

THE DEVELOPMENT, TESTING, AND USE OF A
COMPUTER INTERFACE TO EVALUATE AN INFORMATION PROCESSING
MODEL DESCRIBING THE RATES OF ENCODING AND MENTAL ROTATION
IN HIGH SCHOOL STUDENTS OF HIGH AND LOW SPATIAL ABILITY

A Thesis

Presented in Partial Fulfillment of the Requirements for
the degree Master of Arts in the
Graduate School of the Ohio State University

by

Frederick Loye Donelson, B.A.

* * * * *

The Ohio State University

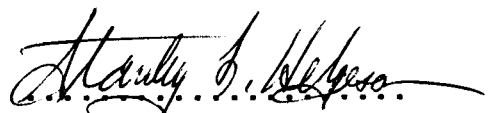
1990

Master's Examination Committee:

Stanley Helgeson

Patricia Blosser

Approved by

A handwritten signature in cursive script, reading "Stanley Helgeson". The signature is written in dark ink and is positioned above the printed name "Stanley Helgeson".

Advisor

College of Education

To Brenda
My Most Enthusiastic Fan
and
Closest Friend

ACKNOWLEDGEMENTS

I wish to express appreciation to Dr. Stanley Helgeson for his guidance and direction, not only during this project, but throughout my graduate program at Ohio State. His willingness to advise rather than dictate made my research much more personal and meaningful. Thanks also goes to Dr. Patricia Blosser for her suggestions and comments during my many hours with her in class and during my oral exam. A special thanks is expressed to Dr. Marlin Languis, whose classes on learning styles and thinking skills have inspired not only this project, but many new and meaningful experiences for my classroom students. Finally, to my wife Brenda and my girls Ashley, Lindsey, and Chelsea, I offer my heart-felt thanks for your sacrifices over the last few years. They were appreciated more than you will ever know.

VITA

December 31, 1953Born - Westfield, New York

1976B.A., Otterbein College,
Westerville, Ohio

1976-1979Physical Science, Biology
Chemistry, and Physics Teacher,
Worthington Christian School,
Worthington, Ohio

1979-1982 Middle School Biology, Physical
Science, and Earth Science
Teacher, Plain Local Schools,
New Albany, Ohio

1982-1984High School Biology, Biology II,
Meteorology, and Ecology
Teacher, Plain Local Schools,
New Albany, Ohio

1984-Present High School Biology, General
Science, and Special Aspects
Teacher, Gahanna Jefferson
City Schools, Gahanna, Ohio

FIELDS OF STUDY

Major Field: Educational Studies, Science Education

TABLE OF CONTENTS

DEDICATION	ii
ACKNOWLEDGMENTS	iii
VITA	iv
LIST OF TABLES	vii
LIST OF FIGURES	viii

CHAPTER	PAGE
I. PROBLEM SECTION	1
Introduction	1
Problem Statement	6
Definitions	7
Limitations	10
Delimitations	11
Variables	13
Conditions and Constraints	15
Background	16
II. REVIEW OF LITERATURE	21
III. METHODS	36
Subjects	36
Materials	37
Procedure	41
IV. RESULTS	43

V. CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS	61
Generalizations	61
Interpretations	63
Implications	66
Recommendations	68
REFERENCES CITED	70
APPENDIX	75
Listing of Developed Program	76

LIST OF TABLES

TABLE		PAGE
1.	Cognitive Differences of High and Low Spatial Groups	45
2.	Comparison of High and Low Spatial Ability Groups for Significant Differences	46
3.	Test Scores - Percentage Correct	46
4.	Mean Response Times for Rotation of Alpha-Numeric Characters	51
5.	Mean Response Times for Rotation of PMA Characters	52
6.	Total Rotational Response Time Statistics	55
7.	Response Times from Least Squares Functions	58
8.	Linear Fit as Measured in R Squared Values	58

LIST OF FIGURES

FIGURES	PAGE
1. Student Satisfaction Survey Results	38
2. PMA Characters and Rotational Orientations	39
3. Additional Times for Wrong Responses	49
4. Mean Response Times for Alpha-Numeric Characters	53
5. Mean Response Times for PMA Characters	54
6. Total Mean Response Times for All Characters	56

CHAPTER I

THE PROBLEM

Introduction

Public schools in America are under attack. Over the past few years, a great concern has surfaced in this country. Teachers, business leaders, parents, and politicians alike are deeply troubled by the increasing number of students who do not make it through high school. Dropout rates hover around twenty-five percent; in some urban schools the rate is more than fifty percent (Roberts, 1988). A new label has emerged; the "at risk" student. It is estimated that as many as thirty to forty percent of students may be classified as being "at risk" (Roberts, 1988).

Much discussion has taken place concerning students "at risk." Several states have set up special commissions just to define who is an "at risk" student. The 1985 School Based Pupil Motivation and Maintenance Program and Dropout Recovery Act in California defined "high risk" student as ones who were frequently absent, scored low in math and reading, lacked identification with school, exhibited boredom and disruptive behavior

and had an inability to tolerate structured activities. Several states, such as California, Connecticut, Texas, and Illinois have established state-wide programs to help solve the problems associated with "at-risk" kids. Job training, counseling, and general remediation programs have been enlisted to help counter the problems contributing to students becoming "at-risk" (Mirga, 1988).

The state of science education in America has also come under attack. *The Science Report Card* (1988) illuminated several areas of deficiency in science classrooms. Miller (1989) has estimated that as few as five or six percent of American adults may be considered scientifically literate. Project 2061 (Clark, 1989), one of the new plans for science education in the next century, implies that science classes have moved away from meaningful "hands-on" discovery learning and have replaced it with worksheets and symbolic science, where students talk about experiments rather than actually performing them. Many schools lack adequate equipment for meaningful "hands-on" learning and those that do have equipment often funnel most of it to upper level, college preparatory courses rather than to lower level general science ones. As a result, more and more students are

scientifically disadvantaged. Business leaders and parents are increasingly concerned about this trend and, consequently, education in general and science education in particular has come under fire.

One of the most notable areas to emerge because of this public scrutiny is the idea that students process information differently; they have their own unique learning style. Some today feel that one of the main reasons for student failure is a lack of learning style knowledge in the general classroom. Much has been written by Dunn and her colleagues (1978, 1982), Winn (1982, 1988), and others illustrating that while some students process information holistically, others process items in a step-by-step, sequential way. Letteri (1985) has discussed several areas of "cognitive control" that may influence the way a student perceives or learns new information.

Many teachers across America regularly use learning style instruments to assess the learning styles of students. Most tests are truly preference tests, assessing items such as environmental conditions and feelings about certain types of activities or actions of others. Some instruments, such as the *Learning Style Profile* by Keefe and Monk (1986), measure not only preferences, but strengths or

weaknesses in certain cognitive processing styles, such as the ability to be analytical or to place things into categories accurately. Gardner (1985) has conjectured that students may have many different areas in which they may be talented or deficient. His theory of "multiple intelligences" is gaining support throughout education circles because it seems to better explain the unique ways in which students learn. He suggests that students may have several areas of competency, including music, linguistics, mathematics, kinesthetics, and spatial relationships.

The last one, spatial ability, rarely finds its way into American science classrooms in a planned, deliberate way. In fact, it often is associated with music or the arts. Yet a close examination of this type of thinking reveals that it is intertwined with all aspects of our lives. If one places furniture in a moving van or rearranges some pieces in the family room, spatial thinking is used. Reading road maps, planning a future move during a chess game, or packing a suitcase all involve spatial thought. Visualizing atomic models, organic ring structures, or the DNA double helix demands that the mind visualize in a spatial manner. Returning to science classrooms after lunch or to our homes after work would be impossible if

not for a memory based on spatial ability.

