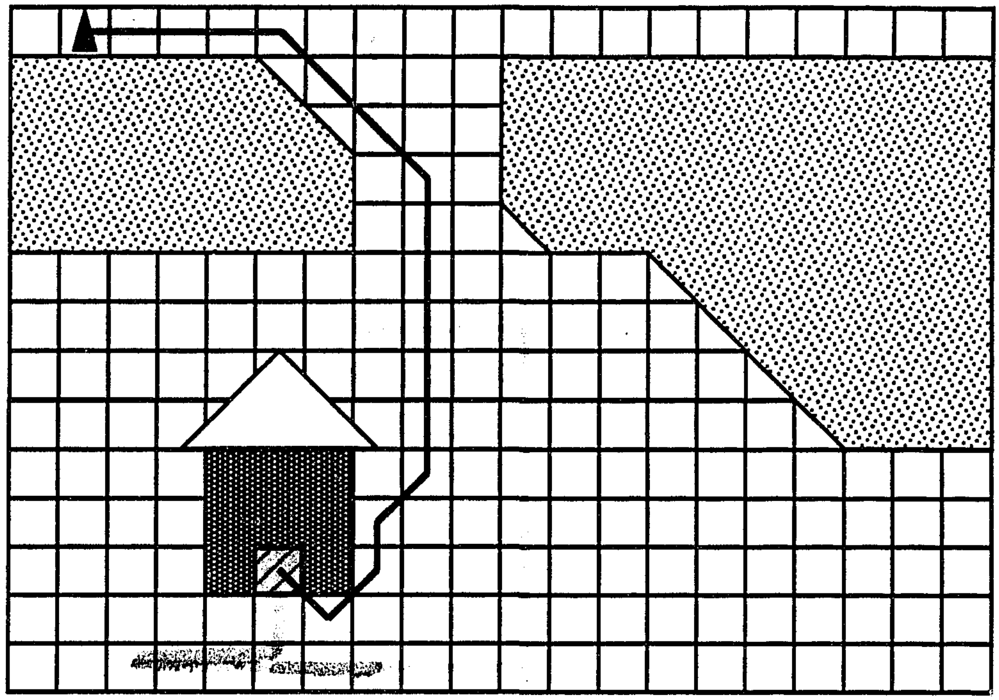


Test 2A - Problem 17



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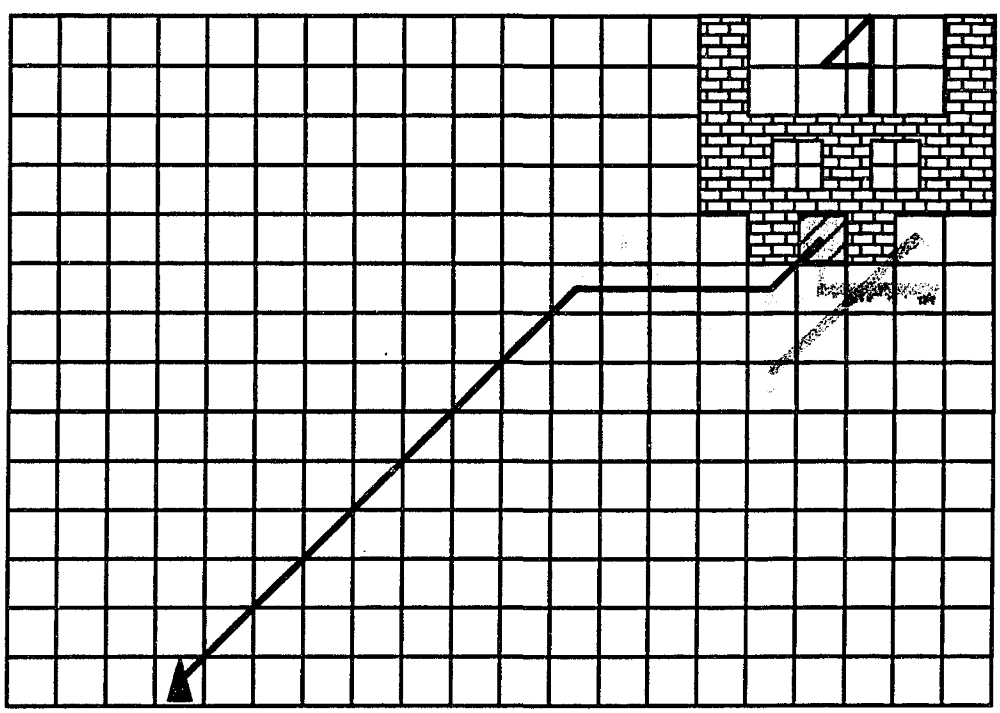

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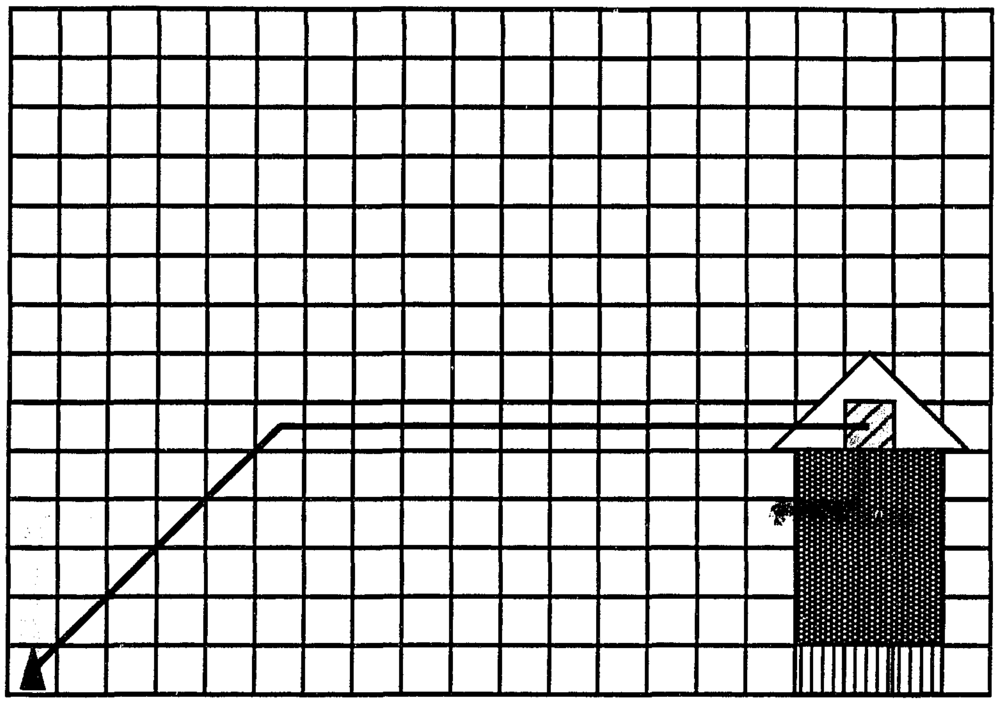
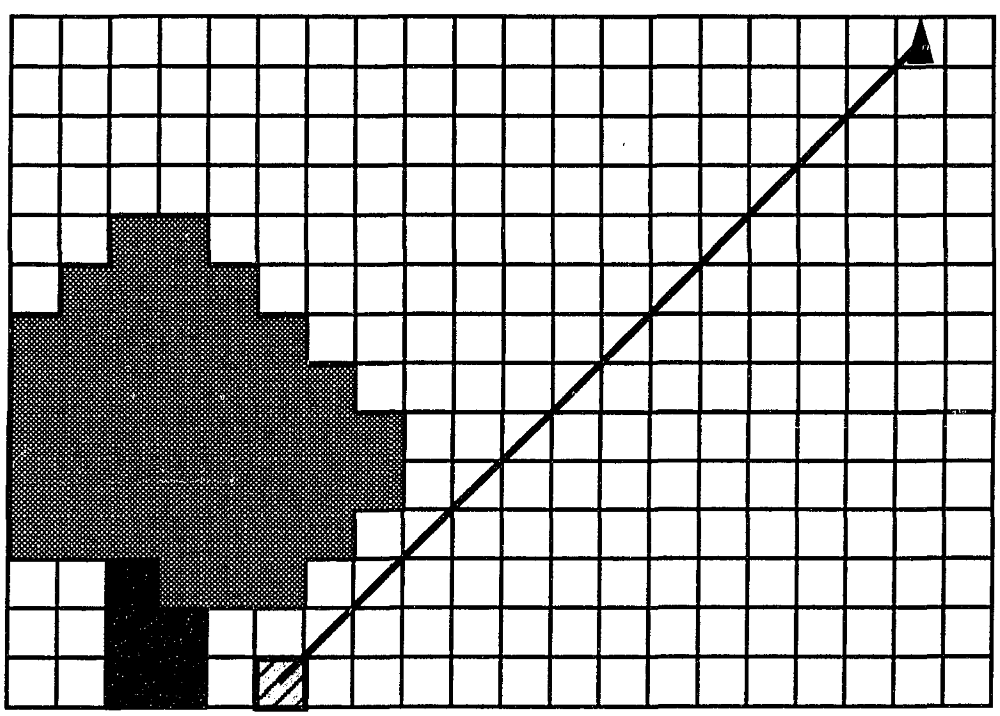
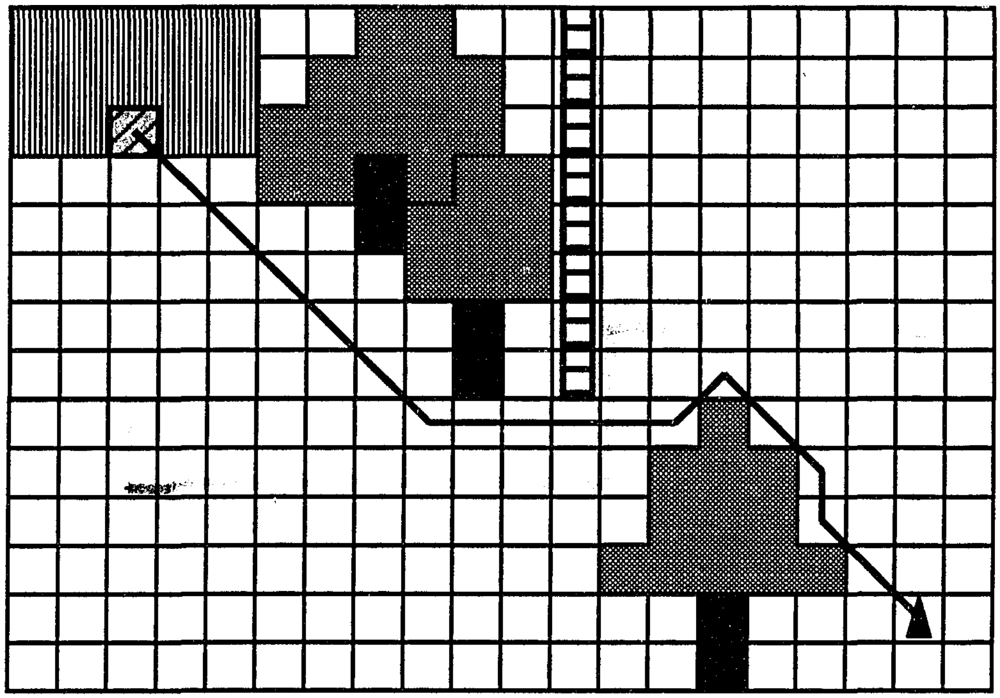


Test 2B - Problem 25



Test 2B - Problem 27



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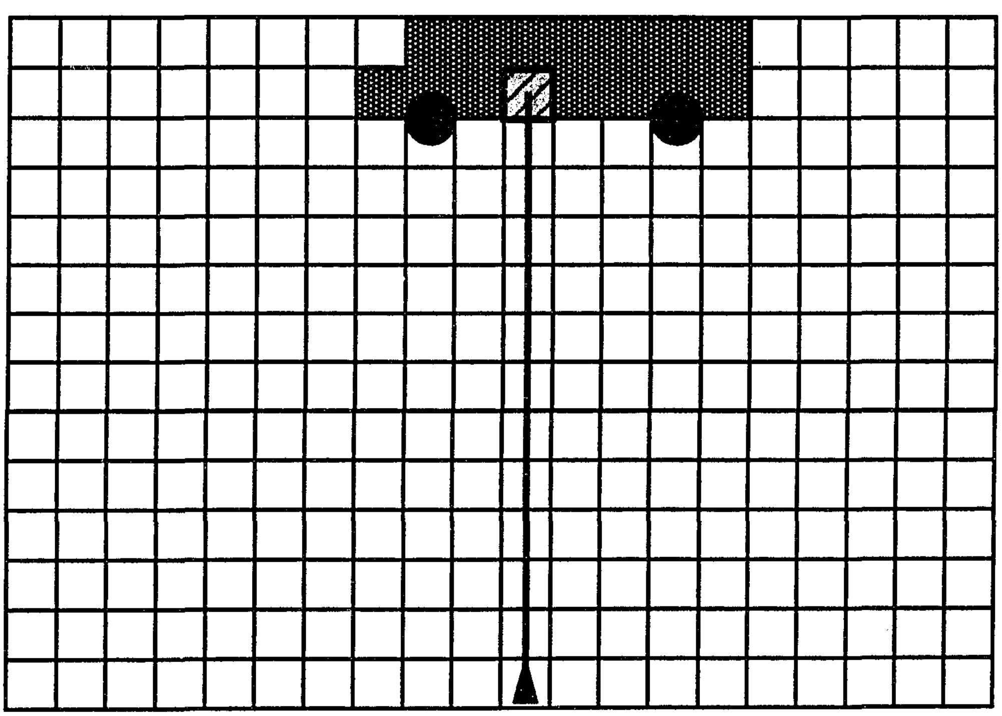

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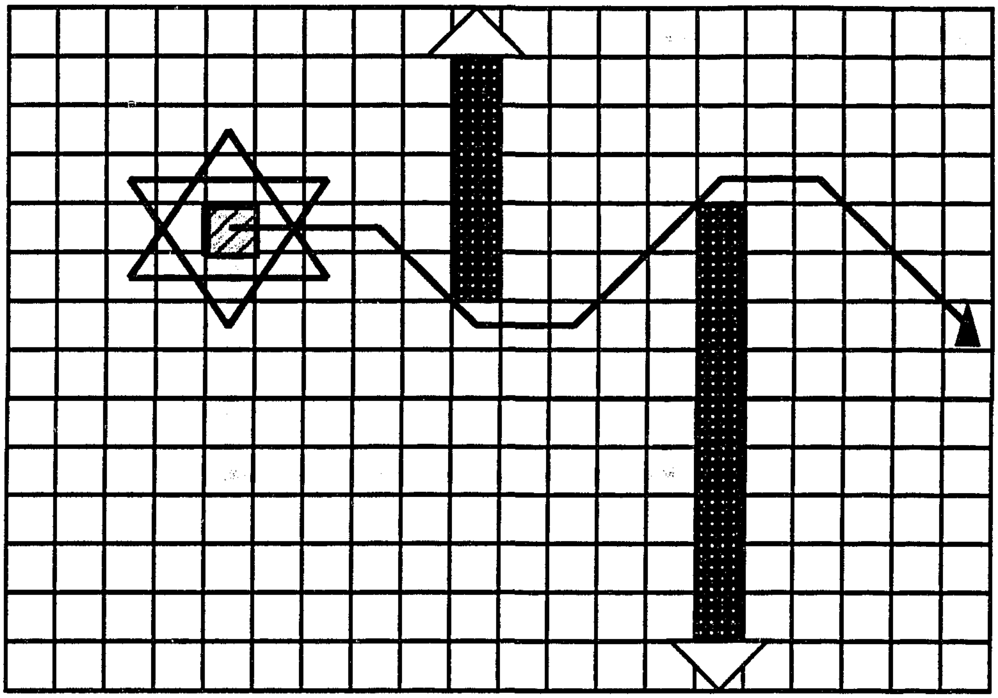
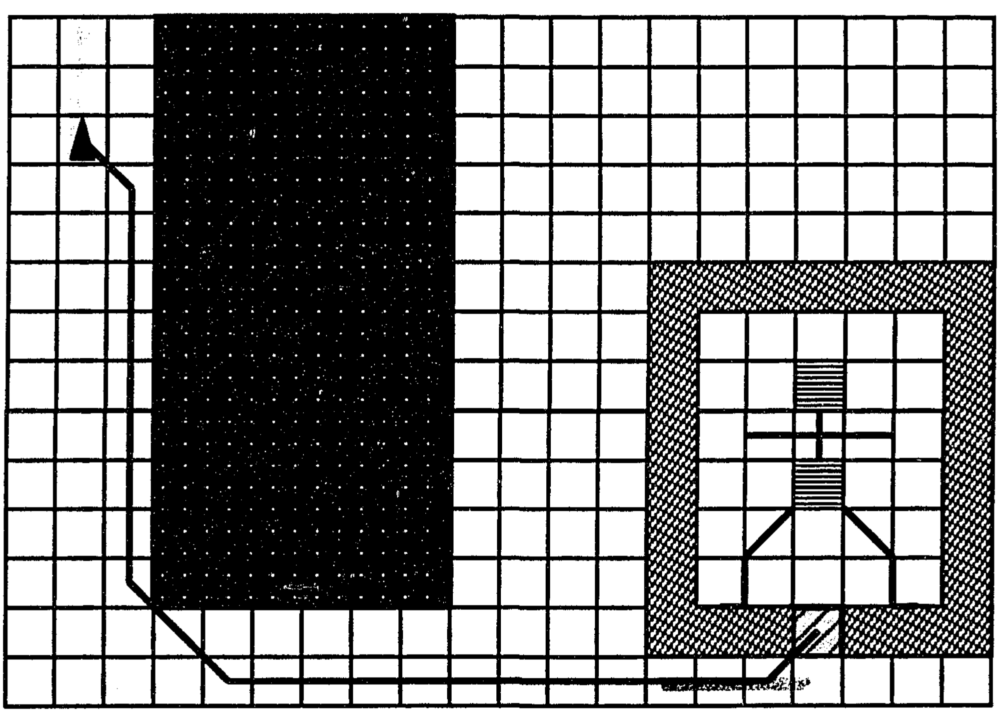