Research by Pallrand and Seeber (1984) and Stuessy (1988) also indicates that successful scientific reasoning ability may be dependent on one's spatial ability. Grasha (1981) advises that, instead of matching learning styles, teachers need to intervene to enable weaker areas in style to develop more fully. Languis and Wittrock (1986) have used brain mapping to show that intervention strategies actually change processing modes in the brain. Certainly spatial ability invades our everyday life and is an important skill to examine, especially as it relates to the teaching of science.

Although spatial ability has been effectively measured in students for several years, many questions remain as to how the brain actually thinks spatially. How does one rotate objects in the mind? Is the encoding process important in spatial thought? What about short term memory? Do students of various spatial ability differ in any of these important areas? If so, how do they differ? What happens to these processes in the brain if intervention strategies are used on a regular basis? How can these ideas be tested in the normal science classroom? If a working model of spatial thought could be adequately developed,

it might be of use in persuading teachers to use intervention strategies on a more regular basis in the classroom.

That was the purpose of this project. An instrument was developed, field-tested, and used to evaluate an information processing model of brain encoding and rotational ability for students of differing spatial ability.

Problem Statement

This project investigated the speed of encoding and rotation of images during simple spatial rotational operations in high school students of both high spatial ability and low spatial ability. The independent variable was the angle of rotated images to be compared. Encoding and mental rotation rates were dependent on changes in rotation. Specifically, the following questions were addressed:

1. Do high spatial ability students encode images faster than low spatial ability students during simple rotational tasks?
2. Do high spatial ability students rotate images faster than low spatial ability students after encoding is complete?
3. Is the rotating process of both high and low spatial students linear in nature?
4. Is there a significant difference between the short term visual memories of high spatial students and low spatial students?

5. Does a correlation exist between short term visual memory and spatial ability?

This project was subdivided into five basic subproblems. First, research was done to arrive at a simple, easily testable information processing model that could describe both the encoding and rotation components of spatial thought. Second, a computer software/hardware package was developed that could measure reaction times of encoding and rotational tasks using equipment that would be affordable to the normal high school science teacher. Third, the instrument was field tested with high school students. Fourth, 37 students from a field of 107 biology and earth science students were identified as being of high or low spatial ability. Finally, these students were tested with the developed instrument to investigate more fully the roles of encoding and mental rotation during spatial activity.

Definitions

Encoding - This process is the ability to form a mental image of received stimuli in the mind. Specifically, this paper analyzes the speed of encoding a visual stimulus made up of letters, numbers, or odd

shapes from the *Primary Mental Abilities Test* (Thurstone, 1958).

Mental Rotation - The process of mental rotation involves movement in the mind of an encoded image around one or more axes. In this project, images are rotated in the mind from 30 to 150 degrees away from vertical back to a vertical position.

Reaction Time (RT) - Referring to the measurements in this paper, reaction time is the amount of time it takes to encode two images, compare them, rotate them in the mind, and react by pushing a judgement button.

Sequential Processing - This ability to integrate stimuli into an organized serial order (Languis, 1990) is also described by the construct successive processing.

Short Term Memory (STM) - Stewart and Atkin (1982) suggest that STM is the site of information storage while one attempts to organize and store information in long term memory. It can maintain information from a few seconds to a few minutes and can only hold seven to twelve chunks of information at a time. They also suggest that it is composed of two sections: (1) the "echo box" where information is quickly lost unless rehearsed; and (2) "working memory" where information is stored while integrative processes are used to make

it part of long term memory. In this project, only the visual aspect of STM is measured and memory scores should be considered in terms of short term visual memory (STVM).

Simultaneous Processing - The ability to apprehend and integrate various elements of an experience immediately during the encoding and organizing process is considered simultaneous processing. The individual processes the experience holistically; the totality of the experience is grasped all at once (Languis, 1990).

Spatial Relations Tasks - These tasks are performed on simple types of stimuli and require mental rotation and comparison processes to make judgements about the identity of a pair of stimuli (Mumaw and Pellegrino, 1984). The main event during this type of task is the mental rotation of an image in the mind.

Spatial Visualization Tasks - Tasks such as these employ complex stimuli and frequently require mental operations on a stimulus array. Often, there is movement among the internal parts of the stimulus configuration or the folding of flat patterns (Mumaw and Pellegrino, 1984). Individuals performing these tasks often take perspectives or determine directions from different orientations (Languis, 1990).

Limitations

This project only deals with the simpler type of spatial tasks known as Spatial Relations. Simple encoding and comparison of images and rotation of simple stimuli are the only types of processes measured in the developed instrument. Although findings may also relate to more complex spatial visualization tasks, processing models for those tasks are much more complex and do not necessarily entail the same features.

Student testing was limited to 144 trials, administered in two blocks with a thirty second intervening rest time. Although some students could sustain attention longer than this, it was thought that the time needed for this test would approximate the attention span of the normal lower level science student. Including directions, tests rarely exceeded twenty minutes.

After giving directions, it was assumed that students knew how to correctly identify mirror images. Part of the directions involved students physically moving cut-out images and making correct judgements on several projected images. Incorrect responses on the test were considered examples of incorrectly rotated images rather than not understanding directions.

The developed instrument was field tested and administered to high school students aged fourteen to eighteen. Although students may not be at the same developmental age, this study assumed that students were able to visualize Euclidean notions of vertical and horizontal coordinates coupled with conservation of length, figure shapes, area, volume, and angles (McCormack, 1988).

Delimitations

Students were not selected randomly for this sample. They came from three college-bound biology classes and one general earth science class. The biology students were a mixture of ninth and tenth grade students who maintained a 2.0 average or better in middle school. Many earth science students would fall under the label of "at risk." They traditionally are low achievers who normally take the course to meet science requirements for graduation. Since approximately equal numbers of earth and biology students were found in each group (high and low spatial), it was assumed that past academic achievement would not be a factor.

Classification of students as high or low ability students was decided by performance on the spatial section of the *Learning Style Profile*. Any student scoring more than one standard deviation from the national norm mean for the test was considered a potential qualifier of high or low spatial ability. Since the *LSP* is a second generation test intended only to give general knowledge about student learning style, one cannot be dogmatic about the results. A second measure of spatial ability was desirable. The *Mental Rotation Test* developed by Vandenberg in 1971 and revised by Crawford in 1979 was also administered. Students qualifying as spatially high on the *LSP* and the *MRT* test were assumed to be proficient at spatial thought. Those low on each test were assumed to experience problems. It should be noted that these tests also assess more complex spatial visualization skills. Those who exhibited low scores may have done so due to poor spatial relations ability as well as difficulty in visualization.

Unlike some instruments which contain an auditory component, the *LSP* measures short term visual memory (STVM). This coincided nicely with the instrument developed, since it used visual stimuli to measure encoding and rotational time.

According to the work of Pelligrino and Kail (1982), images judged as different by subjects were not included in the analysis of linear fit. Instead, different judgement results were analyzed separately in order to better understand basic brain processes.

Variables

Students were given tests during study hall periods throughout the school day or within the first hour after school. Since all periods throughout the day were used for each group, the time of day the test was taken was assumed not to be a factor in this study.

Motivation of students was accounted for in two ways. First, science extra credit points were awarded those students participating in the test. Secondly, the NASSP *Student Satisfaction Survey* (Form A) by Schmitt and Loher (1986) was administered to students of both high and low spatial ability groups in order to assure similar feelings about teachers, students, communication, and other activities.

Although predominantly Caucasian, several other ethnic groups were represented in the test groups (Arab, Hispanic, and Afro-American). Since they were evenly distributed in both high and low spatial groups, ethnic grouping was not considered a significant

factor.

Many studies have indicated that gender can have significant effects on spatial ability. Kail, Pelligrino, and Carter (1980) found women to have much slower rotational rates than men. Herzberg and Lepkin (1954) found a significant difference between genders while administering the *Primary Mental Abilities Test* to over 1000 high school students. Boys were significantly superior to girls in every age studied. McGee (1979, 1982) contends that sex differences in visual/spatial thinking skills are among the most persistent of all individual differences in psychological research literature. Although some researchers have suggested possible physiological causes (Naour, 1985), others point to limited access for females in school and society to develop spatial skills. Female subjects were found in both high and low spatial groups. Percentages of females were greater in the low group (68%) than in the high group (38%), and might have a bearing on the results. Although some recent research has suggested that menstruation times may affect spatial ability, no information was obtained regarding menstruation cycles, since it was thought inappropriate and possibly embarrassing for high school students.

Conditions and Constraints

The basic science philosophy in the district from which the subjects came has traditionally been one of little discovery or "hands-on" learning. Although isolated teachers are very lab-oriented, most students have been exposed to "cook book" science, where labs are spelled out ahead of time. Most teachers have access to functional lab equipment, usually in enough quantities for students to work in small groups of twos or threes. Students are required to take three years of science in middle school, consisting of approximately equal units of physical, earth, and life science. Time constraints limit classes to about 40 minutes in the middle school and 48 minutes in the high school.

Because of the variety of teaching methods exhibited by teachers within the district, as well as varying home environments, students have been exposed to a wide variety of spatial experiences. Stuessy (1988) has demonstrated that success in scientific reasoning may be linked to past experiences. Selection processes of students took no account of this factor.

Background

The field of artificial intelligence (AI) has done much to help unravel some of the processes of the mind. One area of research that started because of AI work is that of developing information processing models. According to Larkin and Rainard (1984), the development of any problem solving process model involves three components: (1) a basic representation of knowledge about a problem; (2) a set of condition-action rules to govern the solving of the problem; and (3) an interpreter which selects rules in a particular sequence in order to solve the problem. Together, these are known as a production system. Larkin and Rainard discovered while working with high school chemistry students ($n=12$) that production rules are separated into two groups; rules of theoretical inference and rules of spatial inference. After development of a chemistry problem-solving computer model, tests were run on the model with and without the spatial rules. The impaired computer production system (without spatial rules) consistently produced many erroneous algebraic statements while trying to solve chemistry pressure problems.

Luria's model of cognitive brain functioning (1970, 1980) relates to basic production system functions. According to Luria, the brain has three functional units. The first, called the Arousal/Attention unit is responsible for regulating cortical tone and selective attention. It essentially allows individuals to "focus in" on experiences. Without this initial function, information cannot be encoded or processed in any meaningful manner.

The second functional unit is known as the Sensory Input and Integration Unit. It is responsible for receiving, sorting, and encoding information from the outside world (Languis, 1990). Because one of its main functions is association, it is represented at the intersection of the temporal, parietal and occipital lobes of the brain. Luria also suggested that this integrative unit of the brain had two basic forms. The two forms of encoding are simultaneous and sequential processing. Simultaneous is often characterized as having a spatial feature, while sequential processing involves putting ideas into a logical, seriated order. This unit certainly parallels the functions of the basic representation and the condition-action rules of the Larkin and Rainard processing model. Perhaps the spatial and theoretical rules of the production system

represent the two basic processing styles. If this is the case, then simultaneous and sequential processing cannot be interpreted as being resident in the right and left hemispheres of the brain, as has been popular in the last decade. Instead, the two processes may represent differences in a learner's style, both of which are important in processing information.

The third functional unit of the Lurian model is the Planning and Organizing Unit. Any higher order process involving planning, organizing or conscious implementation is involved in this unit. Self-monitoring, problem solving and impulse control are probably activated by this unit. It is centered in the frontal and prefrontal cortex. Its activities closely parallel the interpreter phase of process models, in that it is the controller or "executor" of the brain. Thus it appears as if production systems in information processing models may be a subset of the overall structure of the functioning brain.

In an attempt to develop a mathematical formula for a production system, one must incorporate all three components. Cooper (1975) was one of the first to develop a model to describe mental rotation. She presented two nonsense shapes that differed in orientation from zero to 300 degrees. Students judged

whether the shapes were identical or mirror images of each other. Reaction times in this task were basically linear and increased as a function of the angular disparity between the two shapes. The general interpretation of these results has been that subjects rotate the objects in their mind in a manner similar to the way they would physically rotate it. The longer the mental distance to be traveled, the greater time needed to solve the problem. In terms of spatial relations problems where simple stimuli are rotated and judgements made about those stimuli, the following mathematical formula (Mumaw and others, 1984) seems to account for all three production system components:

$$RT = x(r) + (e + c + m) \quad [1]$$

where RT stands for reaction time, x stands for the angular disparity between stimuli being compared, and r , e , c , and m standing for rotation, encoding, comparison, and motor response respectively. Encoding would represent the production system basic representation, the rotation would be in response to condition-action rules, and the comparison of images with resulting action would represent the interpreter phase.

Mumaw and others (1984) suggest that reaction times in these types of activities reflect four distinct phases of processing. First is making a representation of the stimuli (encoding), including its identity and orientation. Second, the mental representation of the nonvertical image is rotated in order to reach congruence with the vertical stimulus. Next comes a comparison phase to judge whether the stimuli are identical. Finally, a response is made. Since encoding, comparison and motor response times do not vary with the orientation of the stimuli, the above equation enables researchers to rather simply test the effects of angular disparity on rotation. If the rotation of objects is indeed linear, then the slope of the function relating RT to angular disparity can be used to approximate the rate of mental rotation and the intercept of the line can provide an estimate of encoding times.

CHAPTER II

REVIEW OF LITERATURE

Spatial ability probably is not one specific skill but an overall strategy which affects a number of skills. From a researcher's point of view, Lohman (1979) and Mumaw and Pellegrino (1984) argue for two distinct spatial features. The first is spatial relations. This occurs when simple types of stimuli are rotated in the mind and comparison judgements are made as to whether a pair of stimuli are similar or different. The second factor is called spatial visualization. This involves more complex stimuli. Often mental rotations are performed on a stimulus array, and internal parts of the stimulus must be moved or folded.

McCormack (1988) has divided spatial thought into four domains. Visual/Spatial Perception is the ability to form accurate mental images of observed objects. A person of high ability in this area would be able to observe fine detail in objects and make connections between real objects and drawings or photographs of that object. Visual/Spatial Memory involves the

ability to store and later retrieve images in the mind. A person with this ability might be able to visualize objects based on verbal descriptions and communicate previously observed objects through drawings. Logical Visual/Spatial Thinking would involve the use of logical inference on mental images. A Logical Spatial thinker would be good at figure completions, seeing patterns in data, visualizing rotations of three dimensional objects, and visualizing objects from different points of view. A fourth domain would be Creative Visual/Spatial Thinking, involving the formation of unique, original mental images in several domains, such as invention, humor, or metaphor.

For years, many educators have taught under the assumption that a child is born with or without spatial talent, the trait being genetically inherited. However recent evidence is beginning to show that experience is an important factor in spatial ability and that intervention strategies can improve performance. What is this evidence and how can we apply it to the development of improved science curriculums in public education?