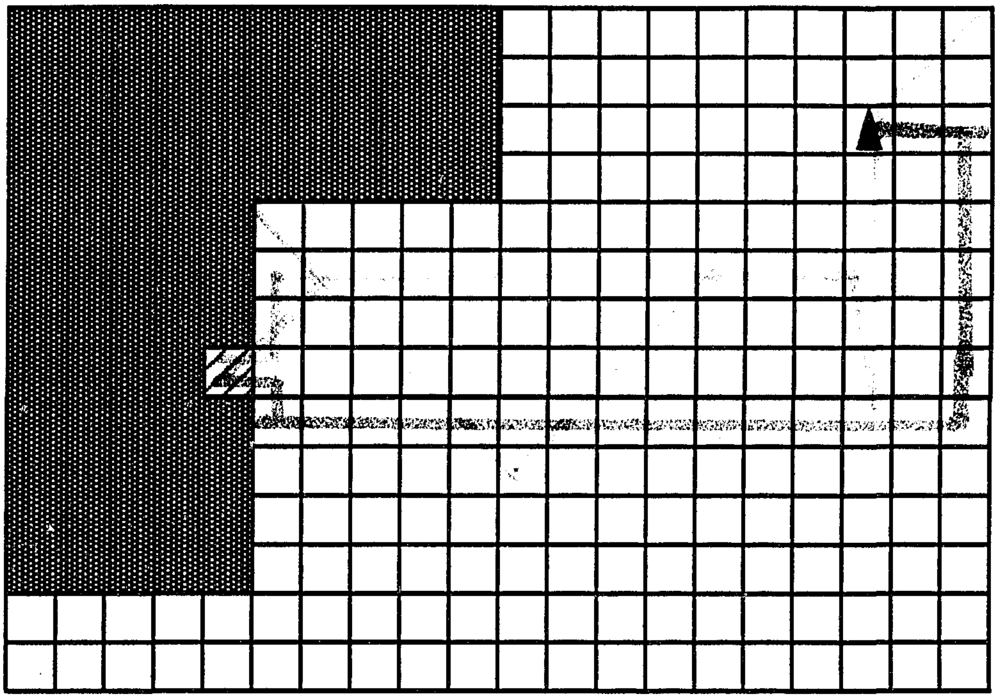
Test 2B - Problem 32



Divergent Problem Solving Set

Orange Lines Represent First Solution
Green Lines Represent Second Solution
Pink Lines Represent Third Solution
Blue Lines Represent Fourth Solution

Test 1A - Problem 2



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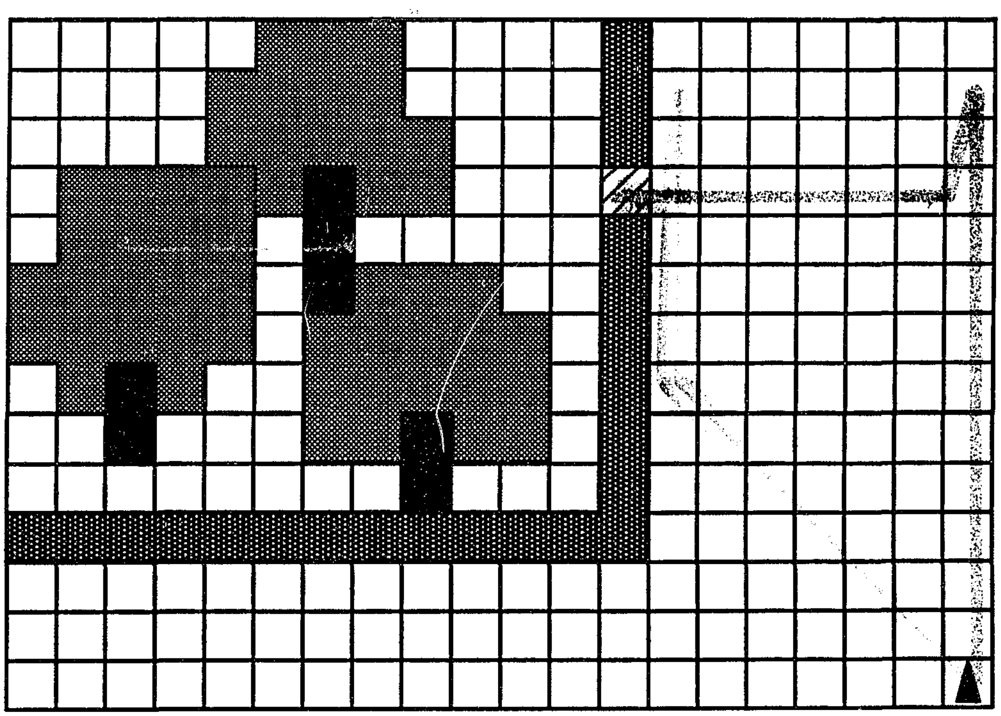

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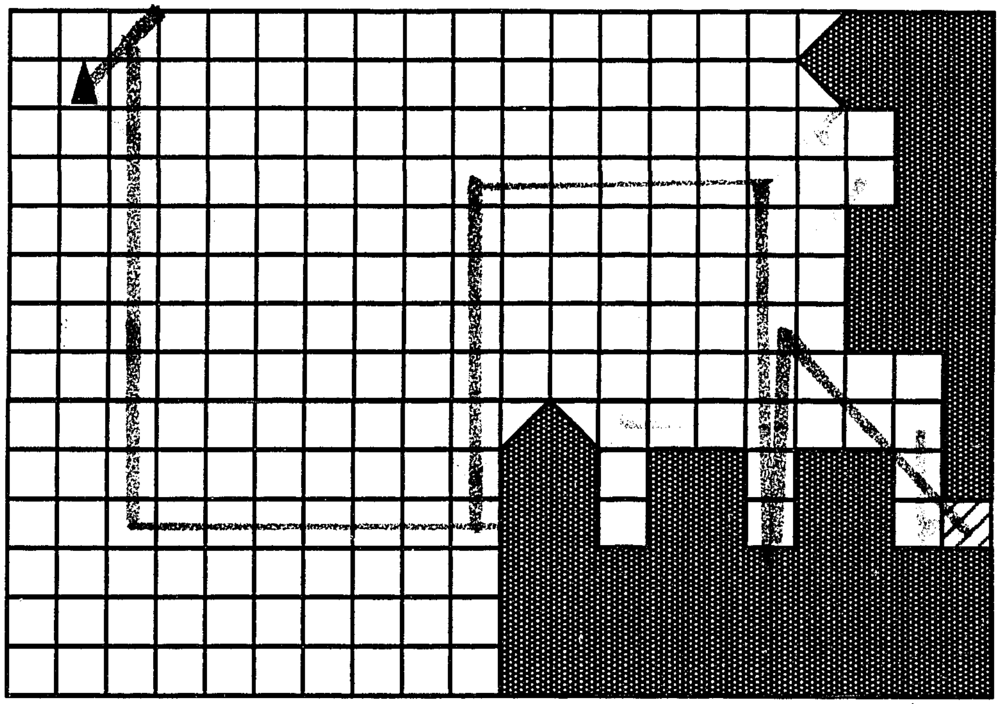

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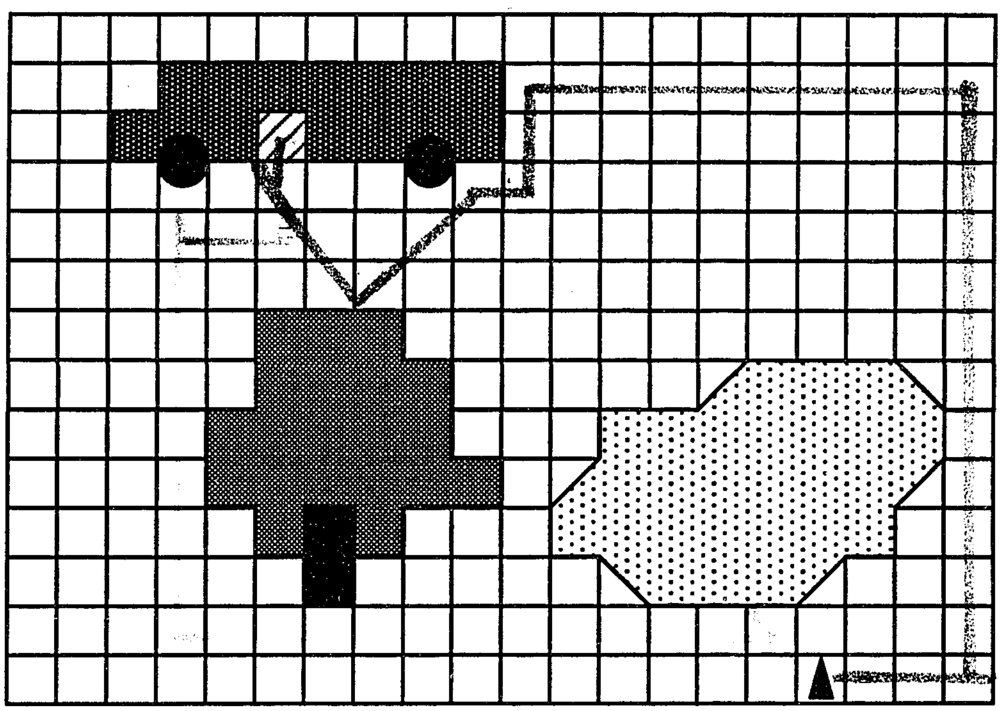

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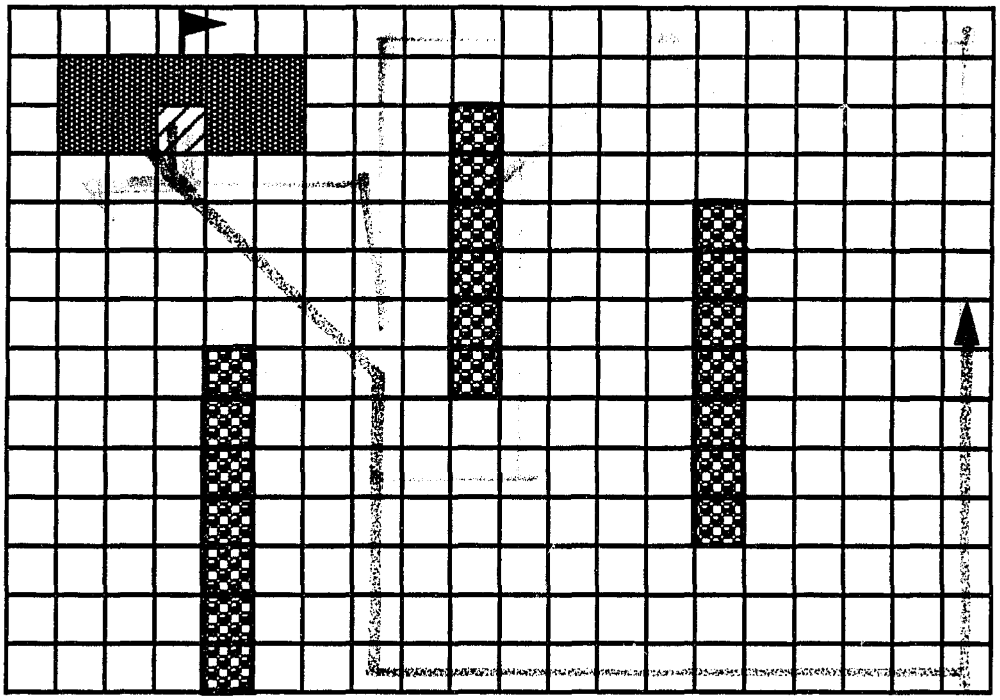

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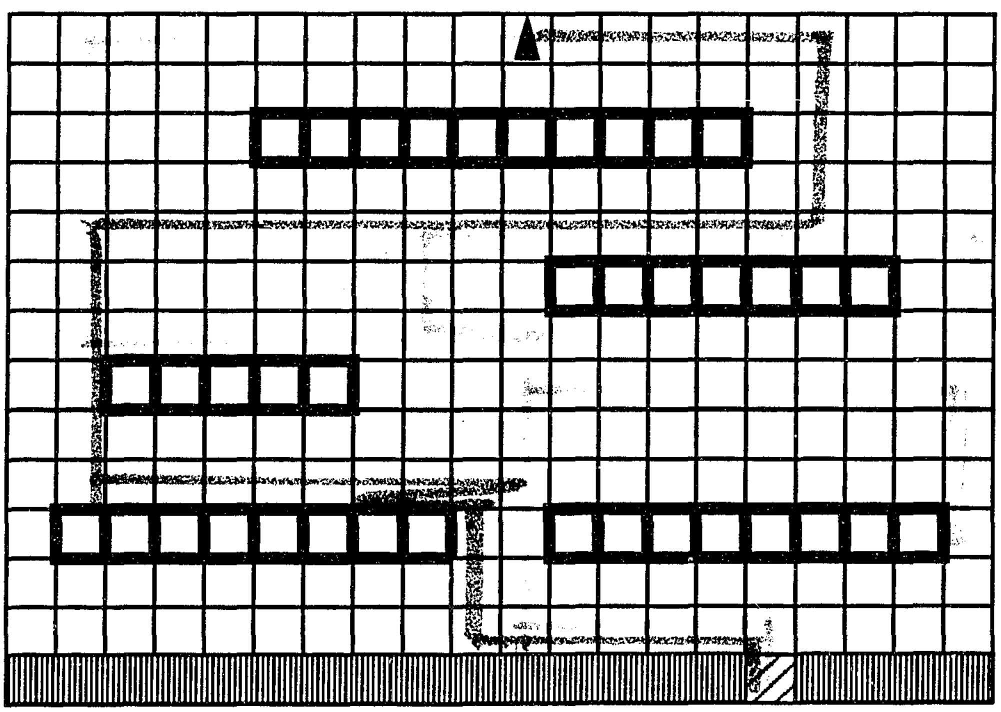

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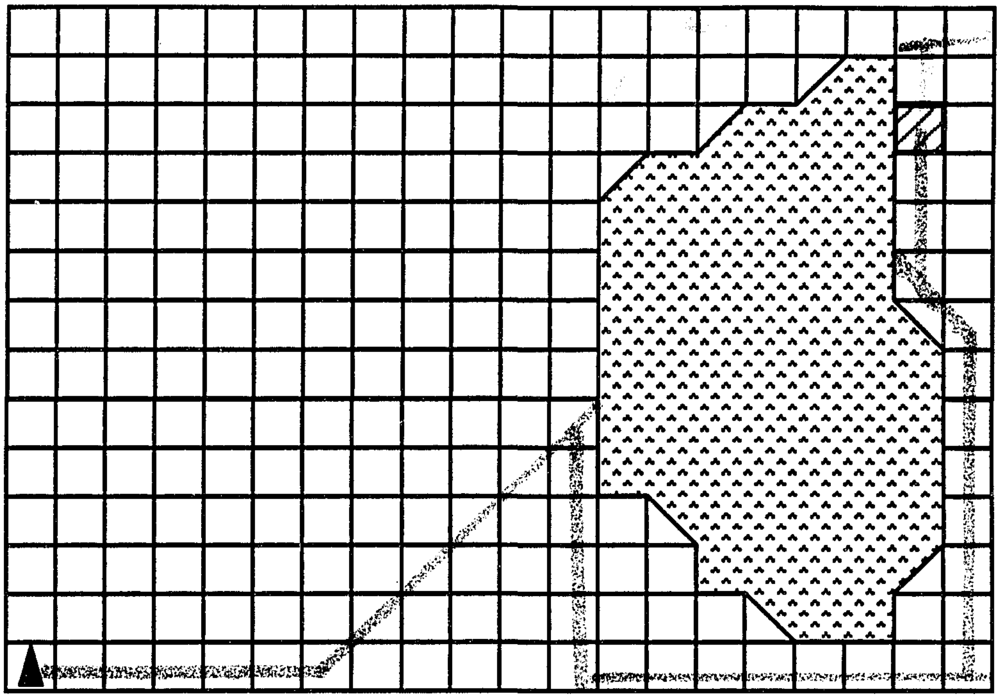

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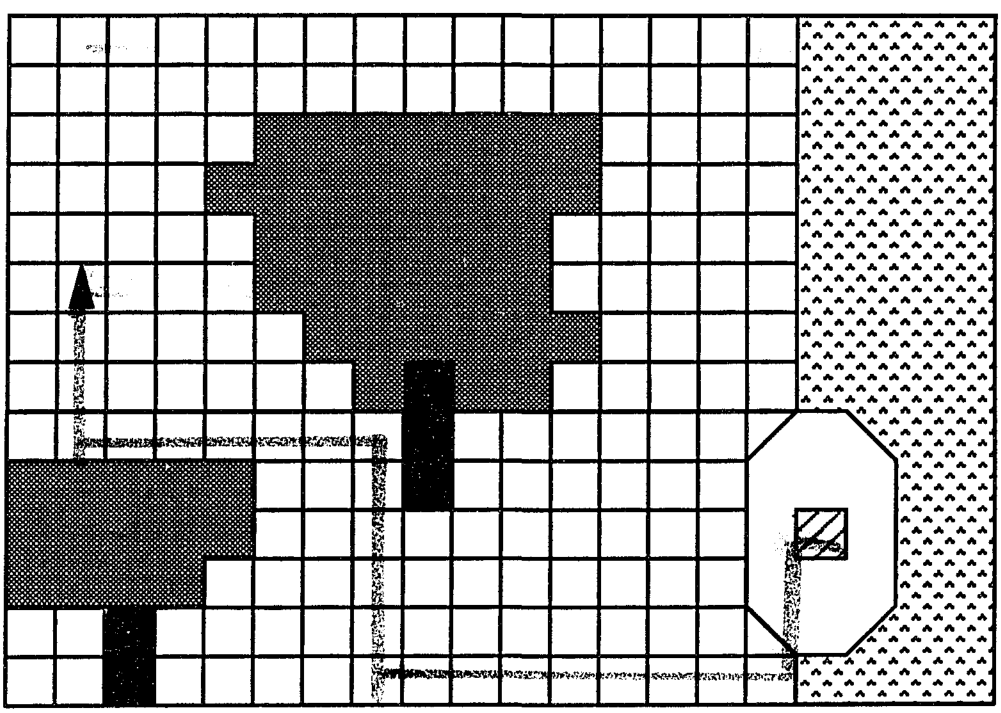

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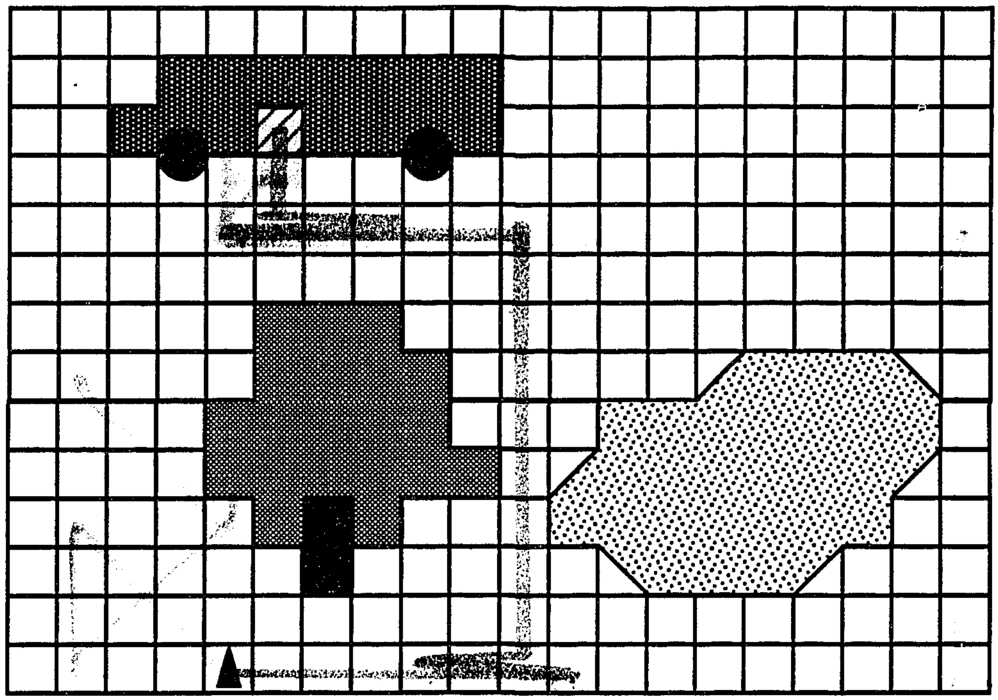

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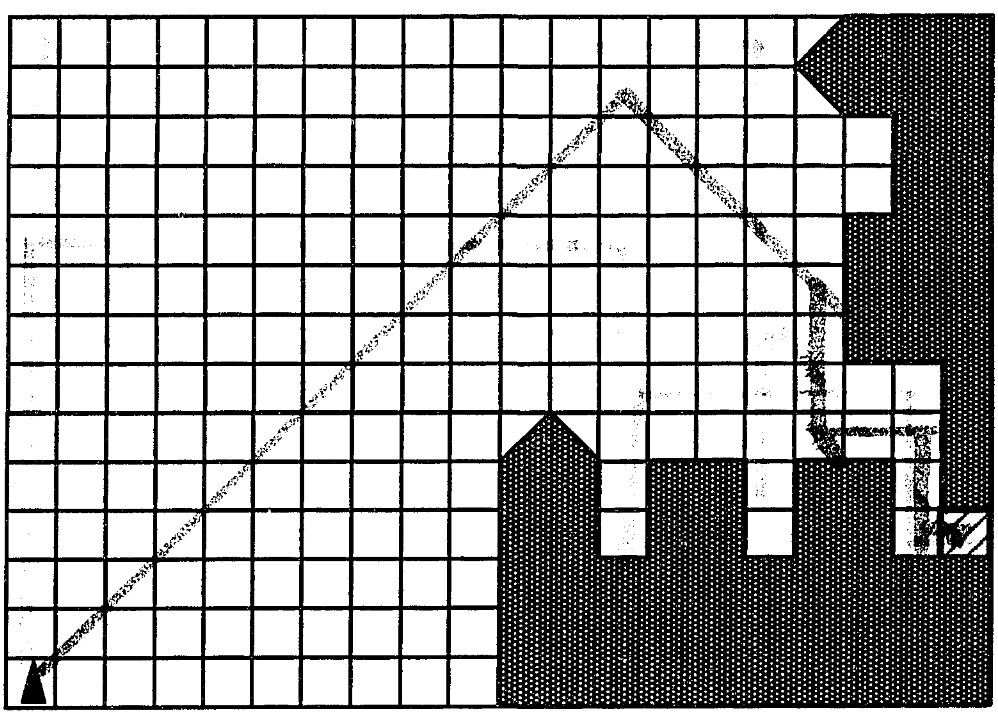

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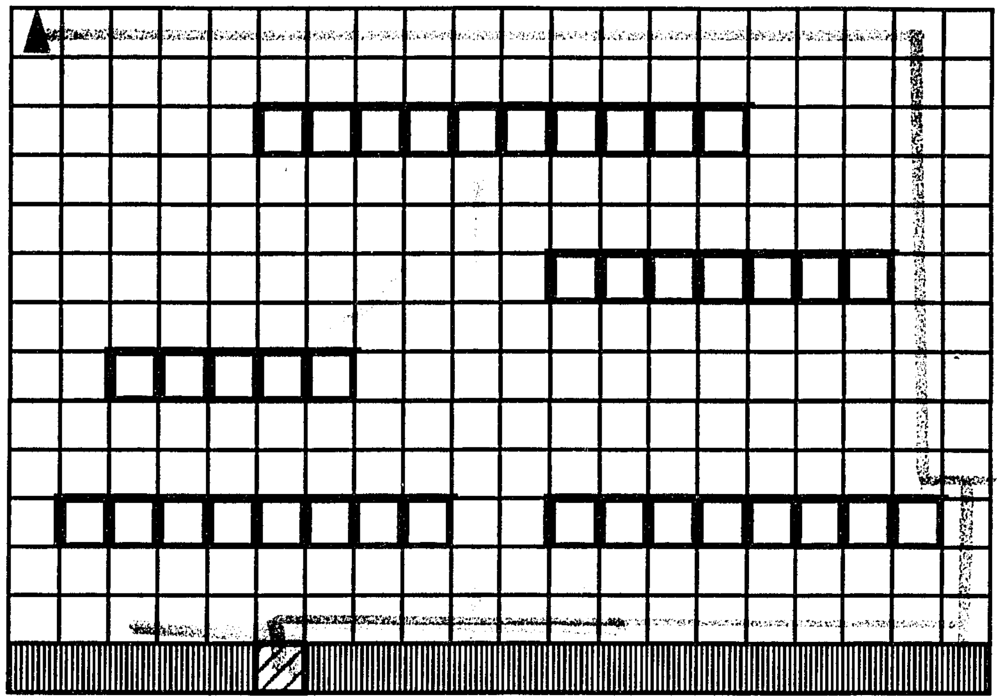
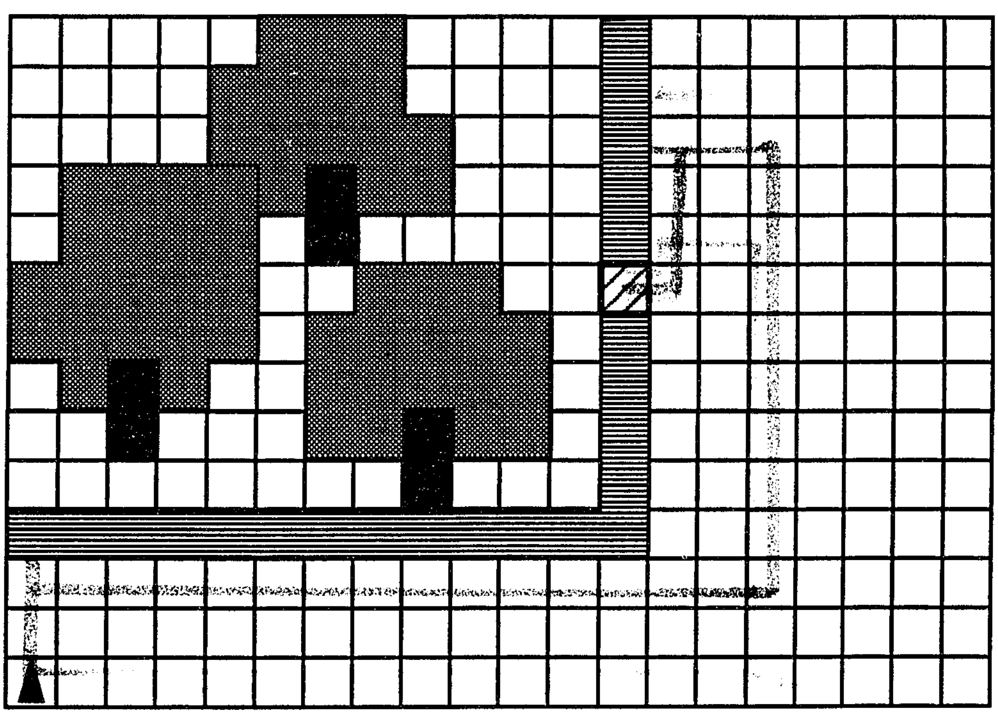


Test 2A - Problem 23



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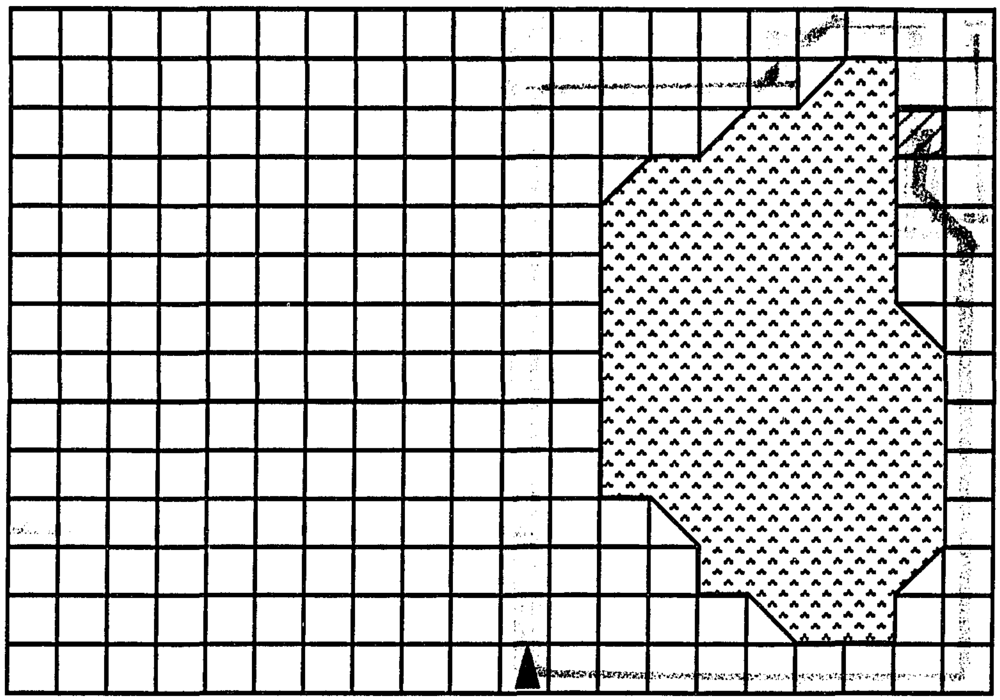

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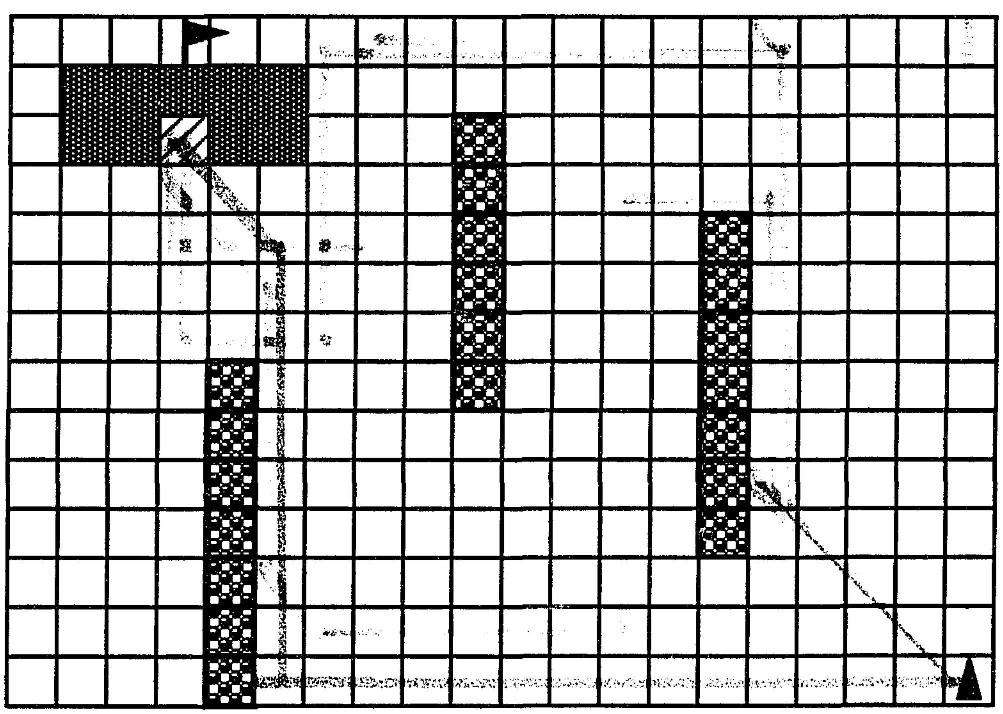
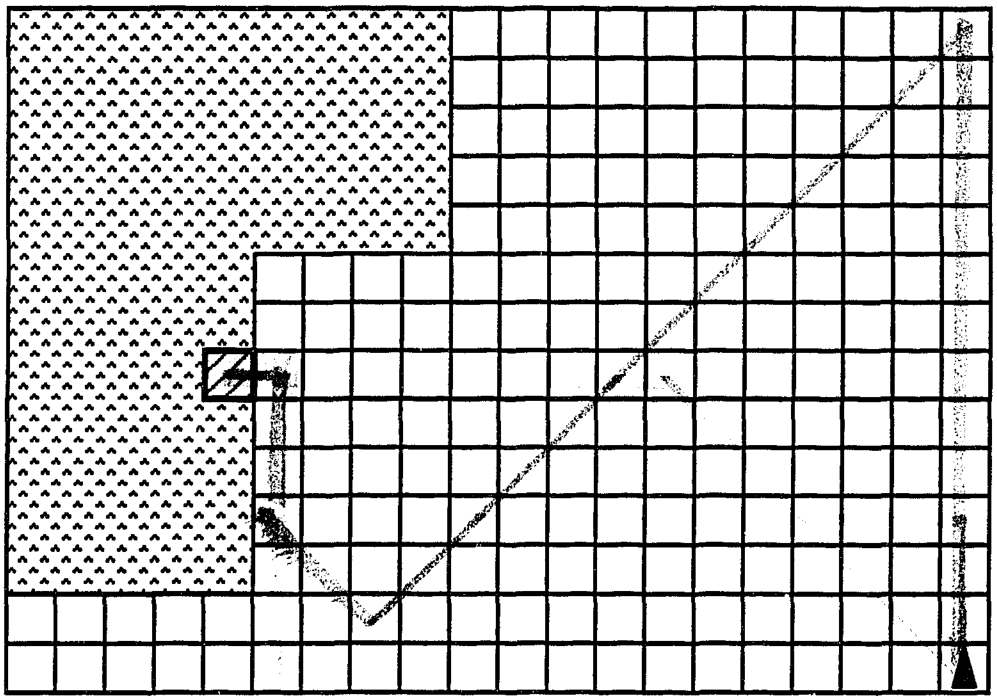


Test 2B - Problem 29



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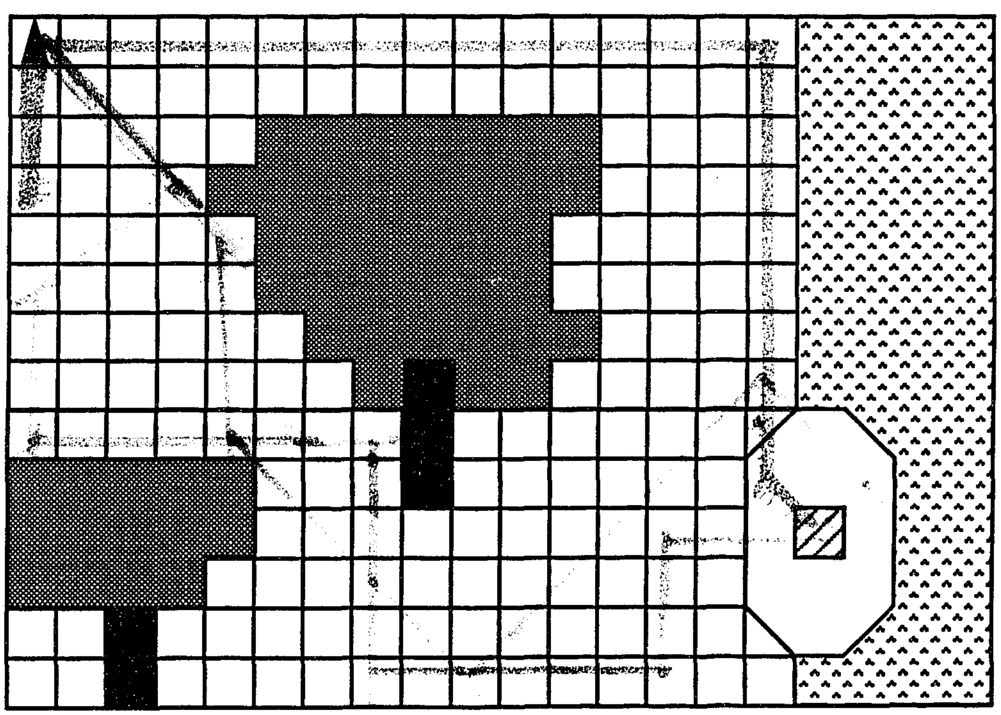


Case Study 2

Results

Jasmine was classified as impulsive on the KRISP, scoring low on average latency time and high on number of errors. Her scores on the Kohn Social Competence Scale - Preschoolers and the Classroom Behavior Inventory validated her placement in the impulsive category.

Convergent thinking problems. Audit trail data from her problem solving experiences showed some definite preferences. Contrary to the results of early research which report a preference for young children to utilize big steps (Brinkley & Watson, 1990; Campbell et al., 1986; Watson & Brinkley, 1990/91; Watson & Busch, 1989), Jasmine showed her personal preference for utilizing little steps in the sixteen convergent thinking problems. She used them exclusively in 6 (37.5%) of the sixteen problem solutions. In 13 of the sixteen problems she made a decision to move the cursor forward by utilizing little steps 50 times in charting her solution paths. This is contrasted to only 22 occasions where she chose to move via big steps. It is interesting to note that big steps were used more frequently in the last eight convergent problems (48% of moves were made as big steps) compared to only 7% in the first set of convergent problems. Jasmine made 87 directional decisions in the 16 solutions, representing a mean of 5.4 decision points per

Jasmine did not seem to have difficulties making up her mind in which direction she wanted the turtle to move as she worked through the convergent problem solving set. Out of the 87 directional headings she utilized in solving the 16 problems, 8% were characterized as points of indecision. In six of the seven points of indecision, two consecutive directional headings were chosen prior to movement being initiated. In one incident, three directional heading changes were made before Jasmine decided to move the turtle. It is interesting to note that at this indecision point, Jasmine ended up moving forward in the directional heading she had initially chosen.

Divergent thinking problems. Jasmine completed 33 solution paths in the 16 divergent problems, which gives her an overall mean of 2.1 completed paths within the two-minute time limit given for each problem. Her completed path mean in the first set of eight divergent problems was 1.8, where she was able to chart 14 different paths. In the second set of divergent problems, Jasmine completed 19 path solutions which represents a mean of 2.4 completed paths per problem.

In one problem (#13), Jasmine was unable to finish one path within the time limit. In two of the problems (#5 and #22), she completed only one route in two minutes. A breakdown of her success includes eight problems in which she completed two unique paths and five problems in which she was able to complete three unique paths.

The presence of barriers in the microworld did not seem to have any significant impact on the number of paths that Jasmine completed. Although she was unsuccessful in completing one path during the two-minute time limit in problem 13, which did contain a barrier, her rate of successfully charting paths seemed almost equally divided between barrier and non-barrier problems. Of the two problems where only one path was charted, one microworld contained a barrier and the other did not. Of the nine problems in which Jasmine succeeded at charting two solution paths, nine of the problems, 66%, contained barriers which she was able to negotiate. In the five divergent problems in which three paths were charted, two (40%) contained a barrier and the other three (60%) were barrier-free.

Jasmine made a total of 221 directional decisions in the 33 solution paths in the divergent problem solving set. This represents a mean of 6.7 decision points per solution. Of the 221 moves, 21, or 9.5%, were diagonal moves. She utilized diagonals in nine of the 16 divergent problems (56.3%), for a total of fourteen paths, or 42.4% of all paths charted in the divergent problem solving set.