The ability to influence spatial ability may start extremely early in one's life. Kermoian and Campos (1988) worked with 8.5 month old infants (n=96) from

predominantly middle class, highly educated families. The infants were divided into three groups: pre-locomotor, pre-locomotor with walker-assisted experience (2 hrs/day for 2-17 weeks), and hands and knees creepers (1-14 weeks). When tested with simple tasks (object permanence) involving spatial ability, results indicated that there was a significant difference ($p < .05$) between the creepers and assisted group and the pre-locomotor group. The walker-assisted group was so similar to the creeper group that the authors concluded that prone maturation could not be the cause. A second study ($n=110$) confirmed the first, with similar significance. The longer the subjects had been moving, the higher they scored on spatial tasks. The authors suggested that with the onset of crawling, the coding strategy of infants changes, permitting abandonment of an egocentric localization of objects to one based on the use of environmental landmarks. Importantly, the artificial experience of walker assistance seemed to be as effective as the natural ability to crawl in causing this transition.

Cohen (1983) wanted to see if examining manipulative materials from a variety of perspectives enhanced projective spatial abilities. Fifth grade students (mean=10yrs/3months) from a predominantly

middle class neighborhood (n=105) were instructed for six weeks (two 45 minute sessions/week) with manipulatives from SCIIS materials. Students were pre/post tested with a battery of eight Piagetian-type tasks designed by Doyle. Both male and female students showed significant increases ($p < .05$) in three of the eight batteries, indicating improved logical spatial abilities as a result of treatment.

Wavering (1986) found that concrete operational students at several grade levels showed significantly higher scores ($p < .05$) on several spatial tasks. Of the students tested (n=101), significant gains were posted in seriation matrix tasks, tilt of cones, location of points, flexible rods, and projections of shadows. Wavering suggests that several of these tasks relate to the ability of students to graph data, measure in three dimensions, and set up controlled experiments.

Pallrand and Seeber (1984), in an attempt to clarify the relationship between spatial abilities and achievement in science courses, studied community college physics students. Three groups (control, intervention, and placebo) were pre/post tested for visual/spatial abilities using cognitive tests developed by Ekstrom in 1976. Perception was tested by identical pictures, number comparisons and hidden

figures. Spatial rotation was examined by card rotation and cube comparison. Paper folding and surface development was used to measure spatial visualization. Intervention was incorporated for eight weeks, using such activities as SCIS's "Mr. O" and perspective drawing. Placebos were given instruction in historical scientific information. Results were unusual in that all groups posted gains, including the controls. This suggests that just taking a course in physics with vector and graph analysis apparently improves spatial ability. More importantly, the intervention group posted significantly higher gains ($p < .05$) than the other groups, indicating that spatial intervention strategies indeed work, at least at the college level.

Lord (1985) pre/post tested 84 freshman college biology majors with cube comparison, paper folding, and hidden figures. The intervention group received treatment of slicing solid figures each week for twelve weeks (30 minutes). Analysis of data indicated that the intervention group posted significant gains at the .05 level in visualization (paper folding) and orientation (cube comparison). Lord (1987) later studied the relationship of classroom performance and spatial ability. Dividing college biology students

(n=125) into three groups, Lord pretested students with Ekstrom's *Educational Testing Service* test involving cube comparison, paper folding, and hidden figures. Half of the lowest scoring students received intervention (1 hour/week) for twelve weeks. Intervention included predicting the shapes of solids being sliced horizontally, transversely, and obliquely. The post test consisted of the final lab exam. Although the low group also scored lowest on the final exam, the treated lows scored significantly higher than the untreated group. Results of this experiment would indicate that students having difficulty with visual/spatial skills may have trouble in the typical life science class, but that intervention, even when applied relatively late in school careers, can significantly improve spatial performance.

Anamuah-Mensay (1986) found while studying 47 seniors from British Columbia that low ability students tend to use a proportional approach to solving volumetric problems in high school chemistry. The students were grouped as high, medium, or low ability based on a Volumetric Analysis Test developed by Anamuah-Mensay in 1981. When given volumetric problems, the high ability students tended to use a

formula approach. Anamuah-Mensay theorized that the different strategies between the high and low groups might be due to processing information in large chunks or small bits at a time. The ability to chunk information is probably related to spatial/visual perception. These outcomes would indicate that success in high school chemistry might be very much related to the ability to perceive and/or think in a spatially efficient manner.

Stuessy (1988) formulated a model and tested for the development of scientific reasoning abilities in adolescents. Working with both middle school ($n=101$) and high school ($n=89$) students, she developed a path analysis for developing scientific reasoning. Independent variables included IQ, field dependence-independence, locus of control, age, and experiences. Results showed that experience was significant ($p<.05$) in the development of good scientific reasoning in adolescents. The results suggest that students using manipulatives and three-dimensional models will develop better scientific reasoning than those who don't. Although not specifically analyzed, it may be that spatial learning is involved in the development of scientific reasoning.

In a related study, Lawrenz and Lawson (1986)

analyzed student gain in reasoning ability as it related to teaching style preference in teachers. Teachers were grouped according to teacher reasoning level (concrete vs. formal) and teaching style preference (inquiry vs. expository). An analysis was run on 30 teachers (mostly female) and their students ranging from fourth to seventh grade. The investigators then analyzed the extremes, including 17 teachers and fourth and seventh grade students ($n=84$ and $n=103$, respectively). The authors found that teachers who used concrete inquiry or concrete expository teaching significantly improved the formal reasoning ability of students (inquiry: $p<.01$; expository: $p<.05$). This would suggest that the more concretely you teach students, the better able you are to help students think in a formal way. Could it be that using manipulatives and concrete ways of learning somehow influences formal thought by improving spatial ability? The possibility exists.

Holly and Dansereau (1984) reported eleven studies which suggest that spatial strategies can be taught successfully to high school students, improving spatial performance. Certainly, a wide body of research would indicate that spatial intervention does indeed improve spatial performance in students, and that perhaps this

ability might also be related to scientific reasoning ability.

But how does this experience help? In the last decade, much research has been done to find out just how the brain processes information. Stewart and Atkin (1982) suggest that an important area of processing is the Sensory Information System. Feature extraction and pattern recognition seem to be tasks that occur as we first input information. According to this model of learning, by the time this information enters short term memory (STM) it is already in a visual and/or spatial "chunk" which is then either integrated into long term memory (LTM) or lost. Larkin and others (1980) as well as Stewart and Atkin suggest that information is stored in LTM in the form of nodes and links. Nodes would represent types of information (such as names, events, etc.) while links would represent the ways the nodes are related. Simmons (1988) refers to the way these nodes and links are stored as production systems or schemes. Using both experts and novices (n=13) at solving genetics problems, she analyzed the problem-solving behaviors of subjects while interacting with a genetics computer simulation. After analysis of results collected in a "think aloud" protocol, she suggested that there is an

overall "superstructure" in the mind consisting of style, motivation and strategies which in turn manipulate or control all aspects of learning. Perhaps this relates to Luria's "executor" unit of the brain. Certainly, trying to figure out how spatial ability specifically relates to learning is a difficult task.

There appears to be three possible areas in which spatial intervention may help the learner. First, it may help the learner to encode larger chunks of information during sensory input. Consequently, more information could be stored and handled in Short Term Memory, which in turn may help establish better links between nodes in production systems. Bower (1988) reports that brief, intense bursts of stimulation to neurons cause a change in the electrical properties between synapses called long-term potentiation. These changes last for hours or even days. Some have suggested that these changes in electrical potential are the ways memories are stored. Perhaps spatial intervention activates a long-term potentiation pattern which then helps the Sensory Information System extract features or recognize patterns.