In one problem (#16, solution 3), Jasmine utilized diagonals three different times in her solution path. In three problems, Jasmine used the same diagonal move on two separate occasions to complete paths. She never utilized all four diagonal directional headings in any of the paths she completed during the divergent problem solving set. She utilized the northwest directional key (7) more frequently than any other, accounting for 33% of all diagonal moves. This was followed by the use of the northeast directional key (9), 28.5% of the time; the southeast directional key (3), 24.4% of the time; and the southwest directional key (1), 14.4% of the time.

The divergent audit trail data reveal a similar usage pattern of big and little steps as was observed in the convergent problem solving set. Jasmine used 134 little steps and 57 big steps in completing the solution paths. This represents 70.2% and 29.8% of the total movement decisions, respectively. The ratio of little steps to big steps in the convergent problem solving set was 2.6:1. The ratio of little steps to big steps in the divergent problem solving set was 2.4:1.

Jasmine moved forward by using big steps on only ten occasions during the first eight divergent problems, as compared to 47 times in the last eight divergent problems. This pattern seems consistent with the convergent problem solving set. In the first eight problems, 18.8% of the movement decisions utilized big steps, as compared to 39% in the last eight divergent problems.

In the 14 completed paths in the first eight problems, Jasmine utilized big steps in six of the solutions. Her use of big steps increased in the second set of problems where she utilized big steps in 14 of the 19 completed paths.

In the divergent problem solving set, Jasmine utilized little steps exclusively in 12 of the 33 solution paths. This represents 36.4% of the problem solutions. This percentage is also consistent with her exclusive use of little steps in problem solutions in the convergent problem solving set, where she used little steps exclusively in 37.5% of the problem solutions.

Jasmine had 19 instances of indecisions about directional heading. which represents an 8.6% indecision point percentage. The indecision points were located in 11 of the 33 solution paths and involved nine of the problems. Six of the microworlds which appeared to cause some difficulty for Jasmine contained barriers, while the remaining three were barrier-free. In only one problem (#19, first solution) did the indecision point occur prior to the first movement decision.

In eight incidences (42%), the point of indecision occurred as Jasmine was deciding her second move after initiating the problem. In only one incident did a point of indecision occur prior to the last movement made which allowed the turtle to move onto the target.

A breakdown of the points of indecision show that in seven of the 11 solution paths (63%) in which indecision did occur, there was only one point of indecision. In six of those (#2, solution 2; #3, solution 1; #8, solution 1; #14, solution 2; #18, solution 1; and #26, solution 2), directional heading was changed only one additional time before movement was initiated. In the other solutions which contained one point of indecision, the directional heading was changed two additional times before movement was initiated.

One solution path (#19, solution 1) contained two points of indecision. The first point of indecision occurred before any movement was initiated, and Jasmine made only one additional directional heading change. The second incident of indecision in #19, solution 1 was immediately before the turtle was moved onto the target and contained four additional directional heading changes before Jasmine succeeded in reaching the target. It is interesting that at this point of indecision Jasmine decided to proceed in the direction she had initially chosen.

In two solution paths (#18, solution 2, and #22, solution 1), Jasmine had three points of indecision. In one problem (#19, solution 2), Jasmine had four separate incidences of indecision. Problem 19 seemed to cause Jasmine more problems than any of the others because six of the total nineteen indecision points (32%) occurred within solutions one and two of this problem. Table 2 shows the problem numbers and solution paths in which indecision points occurred.

Examination of Table 2 shows that indecisions occurred at almost the same rate in first solutions as in second solutions, and did not occur at all during third solution

Table 2

Divergent Solution Paths in Which One or More Points of Indecision Occurred in Case Study Two

Problem Number	Barrier/ No Barrier	First Solution	Second Solution	Third Solution	Fourth Solution	Total Solutions
2	No Barrier	-	√			2
3	No Barrier	√	-	-		3
8	Barrier	√	-			2
10	Barrier	-	√			2
14	Barrier	-	√			2
18	Barrier	√	√			2
19	No Barrier	√	√			2
22	Barrier	√				1
26	Barrier	-	√	-		3

paths. It is also evident that Jasmine's instances of indecision occurred at almost the same frequency in the first half of the problem solving test as in the second half. It is also apparent that the presence of some type of barrier did have an impact on when decisions occurred. Analysis of the audit trails revealed that points of indecision occurred twice as frequently in problems containing barriers as in problems that were barrier-free.

Discussion

Earlier research concluded that young children, regardless of cognitive stylistic preference, adopt a pre-mathematic big step strategy over a little step strategy as the most efficient way to maneuver the turtle through Logo microworlds. This was found to be especially true when the directions given to the child called for the child to find the quickest path to the goal or target (Brinkley & Watson, 1990; Watson & Brinkley, 1990/91).

When the audit trail data from Jasmine's Logo problem solving were examined, it was apparent that she demonstrated a preference for the use of small steps throughout the convergent and divergent problem solving sets. If the conclusions drawn from previous research were to be supported by this individual child, one would expect that big steps would be used to a higher percentage in the convergent problem solving set since the directions were to find the shortest, quickest path to the target. Jasmine employed little steps as her movement of choice at a rate of 73% compared to 27% for big step movement in the convergent problem solving set. When these data were compared to the data from the divergent problem solving set, the preference for little steps over big steps was confirmed. Jasmine's use of little steps over big steps was 70% as compared to 30%.

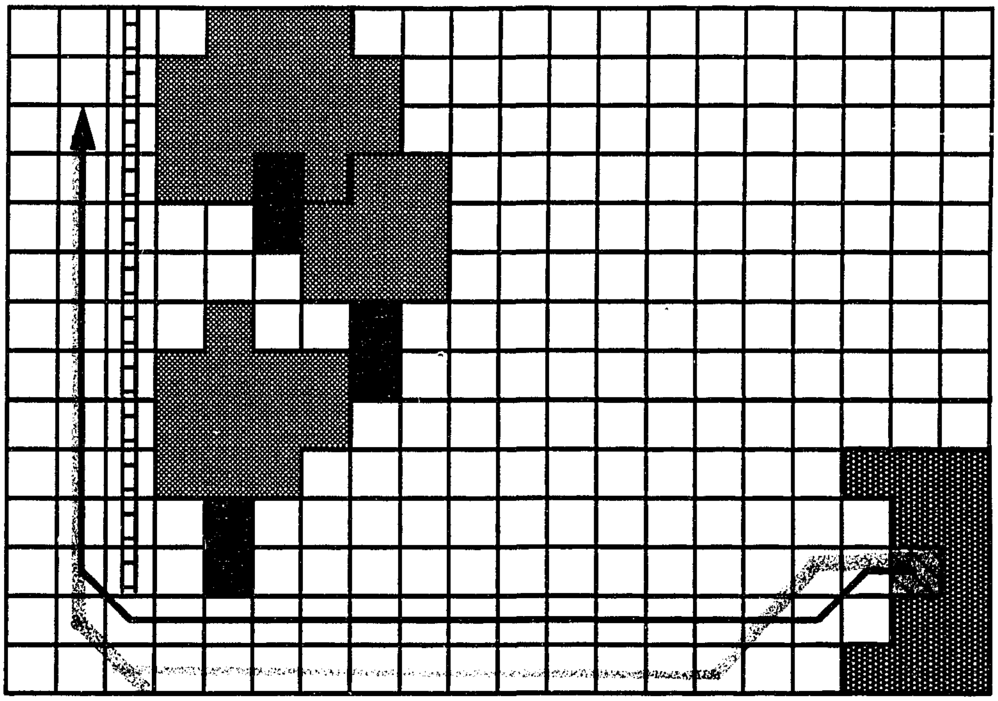
In the convergent problem solving set, Jasmine used little steps exclusively in seven of the sixteen problems representing 43.8% of the solutions where all movement was made via little steps. In five additional problems, Jasmine moved via a big step move only one time in the problem solution. All other moves in the solution paths were made as small steps. The percentage of use of little steps exclusively in the divergent problem solving set was 36%, where Jasmine completed twelve of the 33 paths via little steps exclusively.

In both problem solving sets, a greater use of big steps was seen in the second half of each problem solving set. Perhaps this pattern indicated that Jasmine was tentative in the first portion of the problems; and as her confidence grew and she became more comfortable, she began to move across the screen using big steps.

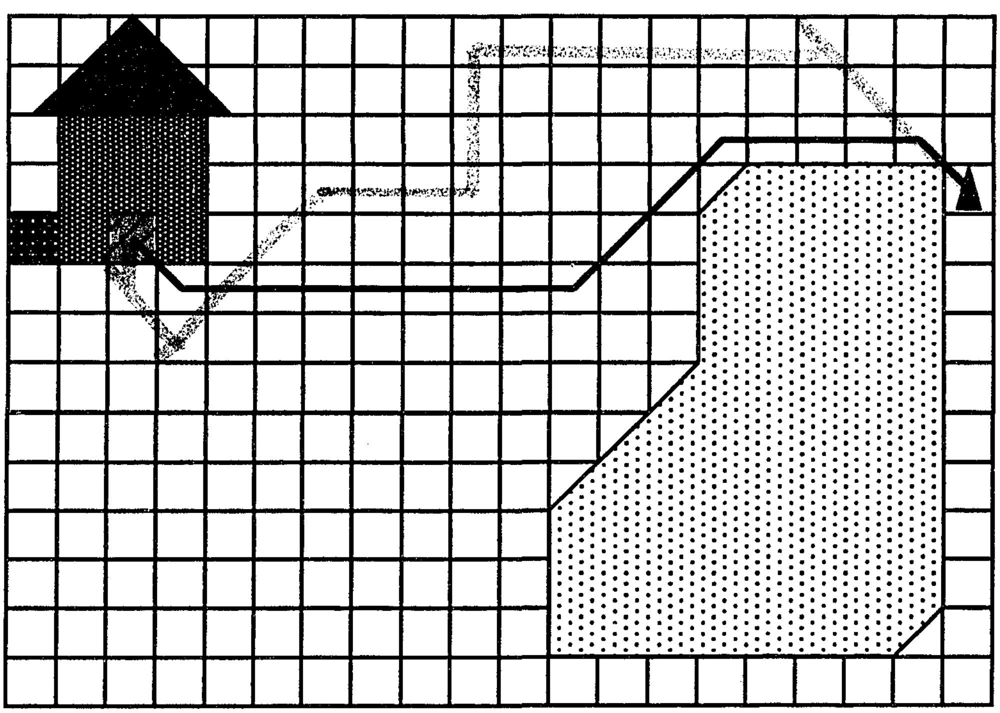
<u>Convergent Problem Solving Set</u>

Orange Lines Represent Big Steps
Green Lines Represent Little Steps
Solid Black Line Represents Shortest Possible Path

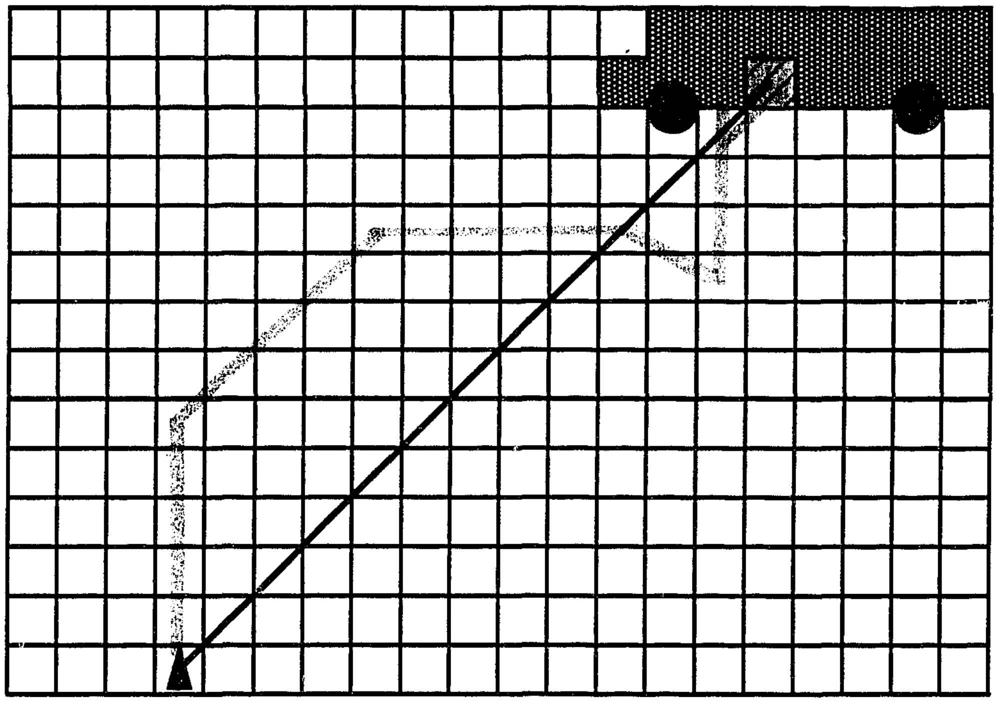
Test 1A - Problem 1



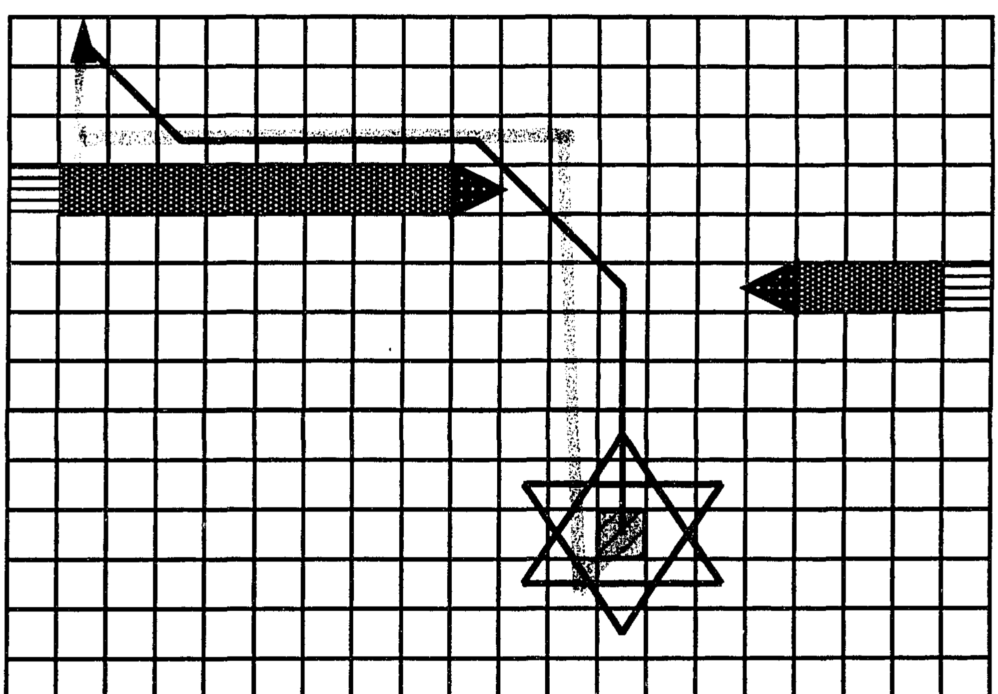
Test 1A - Problem 4



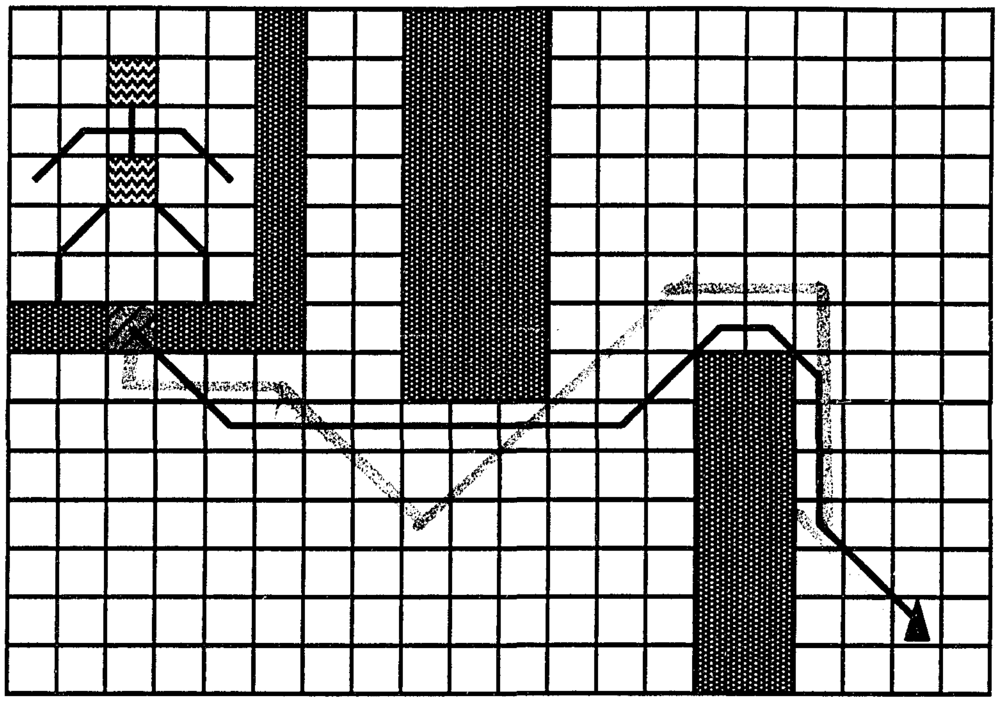
Test 1A - Problem 6



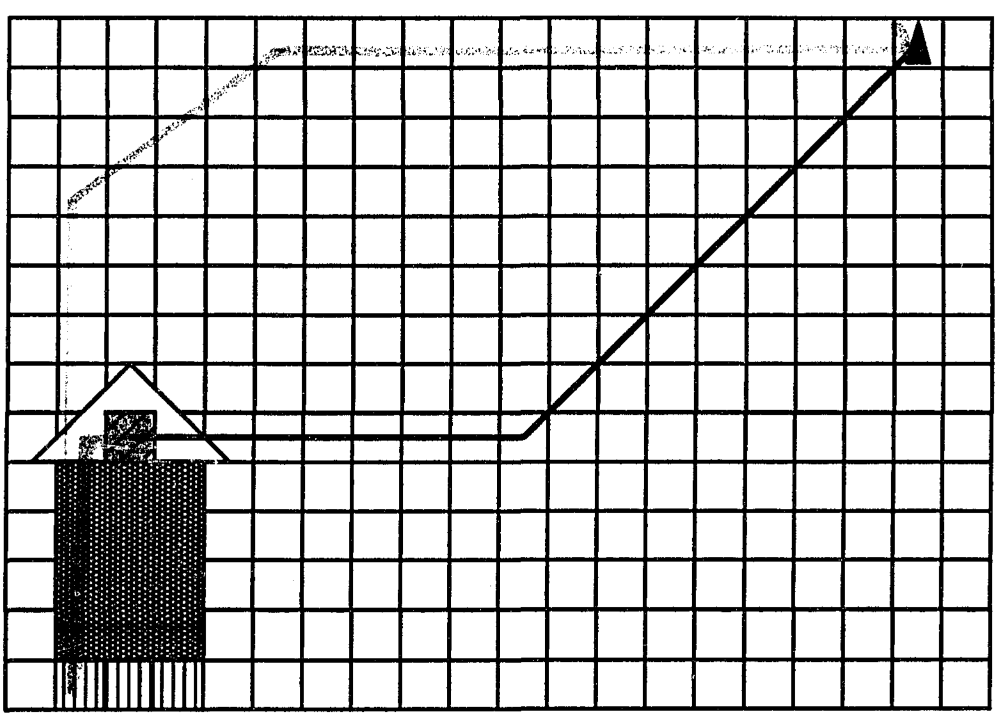
Test 1A - Problem 7



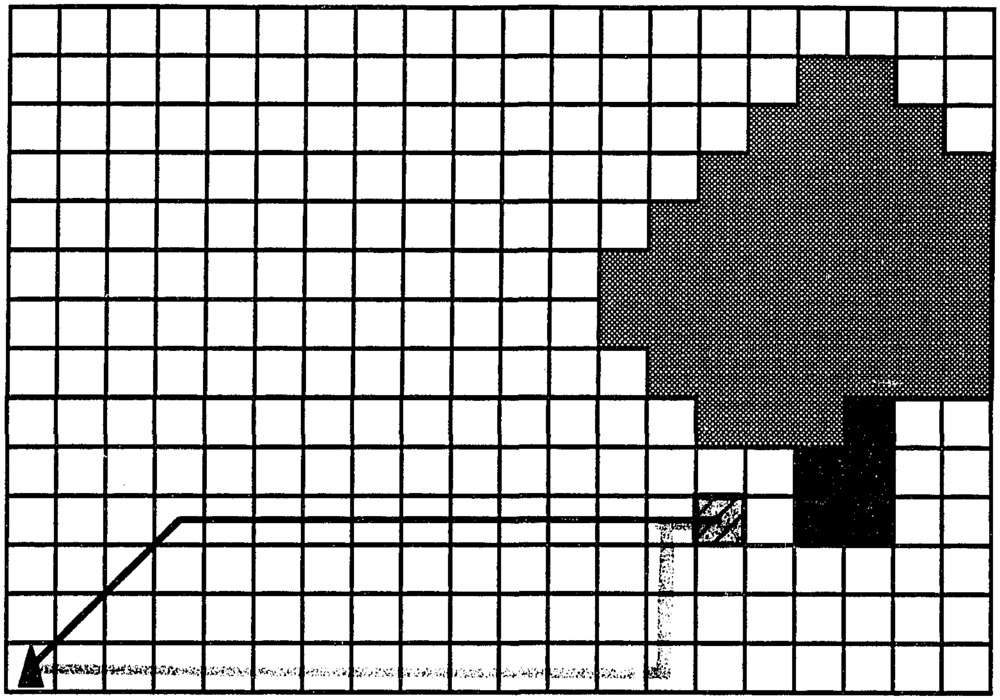
Test 1B - Problem 9



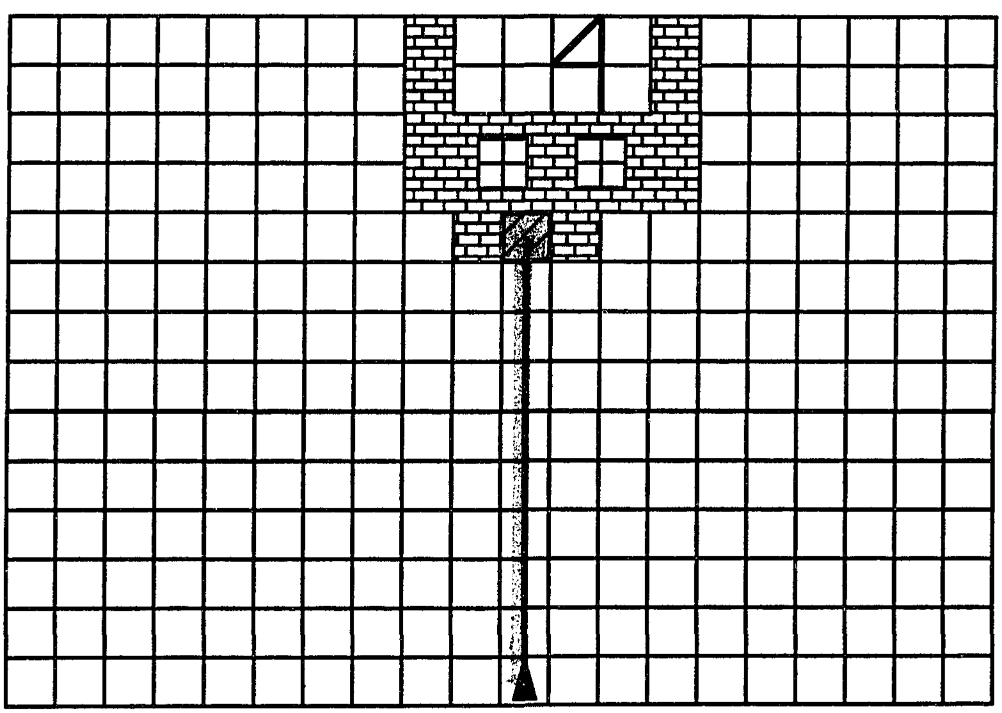
Test 1B - Problem 11



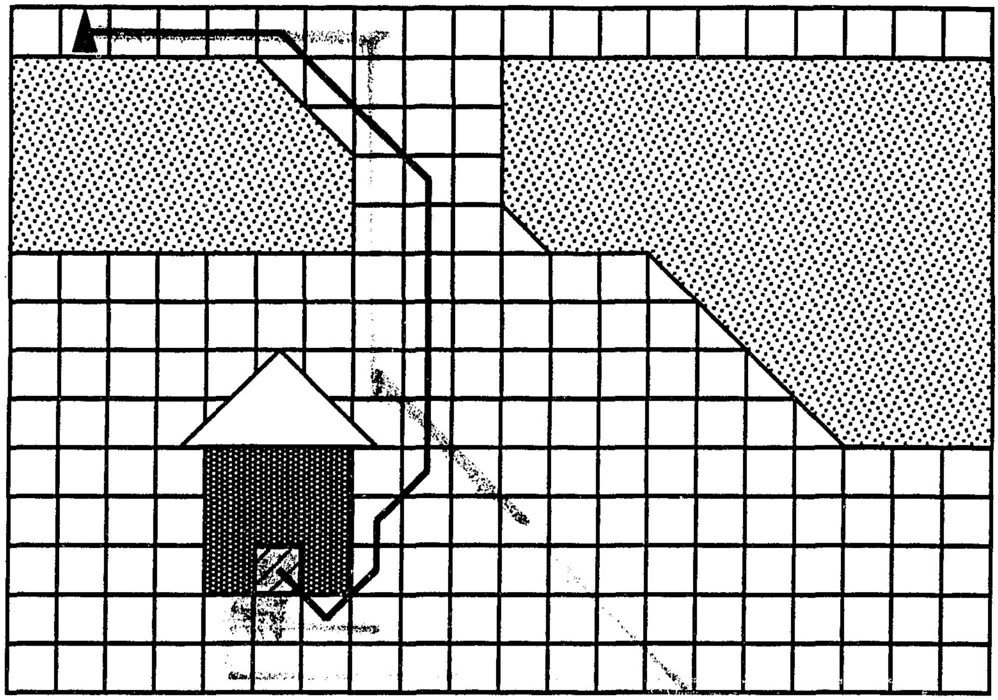
Test 1B - Problem 12



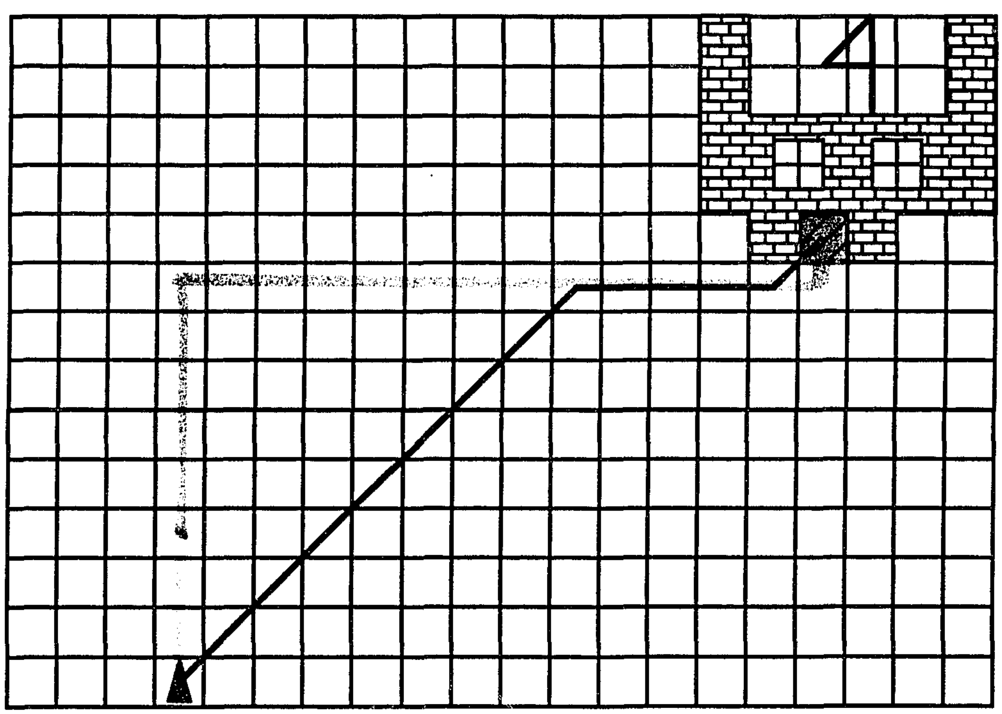
Test 1B - Problem 15



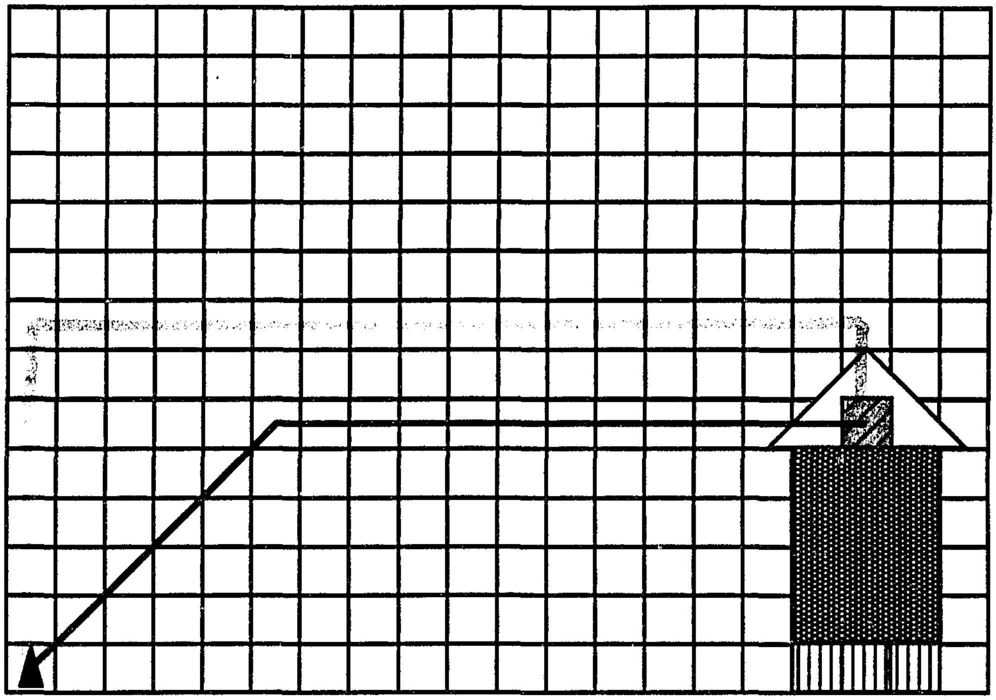
Test 2A - Problem 17



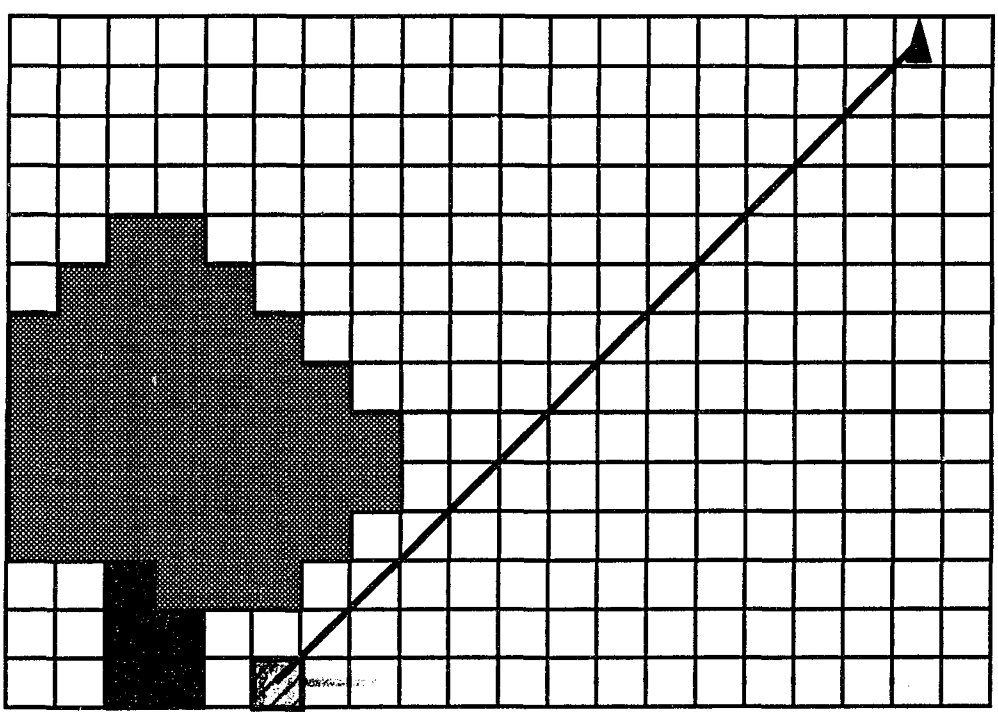