Kail, Pellegrino, and Carter (1980), using an approach similar to the one used in this project, studied simple types of mental rotations. Two images were projected on a screen and students were asked to judge whether the objects were the same or mirror images. One stimulus was rotated between zero and 150 degrees from vertical. Reaction times were then analyzed using a linear processing model. Two experiments were run ($n=44$ and 117 respectively). The mean r squared value for both experiments was .69, suggesting that mental rotation was essentially linear. Results indicated that (1) as age increased, mental rotation did as well; and (2) unfamiliar characters took longer to encode and rotate than familiar ones. Mumaw, Pelligrino and others (1984) did a similar study with 99 university students and related encoding and mental rotation times to spatial ability as measured by the *Primary Mental Abilities Test* (Thurstone, 1958). Results again showed a linear type of mental rotation (r squared $> .90$) and an increased time needed to rotate unfamiliar PMA figures. These studies might suggest that perhaps spatial intervention helps speed rotation or helps the mind hold the image intact while rotating the image during processing. In either case, the intervention would affect the rotation

of the image rather than the speed or efficiency of encoding the image.

A third possibility is that perhaps an increase in spatial ability reflects a change in the overall strategy of approaching the problem. Perhaps the "superstructures" of Simmons are changed in such a way that new strategies are used to think about or solve problems involving spatial ability. It may be that the Planning Unit of Luria controls an overall strategy that affects both the encoding and rotational process.

In a recent brain mapping study, Languis (1990) mapped 33 university students. Using a Spatial Visualization Test, developed by Dan Miller at Ohio State to run on a Macintosh computer, students were brain mapped to investigate the sections of the brain involved in spatial visualization tasks. Results showed that subjects performing well on the SVT (high spatial) showed a frontal and a parietal focus. This would suggest that once attention is attained, Luria's Integration Unit and Planning Unit are both used during spatial visualization tasks. This would also coincide with the functioning of a production system.

Miller (1989) assessed the validity of a computerized Category Test with 31 high school males. He found results similar to the SVT findings reported by Languis, but failed to reach significance. Since categorization is a higher order thinking skill, Luria's theory would predict frontal and parietal activity which did occur. An added factor analyzed by Miller was subject response for an incorrect data set. Luria's model would predict that greater frontal activity would be necessary following incorrect feedback. What Miller found was that high performers did exhibit greater and more focused brain activity following incorrect feedback. However, poor performers who made many errors showed weak, diffuse activity and very disorganized brain processing. Interpretation of this outcome is ongoing, but the response suggests that high performers have a better overall strategy and planning unit which is flexible enough to adjust itself during incorrect feedback. Indeed, it may be that intervention strategies cause a change in the Executor Unit of the brain rather than the specific area that rotates the image. Certainly, more research needs to be done to examine the specific role of spatial intervention in the classroom.

Evidence exists that spatial thought is important, intervention strategies may increase spatial abilities and perhaps scientific reasoning, and that information processing models may provide some clues as to the specific role of spatial intervention. How can it be applied to the actual classroom setting? Moses (1982) suggested several activities to help students to become more spatially proficient. Using the sense of touch to feel objects and then describe them to others is an easy way to improve spatial ability. She also suggests the use of tangram and SOMA cubes, as well as molecular models. Bishop (1978) suggests that earth science is a natural place to build good spatial reasoning skills. Using models and lights to simulate moon phases and eclipses, stream tables to show development over time, and contour mapping all develop spatial ability. In biology, student use of three-dimensional DNA and RNA models and examination of cross and longitudinal sections in dissecting and microscope work causes spatial visualization to improve. Computer simulations, especially ones that use two or three-dimensional graphics would certainly help to improve the ability to think more visually.

McCormack (1988) gives several suggestions for improving spatial ability. Students can be encouraged to make webs or concept maps of ideas they are studying. When brain-storming, have students draw pictures rather than give verbal ideas. Students could react to concepts about animals, pollution, or endangered species artistically by the use of a collage or mobile. Guided visualization could be used to help students imagine concepts from different perspectives. An example would be to help students imagine shrinking to the size of an electron and viewing an atom from the inside. Comparing real objects to their photographs or drawing objects close up and far away improves spatial perception. Taking apart and re-assembling scientific models or devices, or drawing for memory what has been previously seen on a slide, overhead, or microscope would aid in spatial memory. Logical spatial thought can be improved through paper-folding activities, predicting shapes of sectioned objects, or inferring objects' identities from the shadows they cast. There is a wealth of spatial intervention ideas from which to draw.

CHAPTER III

METHODS

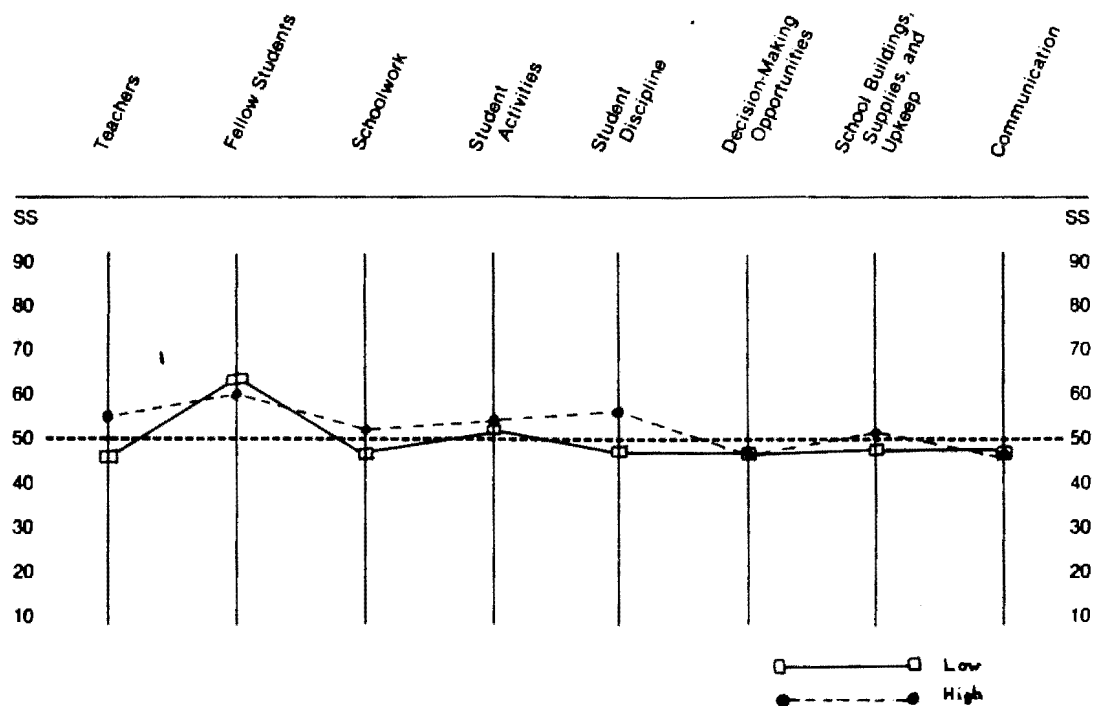
Subjects

Participating in the experiment were 37 high school students from a predominantly white middle class school in a suburban area of Columbus, Ohio. Students varied in ages from 13-17, with a mean age of 14.5 years. Eighteen of the students were female. The sample included a small percentage of minority students (approximately 8%), including those of Black and Arabic descent. Students were selected after being screened by means of spatial ability tests. The *Learning Style Profile* and the *Mental Rotation Ability* tests were administered to 107 biology and earth science students. Students were first identified as strong or weak in spatial ability using the *Learning Style Profile* criteria of being more than one standard deviation from the mean. Thirty seven students fell into this category, with 13 students identified as being in the bottom 16% of scores. A cross check was then made with results from the *Mental Rotation Test* to ensure spatial scores on the LSP indeed reflected spatial deficiency or proficiency.

To insure motivational homogeneity, the NASSP *Student Satisfaction Survey* was administered to each class and tabulated. A profile of all classes is shown in Figure 1.

Materials

Following the work of Kail, Pellegrino, and Carter (1980), the stimuli used were eight alphanumeric characters (R,J,L,P,F,G,4,5) and eight characters from the *SRA Primary Mental Abilities Test*. Nine slides were prepared for each stimulus. Each slide contained a standard and a comparison image. Six of the slides showed two identical images with the comparison image rotated 0, 30, 60, 90, 120, or 150 degrees from the standard. The remaining slides showed two images as well. However, the comparison figure was a mirror-image reversal of the standard. The mirror-image reversals were rotated 0, 90, and 150 degrees. Figure 2 shows the nine possible combinations prepared for the alphanumeric character "5" and the selected PMA characters.



STUDENT SATISFACTION SURVEY RESULTS

FIGURE 1

I-0	I-30	I-60
5 5	5 5	5 5
I-90	I-120	I-150
5 5	5 5	5 5
MIR-0	MIR-90	MIR-150
5 2	5 2	5 2

5 Δ C 40
 4 5 R U

PMA CHARACTERS AND ROTATIONAL ORIENTATIONS

FIGURE 2

Thus, 144 slides were produced, with 96 slides being identical images and 48 slides being mirror-image reversals. The resulting three-by-three experimental design contained 96 identical pairs consisting of 6 Degrees of Rotation (0,30,60,90,120,150) x 2 Stimuli Types (PMA and alphanumeric) x 8 Individual Characters. The 48 mirror-image reversals consisted of 3 Degrees of Rotation x 2 Stimulus Types x 8 Individual Characters.

The slides were then randomly ordered with the following constraints: (1) at least two trials separated the occurrence of the same character; (2) equal rotation values could not occur consecutively unless one was a mirror-image reversal; and (3) no three mirror-image reversals could appear together.

In order to time and record data, a computer program was developed using a Commodore 64 computer in conjunction with a Multibotics MB230 robotic interface system (Witzel, 1986). The interface uses a special robotics version of BASIC which enables one to use an infrared sensing device and a timer accurate to the millisecond. The resulting program sensed the projection of the slide, started a timer, recorded the response times of the subject, and then performed some statistical analysis on the recorded data. A listing

of the program with some appropriate comments can be seen in the Appendix.

Procedure

Approximately six weeks prior to the slide presentations, 107 students were given the *Learning Style Profile*, the *Mental Rotation Abilities Test*, and the *Satisfaction Survey* during normal biology or earth science classes. Analysis of results produced two subgroups of high and low spatial ability totaling 37 students. After development of software to run the measuring device, an initial field test of the program was performed on 15 students and validity and reliability measures were analyzed.

After some modification of instructions, the 37 subjects were individually tested. Subjects were asked to judge whether stimuli were identical ("same") or mirror-image reversals ("different"). Cut-out images on a table were used to explain the concept of mirror-image reversals and three trials were administered using the cut-outs. Then several slides of various characters (alphanumeric and PMA) at various rotations were presented to test the subject's understanding of the distinction between same and different judgements.

Slides were front-projected on a screen two meters in front of the subject. The projected images were 15 centimeters high and had a distance of 7 centimeters between the standard and comparison image. Subjects sat in a chair and slides were presented at approximately eye level. Subjects were instructed to respond as rapidly as possible while minimizing errors.

Presentation of the slide activated the infrared sensor which in turn started the Multibotics timer. The subject stopped the timer by pushing one of two function keys on the computer keyboard. The left button (F7) was labeled "S" for same judgements and the right button (F1) was labeled "D" for different judgements. A center pad was placed between the buttons for resting the index finger of the preferred hand. The distance between the buttons was 3 centimeters. When a subject made a response, an audible tone sounded to ensure the button had been properly pushed. The subject was instructed to place the index finger back on the resting pad after each response. This also enabled the test administrator to know when to advance to the next slide. Slides were administered in two blocks of 72 slides each, with a thirty second rest between blocks.

CHAPTER IV

RESULTS

An initial field test of the developed software/hardware package (Encoding and Rotational Test) was conducted with 15 students. All students tested within one standard deviation from the mean on the *LSP* spatial section of the test. A problem developed on the first test as a 150 degree mirror image slide was damaged by the slide projector. It was decided that since mirror image slides were not to be used to calculate slopes or intercepts (as in Kail, Pellegrino, and Carter, 1980), the test would only contain seven mirror image slides of that rotation instead of the usual eight.

A Kuder-Richardson 21 value of .79 resulted from the field test, showing the instrument to be very reliable. A least squares regression was run on reaction time means for each rotational value except zero. The r squared value was .904, demonstrating that students were most likely rotating the stimuli as directed. The slope of the line was 5.7, which coincided with the results of the Kail study. The intercept was lower than the Kail study, being 440

milliseconds. But since the median was 452 with a standard deviation of 350, and intercept values also included comparing and motor response times (see Equation 1), it was accepted.

Field testing also revealed some problems with giving directions to students. An outline script was developed, since some students seemed to have difficulties understanding the judgements of "same" and "different." Students were shown cut-out symbols and were asked to physically rotate them and make judgements. This added direction seemed to clarify the task much more quickly than just showing example slides. After cut-outs were tested successfully, students then observed example slides and were tested until mastery was demonstrated.

In order to assure that the high and low spatial groups were different, standard descriptive statistics were computed for each group. The results can be seen in Table 1. The Student's *t*-Test was run, comparing high and low ability groups for *LSP* spatial and memory scores, as well as *MRT* test scores. As can be seen from Table 2, significant differences were found in each component, lending strong support for truly different characteristics in both groups. Means of

TABLE 1

COGNITIVE DIFFERENCES OF
HIGH AND LOW SPATIAL GROUPS

High Spatial Ability Students

Test	Mean	Standard Deviation
LSP Spatial	63.2	3.0
LSP Memory	51.8	9.4
MRT Test	29.3	4.7

Low Spatial Ability Students

Test	Mean	Standard Deviation
LSP Spatial	39.3	3.0
LSP Memory	44.9	10.5
MRT Test	22.1	3.0

TABLE 2

COMPARISON OF HIGH AND LOW SPATIAL
ABILITY GROUPS FOR SIGNIFICANT DIFFERENCES

STUDENT'S t-TEST RESULTS

High Spatial versus Low Spatial

Test	T Value	Percentage
LSP Spatial	22.583	.00
LSP Memory	1.988	.03
MRT Test	4.854	.00

TABLE 3

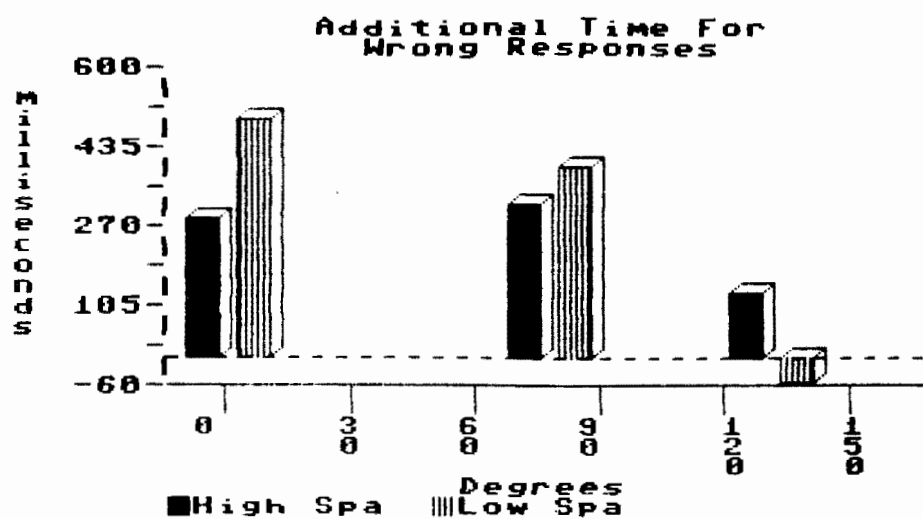
TEST SCORES - PERCENTAGE CORRECT

	Mean	Median	St.Dev.	Kur	Max	Min
High Spatial	93.5	94	3.7	2.4	98	85
Low Spatial	88.2	94	6.8	2.7	99	74

the spatial component on the *LSP* differed from 63.2 for the high spatial ability group to 39.3 for the group of low spatial ability ($p<.00$). Means of the spatial component measured by the *MRT* test also differed significantly with means of 29.3 for the high group and 22.1 for the low group ($p<.00$). The memory scores for high spatial ability students were also significantly higher ($p<.03$) than those of the low ability group (51.8 and 44.9 respectively). However, the standard deviations in these groups were quite high compared to the differences in the means. These results suggest there may be a short term visual memory component associated with spatial ability. However, when spatial scores were correlated with short term visual memory scores from the *LSP*, a Correlation Coefficient of .330 ($p=.05$) was obtained, indicating that this sample of subjects showed slight correlation between the two skills.