Test 2A - Problem 20



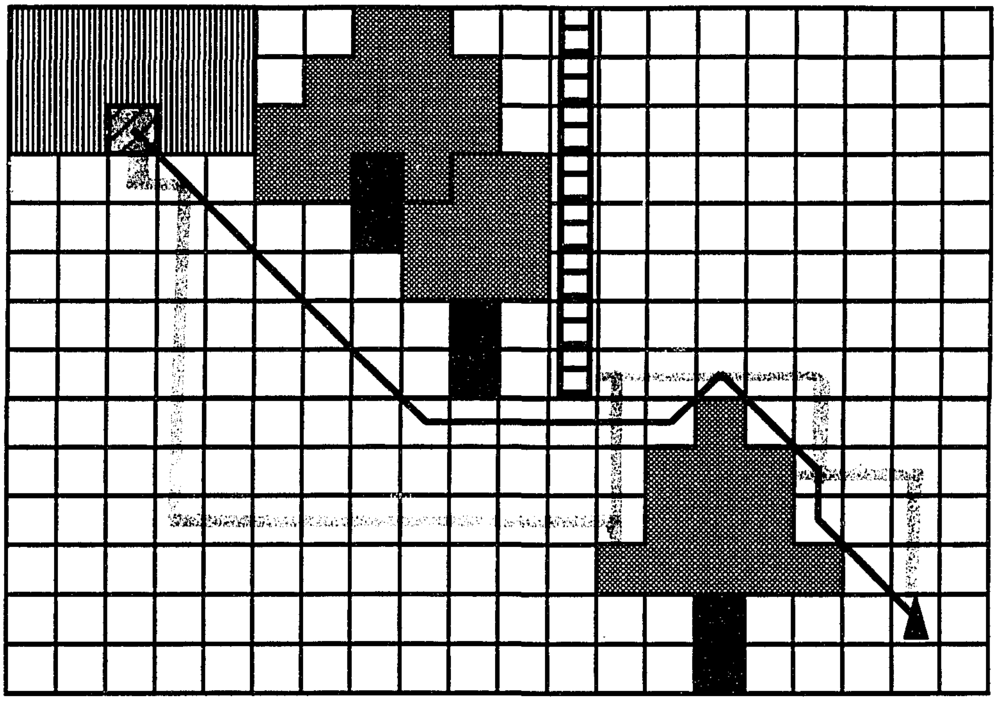
Test 2A - Problem 21



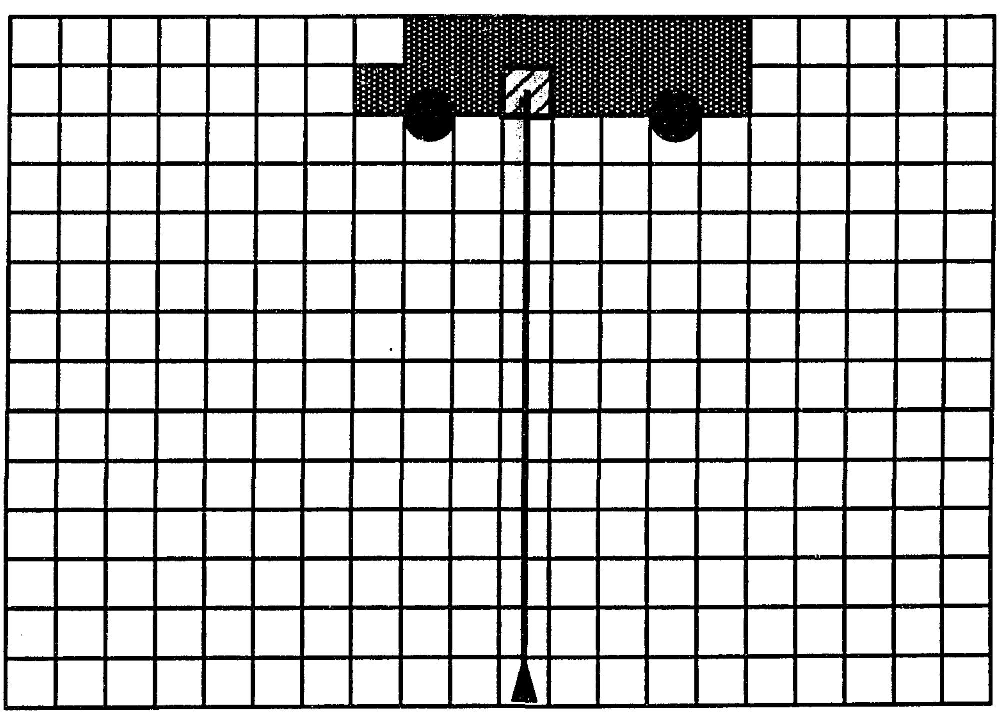
Test 2B - Problem 25



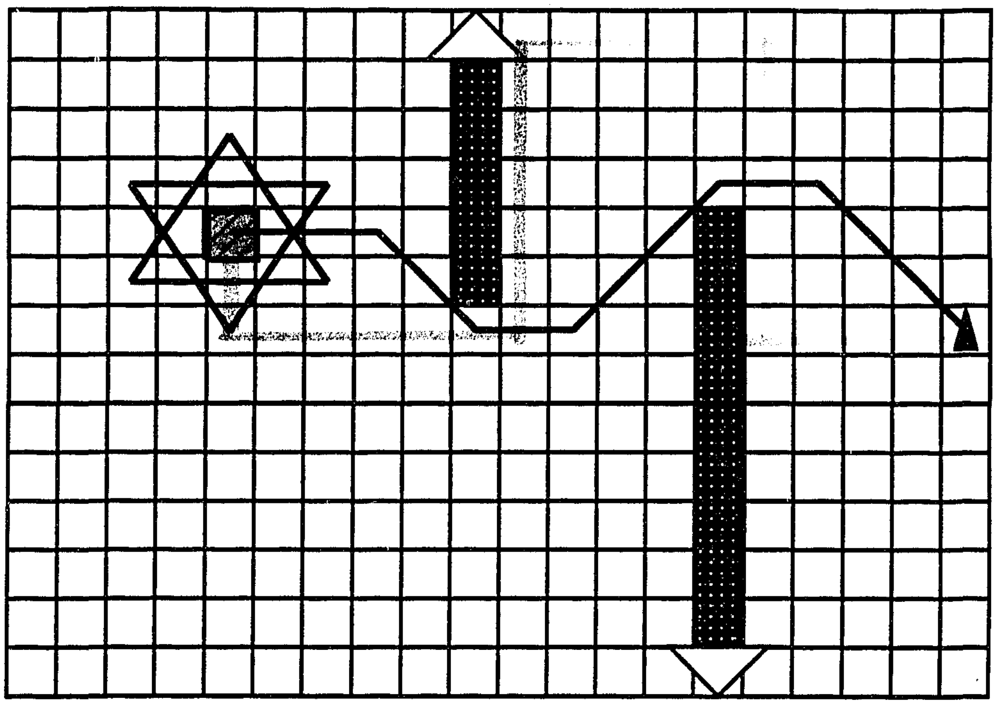
Test 2B - Problem 27



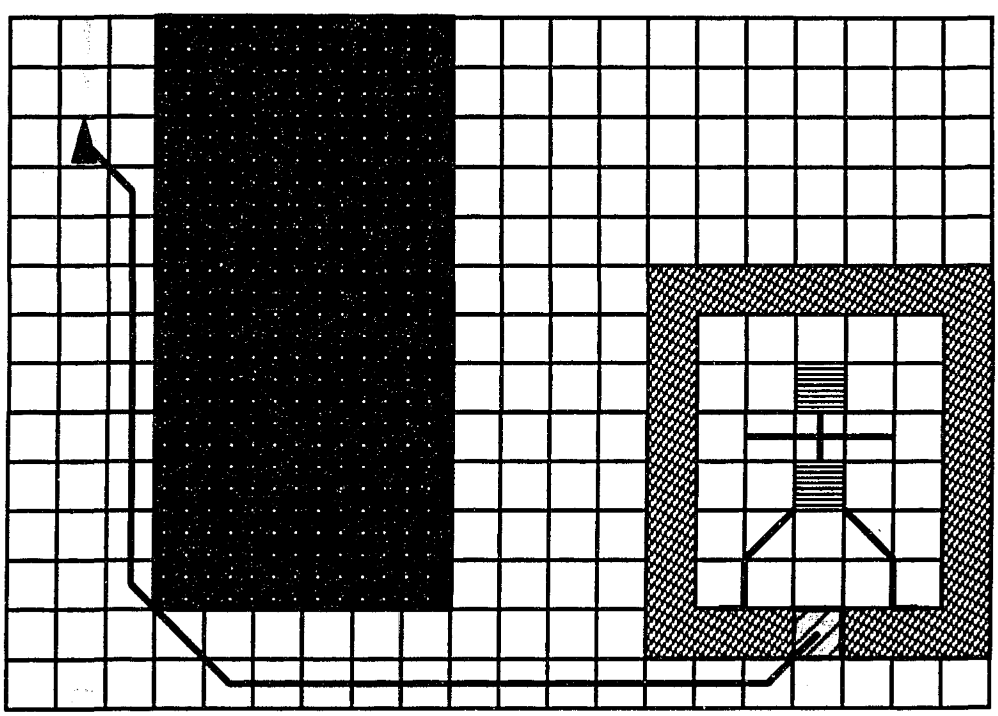
Test 2B - Problem 28



Test 2B - Problem 30



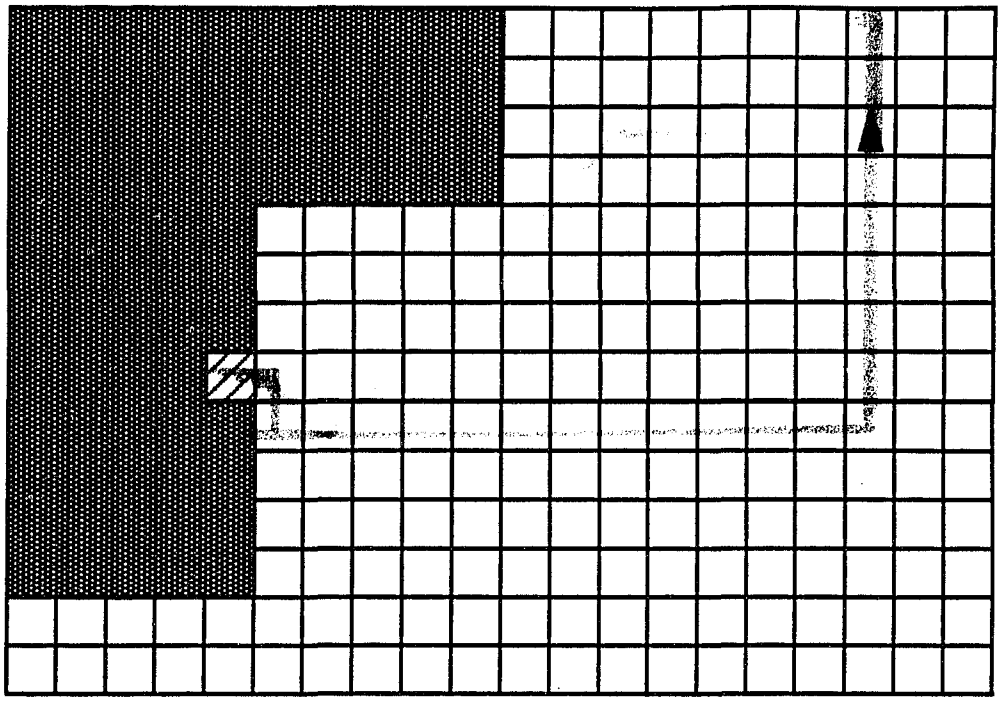
Test 2B - Problem 32



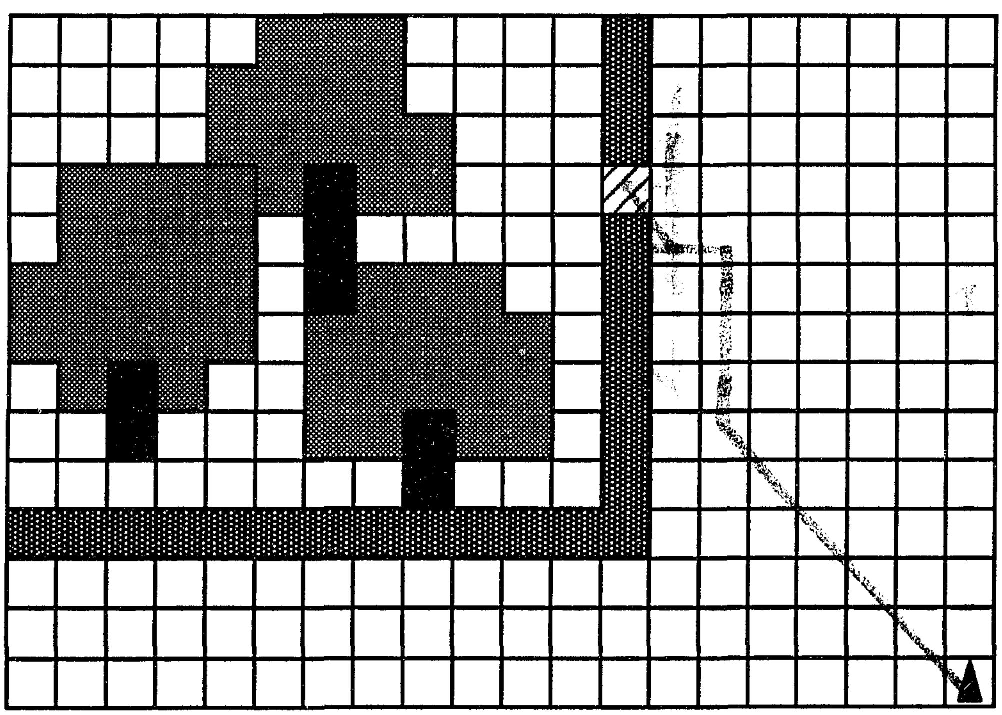
Divergent Problem Solving Set

Orange Lines Represent First Solution
Green Lines Represent Second Solution
Pink Lines Represent Third Solution
Blue Lines Represent Fourth Solution

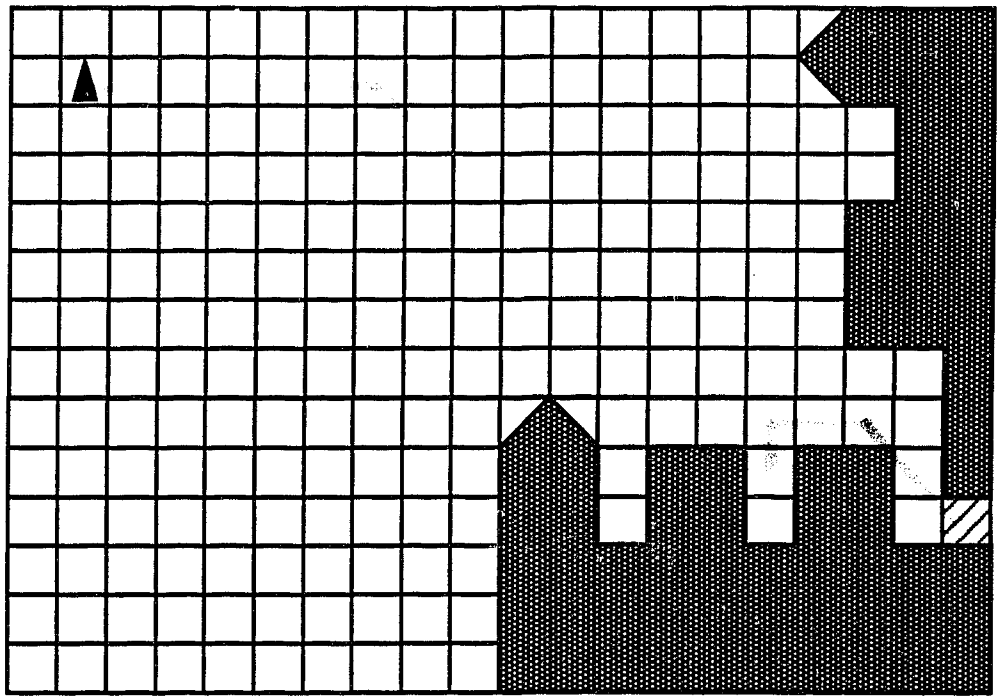
Test 1A - Problem 2



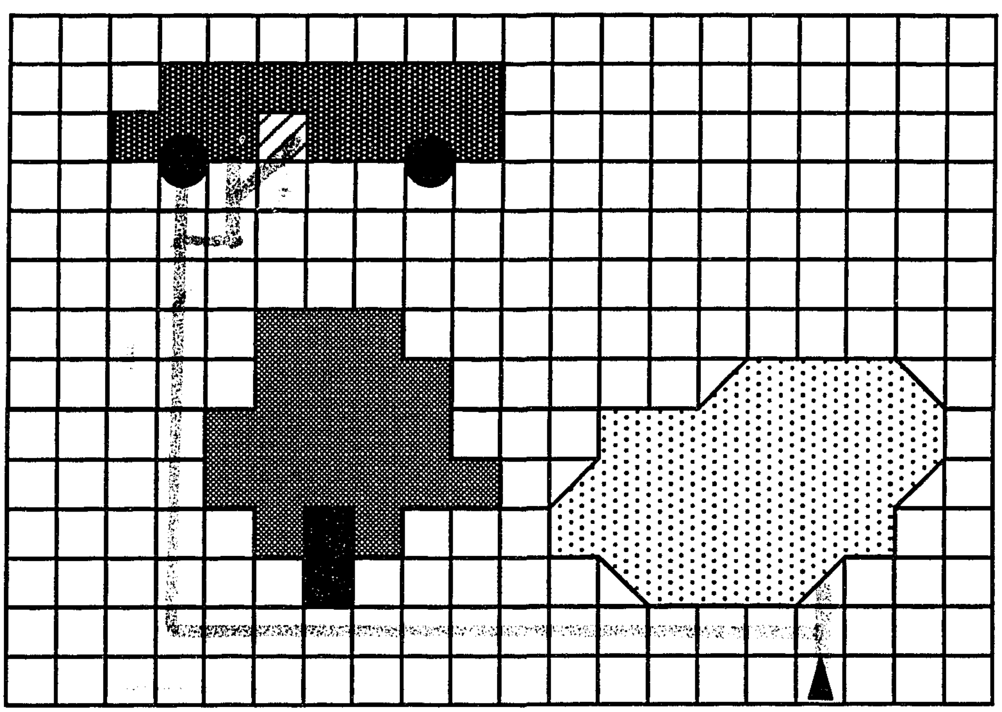
Test 1A - Problem 3



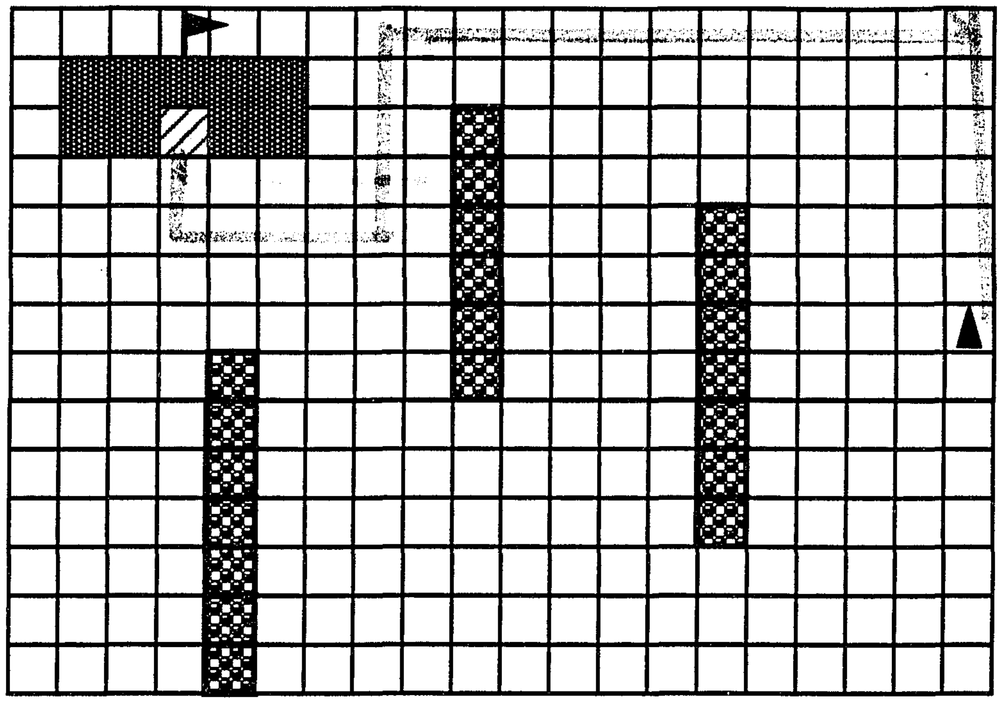
Test 1A - Problem 5



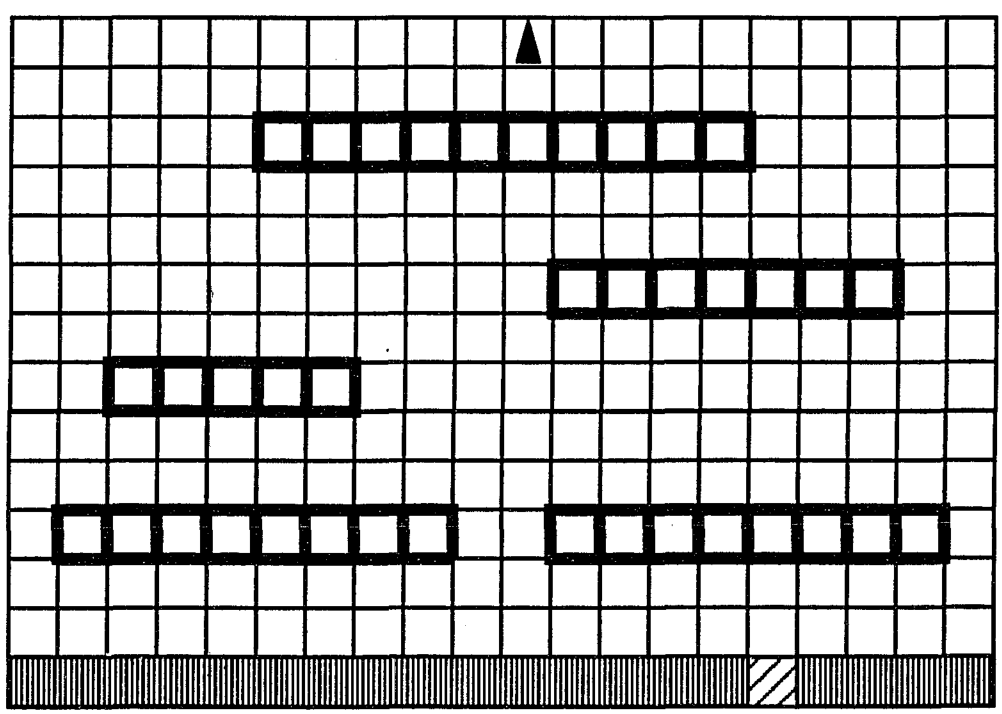
Test 1A - Problem 8



Test 1B - Problem 10

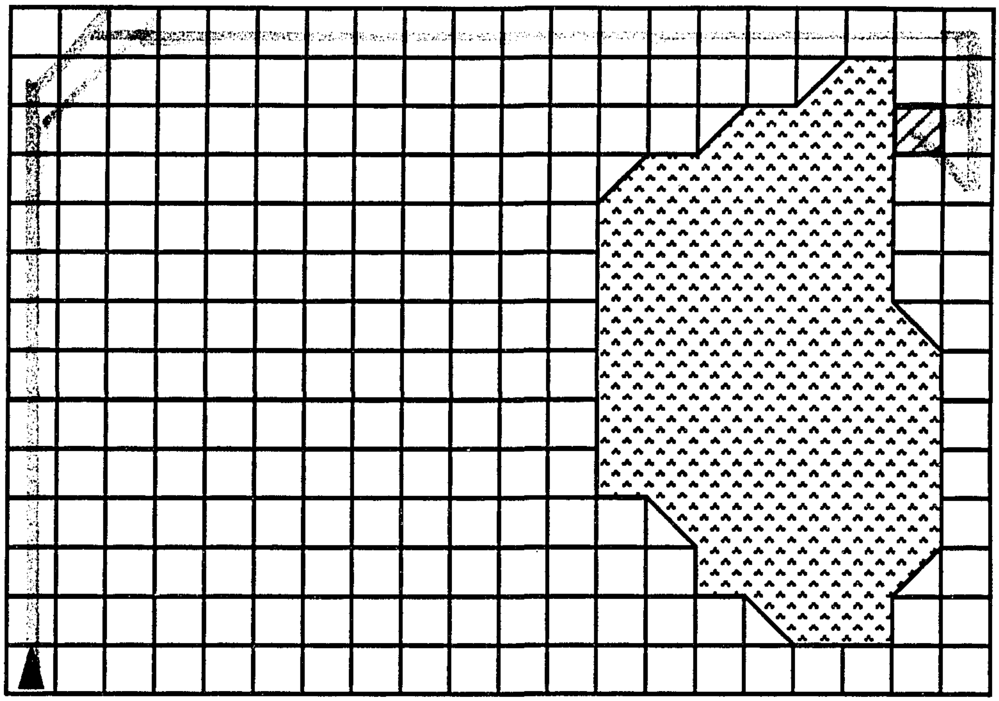


Test 1B - Problem 13

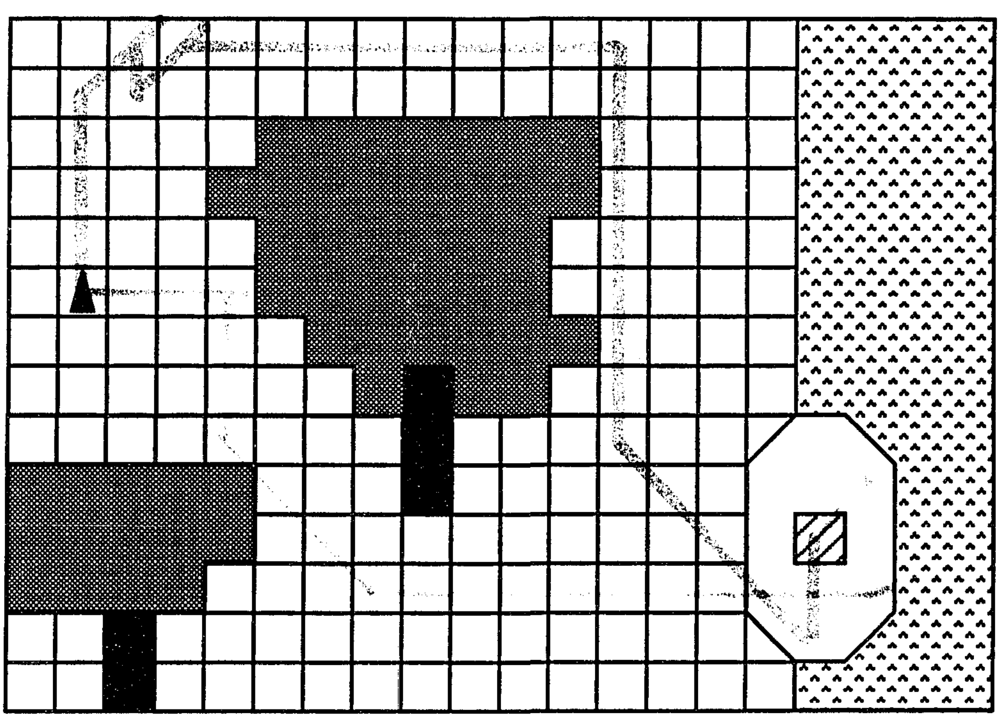


No completed solution path

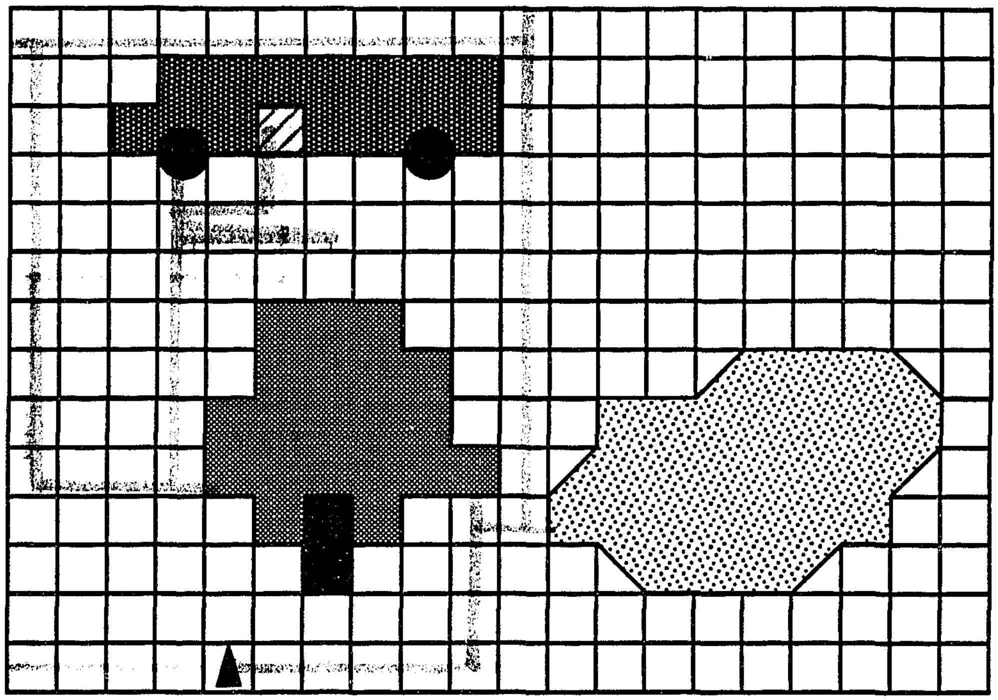
Test 1B - Problem 14



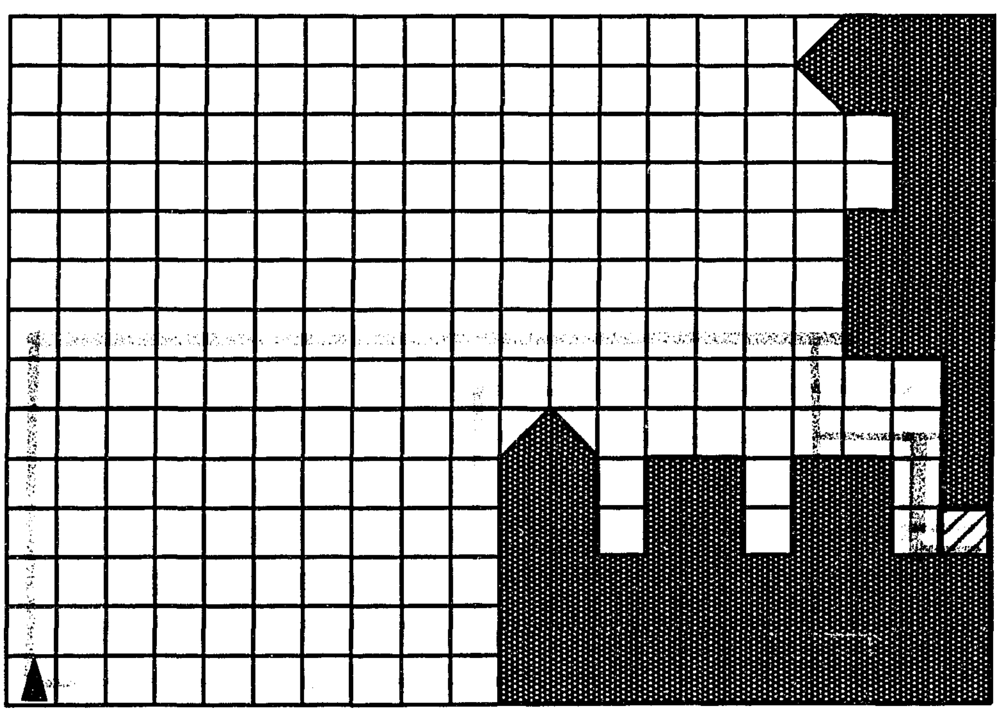
Test 1B - Problem 16



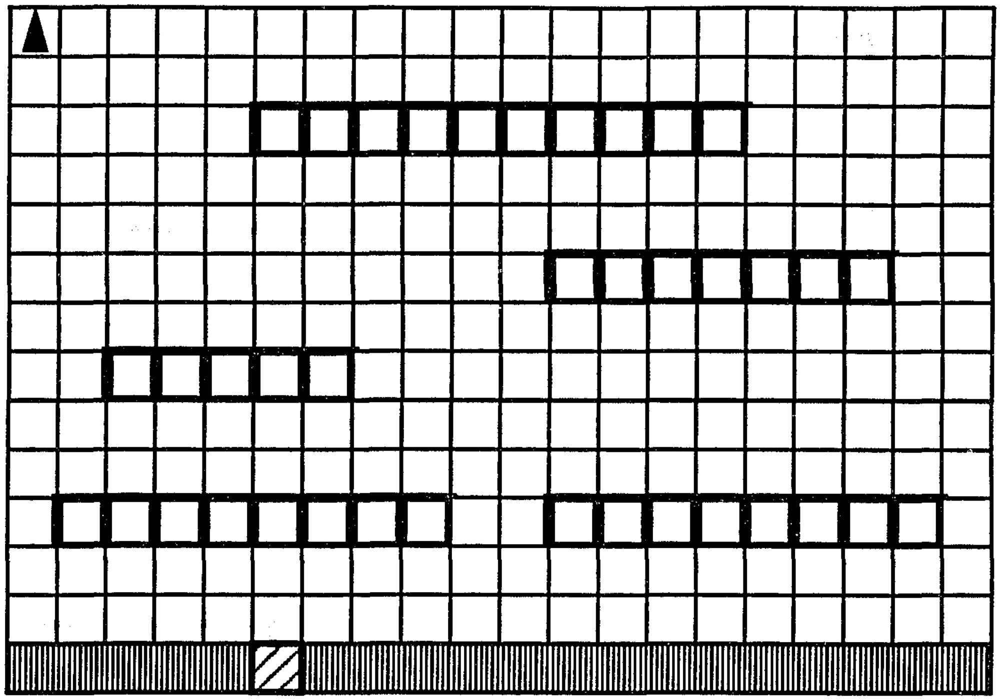
Test 2A - Problem 18



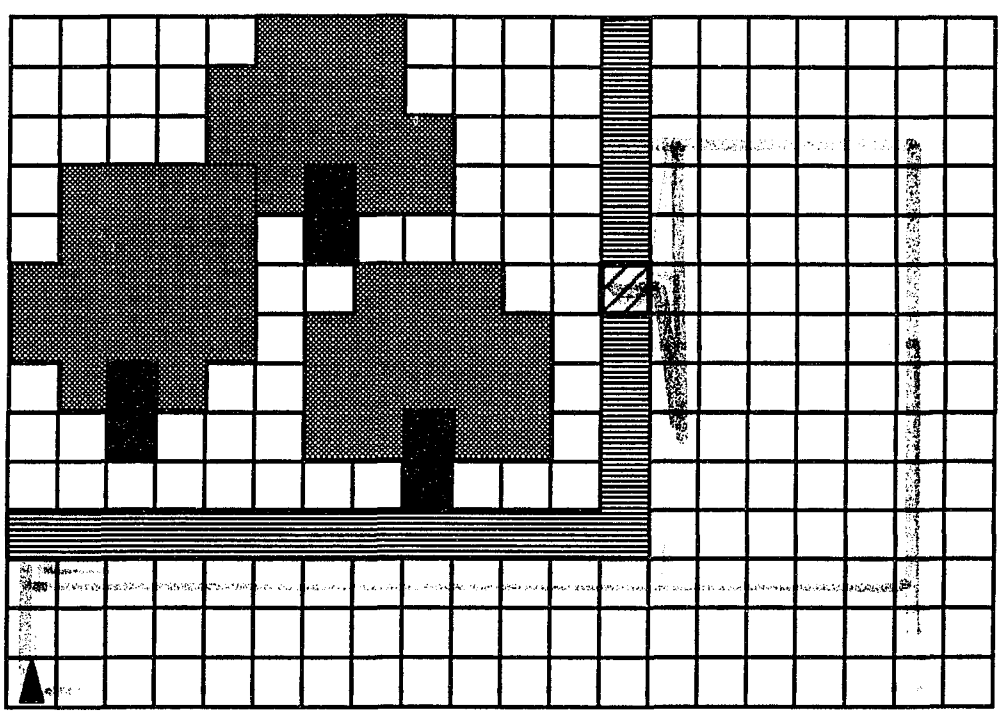
Test 2A - Problem 19



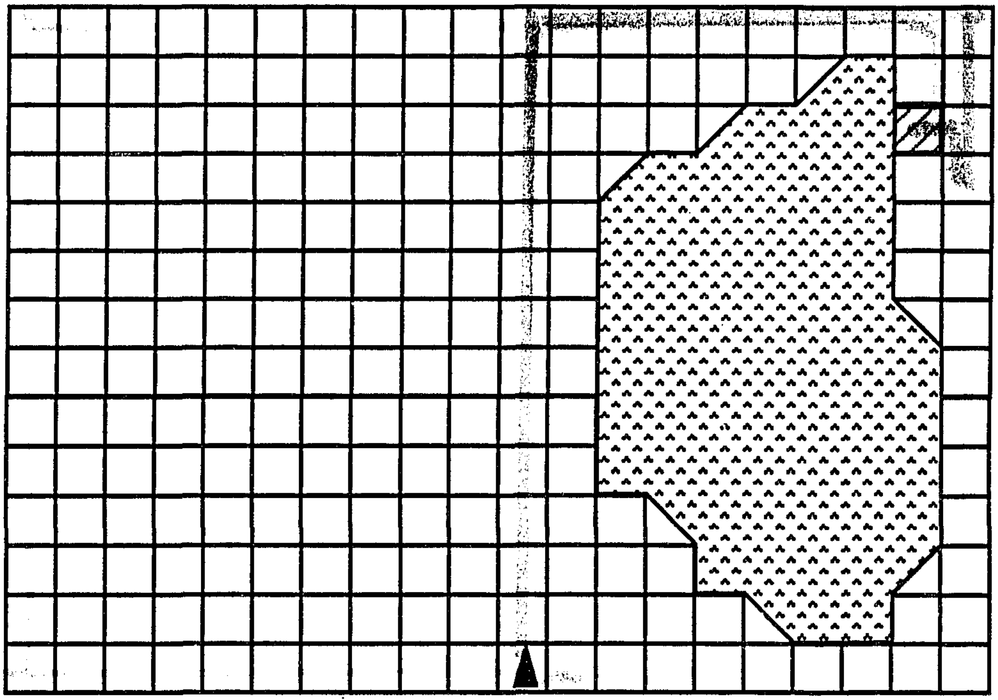
Test 2A - Problem 22



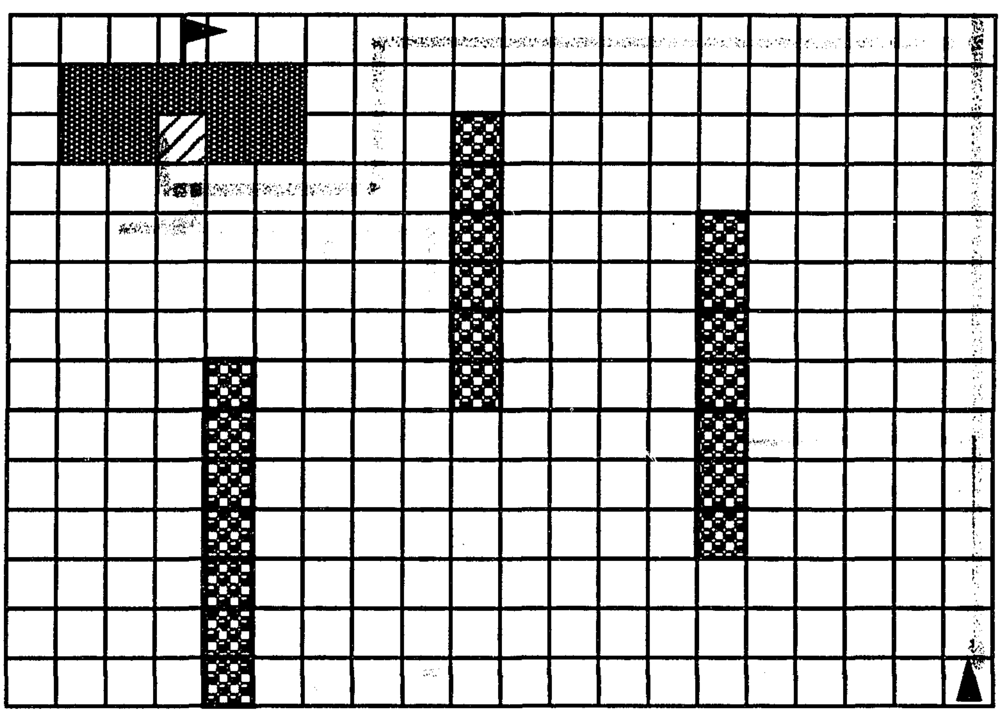
Test 2A - Problem 23



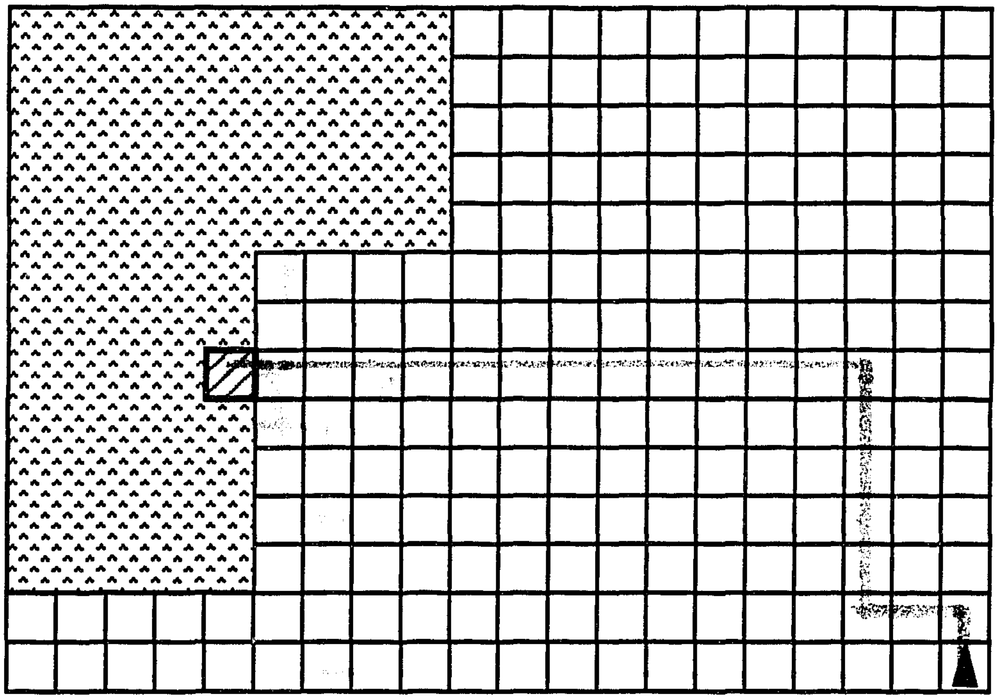
Test 2A - Problem 24



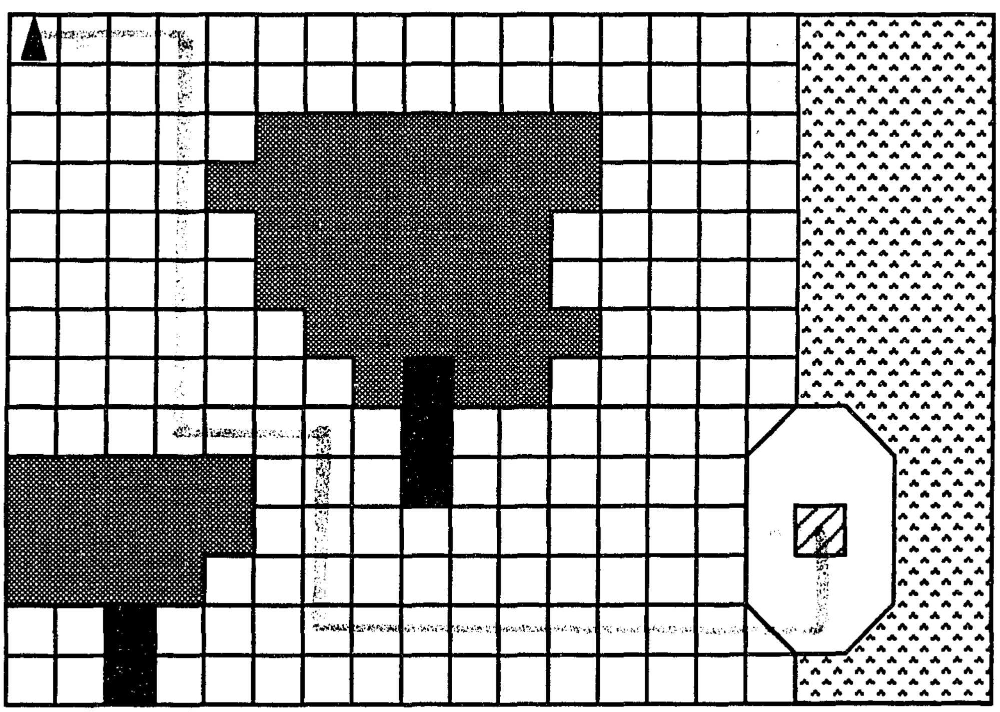
Test 2B - Problem 26



Test 2B - Problem 29



Test 2B - Problem 31



Case Study 3

Results

Damon was classified on the KRISP with high latency time and low errors as being reflective, and his scores on the Kohn Social Competence Scale - Preschoolers and the Classroom Behavior Inventory validated her placement in the category with the more reflective children.