Assured that groups indeed represented students of differing spatial abilities, the test was administered. Reliability remained high, with the 37 subjects posting a KR 21 value of .86. Table 3 shows the test scores of both groups. Although scores ranged from 74 to 99 percent, most students scored in

the 90 percent range, indicating that they were usually accurate in making correct judgements during the comparison phase. The mean in the high ability group was 93.5 percent with a standard deviation of 3.7 while the low group averaged 88.2 percent with a larger deviation (6.8). The few students that seemed to exhibit extreme difficulty were found in the low spatial ability group. It was hypothesized that these students may have been exhibiting the brain patterns associated with Miller's CAT results (1989). Rather than continuing to rotate patterns with "different" feedback until a correct response was found, the students impulsively made a decision which was often wrong. Figure 3 shows an interesting trend related to this problem. It appears that when "different" feedback is given, low students use less and less additional time to make a judgement. In fact, with the mirror image slides of 150 degree rotation, students in the low ability group took over 50 seconds less time to make a decision than with stimuli of similar images. This definitely coincides with Miller's findings and should be examined more closely.



ADDITIONAL TIMES FOR WRONG RESPONSES

FIGURE 3

Mean response times were calculated for all rotations of alpha-numeric and PMA characters (Tables 4 and 5 respectively). Figures 4 and 5 show graphically the relationship between the performances of the two groups. Clearly, alpha-numeric characters were rotated faster than PMA characters and the high spatial ability group was almost twice as fast at rotation as the low ability group. The differences between alpha-numeric and PMA performance probably has to do with information already stored in long term memory. It has been postulated (Kail, Pelligrino, and Carter, 1980) that students already have an internal standard for letters and numbers. Rather than construct new standards, which takes time, they just resort to their internal standard. However, with the PMA figures, a standard must be constructed and encoded, causing an increase in mean times.

Table 6 shows the total response means for both alpha-numeric and PMA characters. Figure 6 graphically illustrates this data. High spatial ability students rotated images from 739 milliseconds with a rotation of 30 degrees to a maximum of 1332 milliseconds with a rotation of 150 degrees.

TABLE 4

MEAN RESPONSE TIMES FOR ROTATION
OF ALPHA-NUMERIC CHARACTERS
(MILLISECONDS)

High Spatial Ability Students

Degrees	Means	Standard Deviations
0	491	228
30	536	278
60	665	316
90	791	311
120	722	295
150	1166	396

Low Spatial Ability Students

Degrees	Means	Standard Deviations
0	661	309
30	826	418
60	1032	504
90	1365	613
120	1198	599
150	1911	925

TABLE 5

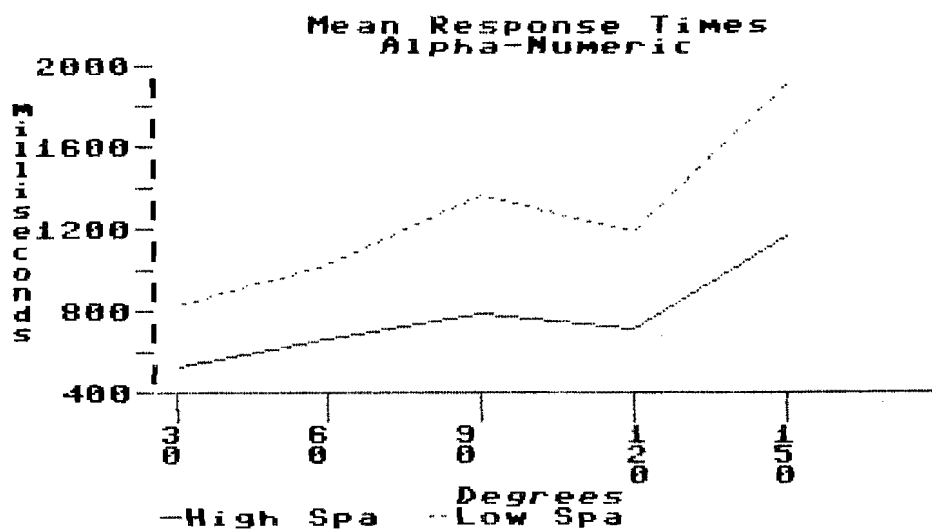
MEAN RESPONSE TIMES FOR ROTATION OF PMA CHARACTERS
(MILLISECONDS)

High Spatial Ability Students

Degrees	Means	Standard Deviations
0	772	334
30	941	392
60	1058	462
90	1087	428
120	1351	548
150	1497	612

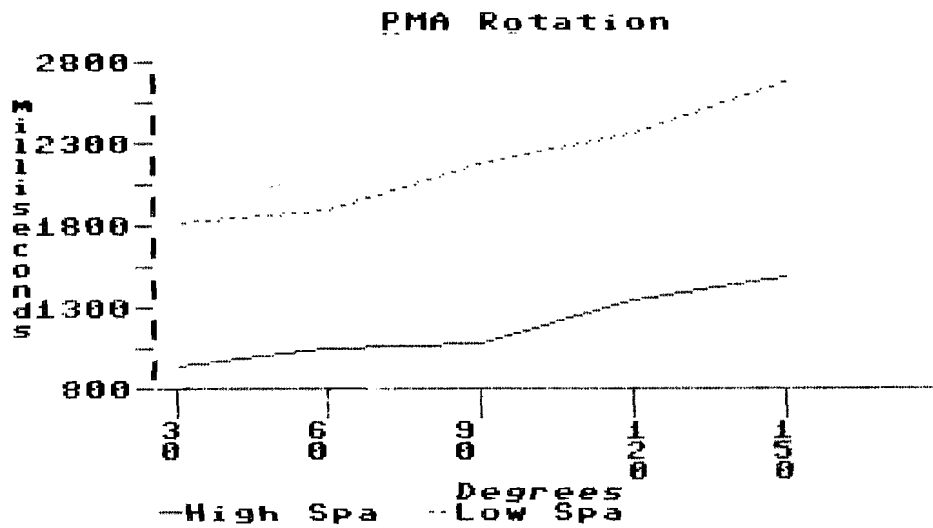
Low Spatial Ability Students

Degrees	Means	Standard Deviations
0	1250	569
30	1825	1180
60	1899	810
90	2177	1282
120	2368	1028
150	2678	1730