Convergent thinking problems. Examination of the audit trails from Damon's problem solving experiences revealed some distinctive preferences. First, he maneuvered the turtle through the 16 convergent problems by making 67 directional moves, representing a mean of 4.2 decision points per solution path. None of the 67 moves was made as a diagonal move. Although Damon had received equal training time in using the diagonal keys (SW, SE, NW, NE directional keys occupying the 1, 3, 7, 9 keys on the keypad), he chose not to utilize them, even in problems when the target could have been reached within one directional heading (see Problem 6, Convergent Problem Solving Set).

Researchers have consistently reported that young children show a preference for using big steps over little steps in their problem solutions; however, Damon's performance did not support this finding. He made only seven decisions to use big steps, representing 10.4% of his total movement decisions in the sixteen solution paths. The remaining movement decisions, a total of 60, representing 89.6% of his total moves, were made utilizing little steps.

It was interesting that on the seven occasions when he used big steps, Damon used then in conjunction with little step moves. Differing from most of the other subjects who, when a directional heading was chosen, moved forward using either little steps or big steps exclusively, Damon would choose a directional heading and then proceed some number of steps by little steps, followed by some number of big steps, or vice versa. In five of the seven instances, Damon moved by little steps followed by big steps, and in the other two he used big steps first, followed by little steps before another directional heading was chosen. On no occasions did he use a combination of little steps, big steps, little steps or vice versa.

Damon used little steps exclusively in solving ten of the convergent problems, representing 63.5% of the entire convergent problem solving set. Of the remaining problems, he used a big step movement only once in the solution of five of the problems (#4, #9, #15, #27, and #28) and twice in one of the problems (#6).

Audit trail analysis revealed that Damon had only three instances of indecision out of the total 67 directional decisions made in solving the 16 convergent problems (#4, #17, and #21). These three incidences represent an indecision point percentage of 4.5%. Two of the points of indecision occurred as Damon began the problem solving process. In problem #4 Damon changed directional heading two times before he made his initial movement decision; in problem #17, he changed directional headings three times before a decision to move was made. Both of these problems where indecision occurred contained barriers which were immediately adjacent to the turtle cursor at the starting point, and this could have interfered with Damon's decision about in which direction to proceed. It is interesting to note that the very first problem he solved also had a barrier immediately adjacent to the cursor, but did not have an impact on a decision about a directional move.

Another interesting observation is that in problem #17, where Damon changed direction two times, he ended up moving forward in the direction he had initially chosen (keys were pressed in the following order: 6, 3, 6, followed by a movement key).

The three problems in which indecision occurred also represented a variety of cursor starting point positions and target position including top-to-top, top-to-bottom, and bottom-to-bottom, as well as left-to-right and right-to-left.

Divergent thinking problems. Damon completed 31 solution paths in the 16 divergent problems, an average of 1.9 completed paths per problem in the two-minute time limit.

His rate of success can be broken down into categories which include three problems where three different paths were completed (#3, #24, #29); ten problems where two different paths were completed (#2, #5, #10, #14, #16, #18, #22, #23, #26, and #31); two problems where only one path was completed in the time limit (#8 and #19); and one problem where Damon failed to chart a completed path (#13). In the first eight divergent problems, Damon charted fourteen solution paths; in the last eight divergent problems, his solution rate increased to seventeen.

He made a total of 215 directional moves in 31 solution paths. This represents a mean of 6.9 decision points per solution. Of the 215 moves, only seven (3.3%) were diagonal moves. He utilized diagonal moves in 5 (31.3%) of the sixteen divergent problems, for a total of 6 paths or 19.4% of all paths charted in the divergent problem solving set. Of the five paths in which diagonals were utilized, three had barriers (#10, #18, and #31) and two were barrier-free (#2 and #29). Damon utilized all four diagonal options at least one time in his problem solutions.

He consistently utilized diagonals at the mid point in his solution paths, except for one time when he moved the cursor onto the target diagonally. In every other problem both convergent and divergent, Damon approached the target head on.

Divergent audit trail data were consistent with convergent data in respect to big and little steps. Damon made 67 decision to use little steps and 21 decisions to use big steps, which represented 76% and 24% of all movement decisions, respectively. Sixteen of the 31 paths that Damon completed were solved exclusively using little step movements. Damon chose to move in some part of his solution path by big steps in fifteen of his problem solutions. In problem #10, solution 1, he used big steps five different times in charting his path. Two of those times he made a directional decision and then proceeded with movement using big steps until he made another directional decision. The other three times, he made a directional decision and then moved some distance with big steps and with little steps. In ten of the 31 solution paths in the divergent problem solving set, Damon used a mixture of big and little steps together before a directional change was made. Damon never used big steps as his first move, nor did he ever use big steps as a last movement to take the turtle to the target.

As Damon worked through the divergent problem solving set, he experienced 26 points of indecision, which occurred when Damon pressed two or more directional keys before a movement was initiated. These 26 points of indecision involved 68 directional changes or 31.6% of the total directional moves made. Six of 26 incidences of indecision occurred at the beginning of the problem before any movement was initiated, representing 23.1% of the indecision points. Four of the incidences of indecision, representing 15.4%, occurred prior to the last move which would move the turtle cursor onto the target.

The points of indecision can be examined in terms of which problems and in which solution paths they occurred. In seven of the 16 problems (#8, #10, #14, #16, #22, #23, and #29), one or more points of indecision occurred in the first solution, representing 43%. In nine of the problems (#2, #3, #10, #14, #16, #18, #23, #29, and #31), representing 36.3%, the points of indecision occurred in the second solution. Indecision points occurred in the third problem solution of two of the problems (#3 and #24), representing 12.5%. See Table 1 for a breakdown of frequencies of indecision points. There were four problems (#5, #19, #22, and #26), representing 13 solution paths, where Damon had no points of indecision. These 13 solutions where Damon had no difficulty in deciding in which directional heading to proceed represent 41.9% of all the solutions in the divergent problem solving set. Therefore, he experienced one or more incidences of indecision in 18 of the 31 solution paths, or 58.1%. In 12 of these paths (66.7%), Damon had only one incident of indecision. He experienced two incidents of indecision in four of these paths, representing 22.2%. In two of the solution paths (#14, solution 1 and #16, solution 1) Damon had three separate incidences of indecision.

Table 1

Divergent Solution Paths in Which One or More Points of Indecision Occurred in Case Study Three

Problem Number	Barrier/ No Barrier	First Solution	Second Solution	Third Solution	Fourth Solution	Total Solutions
2	No Barrier	-	√			2
3	No Barrier	-	√	√		3
8	Barrier	√				1
10	Barrier	√	√			2
14	Barrier	√	√			2
16	Barrier	√	√			2
18	Barrier	-	√			2
23	No Barrier	√	√			2
24	Barrier	√	-	√		3
29	No Barrier	√	√	-		3
24	Barrier	-	√			2

Discussion

One of the most interesting findings from audit trail analyses was Damon's preference for maneuvering throughout the microworlds of both the convergent and divergent problem solving sets by using little steps. Research in the childhood computing literature has consistently reported that young children prefer big step movements over little step movements (Brinkley & Watson, 1990; Watson & Brinkley, 1990/91; Watson & Busch, 1989; Watson, Lange, & Brinkley, 1991; Watson, Lange, & Brinkley, 1992). The 1990 study of Brinkley and Watson cited data revealing that preschoolers think that big steps are more efficient than little steps. Therefore, Damon's preferences for little steps is inconsistent with previous results. This child utilized little steps effectively and it does not appear that it slowed him down any since he was successful at charting multiple paths in the divergent problem solving set. More than 80% of all of Damon's movement decisions resulted in the use of little steps in his problem solutions in the convergent and divergent problem solving sets. Regardless of cursor position, target position, or the presence or absence of barriers in the microworld, Damon consistently utilized little steps. Perhaps using the smaller steps helped Damon feel more in control of the turtle and gave him more time to "reflect" on what directional decisions would be needed to get the turtle cursor to the target.

This seemed especially true in the convergent problem solving set, because Damon only had three incidences of indecision in all sixteen problems. This fact is indicative of Damon's confidence in navigating the turtle through the microworlds. Although his percentage of indecision points was higher in the divergent problem solving set, he was nonetheless successful in charting multiple paths.

Another interesting finding from the audit trail analysis was the lack of use of any diagonal moves. Although Damon received the same amount of training time in using the diagonal keys (1, 3, 7, 9), he only utilized them seven times in all of his problem solutions. These all occurred in the divergent problem solving set. It is interesting that in problems where only one directional decision (a diagonal) was needed to move the turtle to the target, Damon moved up and over or down and over using the (2, 4, 6, 8) directional keys.

This may indicate that Damon was not viewing the screen as a series of concentric circles, but more as a coordinate grid system (Watson & Busch, 1989). Damon may have not reached the higher order thinking skills that are needed to navigate a screen using a system of angles.

Case Study 4

Results

Marko was classified on the _KRISP_ as impulsive with low latency time and high errors. His scores on the _Kohn Social Competence Scale - Preschoolers_ and the _Classroom Behavior Inventory_ validated his placement in this category.

Convergent thinking problems. Marko made 229 directional decisions in solving the 16 convergent problems. This represents a mean of 14.3 decision points per solution path. However, 146 of the total directional moves were involved in 29 incidences of indecision where Marko made two or more directional changes consecutively before he initiated any movement. The 29 incidences of indecision represented a 12.6 indecision point percentage. The indecision points were located in twelve of the 16 solution paths. Seven of the problems (#1, #2, #7, #9, #17, #27, and #32) which appeared to cause some difficulty for Marko contained at least one barrier that he had to negotiate before he could reach the target. The other five problems (#6, #11, #20, #21, and #25) in which indecision occurred were barrier-free. In only two incidences did the indecision incident occur prior to Marko making his initial movement. Table 1 shows the number of incidences of indecision that occurred in the twelve convergent problems.

Table 1

Convergent Solution Paths in Which One or More Points of Indecision Occurred in Case Study Four

Problem Number	Barrier/ No Barrier	Number of Points of Indecision	Number of Directional Changes
1	Barrier	5	10
4	Barrier	2	3
6	No Barrier	3	4
7	Barrier	1	1
9	Barrier	5	8
11	No Barrier	2	3
17	Barrier	2	21
20	No Barrier	1	4
21	No Barrier	1	3
25	No Barrier	2	39
27	Barrier	2	13
32	Barrier	3	7
Total		29	116

Marko made a decision to utilize diagonals on 19 different occasions as he solved the convergent thinking problems. He used diagonals in ten of the 16 problems. On only one occasion did he use a diagonal as his first directional heading, and on only one occasion was a diagonal heading used as the turtle reached the target. A breakdown of the frequencies of his diagonal moves is as follows: in problems #4, #6, #12, #17, and #27 Marko used only one diagonal move in his problem solution; in problems #7 and #25 he used two diagonals; in problems #1 and #11 he used 3 diagonals; and in problem #9 he utilized 4 diagonals in charting his path to the target.

Marko used all four directional keys (1, 3, 7, 9) in his problem solutions. Table 2 shows the frequencies and percentages of diagonal moves in both convergent and divergent contexts.

Table 2

Frequencies of Diagonal Moves in Convergent and Divergent Problem Solving

	Directional Heading				
Test Type	Top-right to Bottom-left (1)	Top-left to Bottom-right (3)	Bottom-right to Top-left (7)	Bottom-left to Top-right (9)	Percentage of all Directions
Convergent	8	5	4	2	8.3
Divergent	5	5	4	3	10.1
Total	13	10	8	5	9.1

Researchers have consistently reported that young children prefer to use big step movements over rather than little step movements in Logo microworlds (Brinkley & Watson, 1990; Watson & Brinkley, 1990/91). Marko's choice of movement keys did not challenge this finding. He made 79 decisions to use big steps and only 40 decisions to use little steps in solving the 16 convergent problems. These numbers represent 66.4% and 33.6% of the total movement steps, respectively.

Both little steps and big steps were used in the problem solutions of 14 of the convergent problems. In two problems, #15 and #28, Marko solved the problems with big steps exclusively. His initial movement in 11 of the problems was with big steps and he moved the turtle cursor onto the target by using big steps in 14 of the 16 problems. It is interesting that Marko would use big and little steps consecutively before he made a decision to change direction. This combination of movement keys was used 21 times.

Divergent thinking problems. Marko charted 18 paths in the 16 divergent problems. He failed to complete even one path in the two-minute time limit on four of the problems (#2, #8, #13, and #16). His rate of success at completing one or more paths includes one problem in which he completed four paths; three problems in which he completed two paths; and eight problems in which he completed only one path in the two-minute time limit.

Marko made a total of 168 directional moves in the 18 paths he completed in the divergent problem solving set. This represents a mean of 9.3 decision points per solution. Of the 168 moves, 17 or 10.1% were diagonal moves. He used diagonals in nine of the problem solutions (50%), for a total of 10 paths or 55.6% of all paths charted in the divergent problem solving set. Five of the problems in which diagonals were used contained some type of barrier that had to be negotiated in order to get the turtle to the target; the other four were barrier-free.

Marko utilized diagonal moves five times in problem 22. In problems #3, solution 1; #26, solution 2; and #31, solution 1, he used diagonals twice. In the other six problem solutions he used a diagonal move only one time. On two occasions (11.1%) he used diagonals as his last move in order to move the turtle cursor onto the target. He never decided to use a diagonal key as an initial directional heading.

Divergent audit trail data are consistent with the convergent data in respect to big and little steps. Marko used 79 big steps and 37 little steps in completing the solution paths. In 13 of the problem solutions Marko utilized both big and little steps in his solution paths. In five of the problems he chose big steps exclusively in charting his solutions. As was observed in the convergent problem solving set, it was found that Marko would combine movement keys and use them consecutively before making a decision to change direction. He used the big step and little step movements in combination on nine different occasions in the divergent problem solving set.

Marko had 16 incidences of indecision about directional heading, which represents a 9.5% indecision point percentage. The indecision points were located in 12 of the 18 solution paths and involved 11 of the problems. Seven of the problems in which Marko experienced some difficulty in making a decision about what direction he wanted to proceed, contained barriers (see Table 3).

As in the convergent problem solving set, where Marko experienced four long runs of indecision (where ten or more directional keys were pressed before any movement key was selected), he had a similar experience in two of the divergent thinking problems.

On four occasions Marko experienced his incidence of indecision at the outset of solving the problem before he made his initial movement decision. He had no incidence of indecision just prior to solving the problem by moving the turtle cursor onto the target. The result of three incidences of indecision resulted in Marko deciding to use a diagonal directional key.

Table 3

Divergent Solution Paths in Which One or More Points of Indecision Occurred in Case Study Four

Problem Number	Barrier/ No Barrier	Number of Points of Indecision	Number of Directional Changes
3	No Barrier	1	3
10	Barrier	1	1
14	Barrier	1	2
18	Barrier	1	27
19	Barrier	1	1
22	Barrier	3	6
23	No Barrier	2	4
24	Barrier	3	5
26	Barrier	1	10
29	No Barrier	1	1
31	Barrier	1	1
Total		16	61

Discussion

Analysis of the convergent and divergent audit trail data for Marko show some distinct patterns. He had multiple incidences of indecision in both sets of problems. In a total of five problems in both problem solving contexts, he had indecision points which involved a range of 10-38 directional heading changes before a movement was initiated. In all five of these problems he had runs of hitting the "4" (W) and the "6" (E) keys. An explanation for why this pattern occurred may lie in Marko's impulsiveness. It appears that he would frequently hit directional keys consecutively before pressing either the little or big step key.

It does appear that Marko was able to utilize the concentric circle concept of the Logo microworld because he utilized all four diagonal movements in both the convergent and divergent problem solving sets. He showed a preference for the diagonal keys in the following order of usage from greatest to least used: 1(SW), 3(SE), 7(NW), and 9(NE). It appears that Marko was able to comprehend the function of the eight directional keys and the two movement keys and to apply this understanding to the successful completion of most of the problems.

It is some concern that he did not finish one completed path in the two-minute time limit in four of the divergent problems. All four of these problems were in the first half of the divergent problem solving set. One possible reason for this lack of performance may be that Marko was not comfortable with the concept of "no one right answer." Children of this age may not have had many experiences or opportunities to use divergent thinking skills. Marko also may have been close to reaching the target when the time limit ran out, but the program would not record data from incomplete paths.

Although Marko showed a preference for big steps over little steps, he used both in the solution paths of a majority of the problems. It is also interesting that he uses the big steps and little steps in combination with each other. His use of big steps is concurrent with previous literature about young children's preferences (Brinkley & Watson, 1990; Watson & Brinkley, 1990/91). No particular strategies for solving the 32 problems emerged from the audit trail data; however, by examining the areas where Marko experienced difficulty, one can see evidence of his more impulsive style in operation as he worked through the computer problems.