MEAN RESPONSE TIMES FOR ALPHA-NUMERIC CHARACTERS

FIGURE 4



MEAN RESPONSE TIMES FOR PMA CHARACTERS

FIGURE 5

TABLE 6

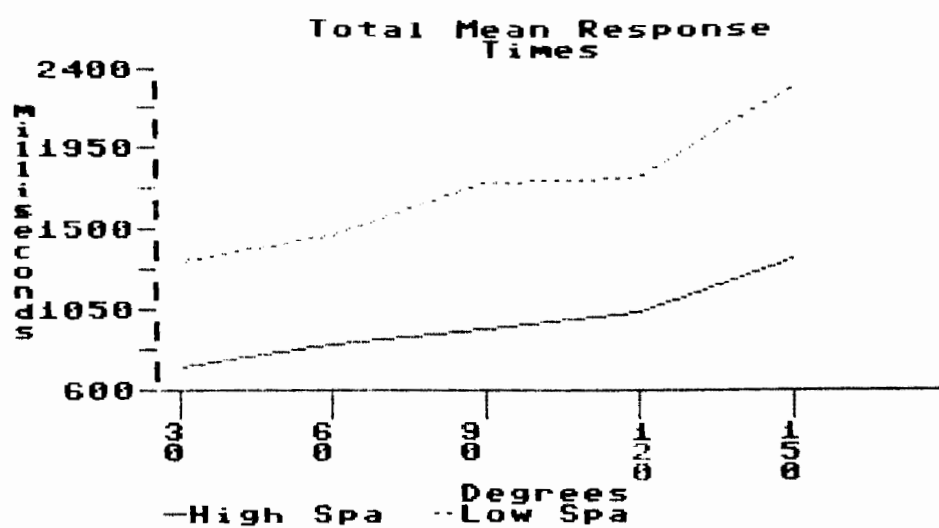
TOTAL ROTATIONAL RESPONSE TIME STATISTICS
(MILLISECONDS)

High Spatial Ability Students

Degree	Mean	Median	St.Dev.	Kur	Max	Min
0	631	619	269	2.3	1200	220
30	739	762	315	1.7	1331	294
60	861	775	362	2.1	1551	358
90	939	933	383	2.5	1777	361
120	1036	996	393	2.0	1756	355
150	1332	1351	479	2.4	2342	540

Low Spatial Ability Students

Degree	Mean	Median	St.Dev.	Kur	Max	Min
0	955	1355	406	1.7	1551	319
30	1325	1725	737	2.2	2655	397
60	1466	1982	622	2.7	2722	462
90	1767	2502	854	2.5	3514	510
120	1783	2675	774	2.1	3165	683
150	2295	3131	1235	4.6	5507	617



TOTAL MEAN RESPONSE TIMES FOR ALL CHARACTERS

FIGURE 6

Students of poor spatial ability took much longer rotating the images, with means of 1325 milliseconds for 30 degree rotations to 2295 milliseconds for rotations of 150 degrees. Standard deviations were much smaller for the spatially adept group, ranging from 315 to 479 milliseconds. The low spatial ability group showed much more variety, with standard deviations from 737 to 1235 milliseconds.

Linear regressions using the least squares function were performed on the data represented in Figures 4-6 for both high and low ability students (Table 7). As can be seen, high spatial ability students appear to rotate stimuli faster (4.53 ms/degree) than low ability students (7.53 ms/degree). The spatially superior group also encodes information about twice as fast as low ability students (573 ms and 1052 ms respectively). This could suggest that high ability students encode images faster and in such an efficient manner that it can be manipulated in a more efficient fashion.

TABLE 7

RESPONSE TIMES (RT)
(Least Squares Functions)

	Alpha/Numerics	PMA	Totals
High Spatial	$4.38x + 382$	$4.68x + 765$	$4.53x + 573$
Low Spatial	$7.79x + 566$	$7.25x + 1537$	$7.53x + 1052$

TABLE 8

LINEAR FIT - R SQUARED VALUES

	Alpha/Numerics	PMA	Totals
High Spatial	.770	.939	.922
Low Spatial	.804	.970	.915

It should also be noted that although rotation and encoding times differed between the two groups, rotation times were not significantly different within each group whether they encoded familiar or unfamiliar stimuli. High ability students had similar values for both alpha-numeric and PMA stimuli (4.38 and 4.68 ms/degree). Low spatial ability students showed the same trend (7.79 and 7.25 ms/degree). This would suggest that the encoding process may be the key element in the spatial rotation of unfamiliar stimuli.

Table 8 shows the linear fit of the equations from Table 7. As can be seen, all rotations appear to be highly linear, with r squared values of .922 and .915 respectively for the high and low groups. It may be that the lower alpha-numeric values (.770 and .804) are caused by students comparing to an internal standard as previously mentioned. Certainly, these good linear fits suggest that the processing equation used is a legitimate one and can be used with confidence.

As can be seen from Table 7, the intercept values (encoding times) were somewhat different than the values obtained by the program itself. Since these values are based on six times as much data as the ones

obtained by the program, it is probably more accurate to use them as a measure of encoding time. Using these values in place of the means for zero degrees found in Table 6, a significant difference ($t=2.2$, $p=.03$) was found between high and low ability students. High ability students had a mean of 882 milliseconds and a standard deviation of 316 milliseconds. Low ability students had a much larger mean (1534 ms) as well as standard deviation (580 ms). These results confirm a significant difference in the encoding and rotational ability of the two groups.

CHAPTER V

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

Generalizations

This project investigated the speed of encoding and rotation of images during simple spatial rotational operations to discover any similarities or differences in groups of differing spatial ability. The results would suggest the following answers to the specific questions proposed in Chapter 1:

Do high spatial ability students encode images faster than low spatial ability students during simple rotational tasks?

Students with high spatial ability encode images significantly faster ($t=2.2$, $p=.03$) than those of low spatial ability. Based on linear regressions of well-fit data ($r^2 > .9$), evidence suggests that high ability students encode images almost twice as fast as students who are not spatially adept. Both types of students are able to encode familiar figures quicker than unfamiliar ones, suggesting use of an internal comparison figure from the mind.

Do high spatial ability students rotate images faster than low spatial ability students after encoding is complete?

Highly adept spatial students also rotate images significantly ($t=2.2$, $p=.03$) faster than low spatial ability students. Again, linear regression analysis suggests that high spatial ability students rotate objects almost two times faster than those of low spatial ability. However, rotations of unfamiliar and familiar figures were carried out at similar rates within the differing groups of students.

Is the rotating process of both high and low spatial students linear in nature?

Rotations of images in the mind appear to be highly linear ($r^2 > .9$) in both groups, suggesting that the linear model proposed by Mumaw and others (1984) is an acceptable one for simple spatial rotational operations.

Is there a significant difference between the short term visual memories of high spatial students and low spatial students?

A significant short term visual memory difference ($t=1.988$, $p=.03$) was discovered, with groups of high

spatial ability having a higher short term visual memory than those of low ability. However, standard deviations and ranges were large and statistical significance should be viewed skeptically.

Does a correlation exist between short term visual memory and spatial ability?

There appears to be a slight correlation ($r=.330$, $p=.05$) between short term visual memory and spatial ability in students.

Interpretations

Results of this project suggest there is an overall strategy or "executor" phase of the mind at work during spatial activity. Although high spatial ability students encoded and rotated stimuli faster than low ability students, they did not rotate familiar and unfamiliar objects at significantly different rates. Likewise, low spatial ability students rotated familiar and unfamiliar stimuli at approximately the same rates. This indicates that the key element in solving spatial rotational problems is not the rate of rotation, but the encoding process of unfamiliar stimuli. Could it be that there is an

"executor" phase of the brain which is more efficient in students of higher spatial ability? If the findings of Miller (1989) and Languis (1990) are correct, the frontal section of the brain is involved in spatial tasks. Activity in this region might suggest an over-all controlling process similar to Luria's Planning Unit (1980) or Simmon's (1988) "superstructure." Students of higher spatial ability may have a more efficient way to encode unfamiliar stimuli and construct an internal image, which can in turn be rotated more efficiently than those constructed by lower ability students. Since familiar and unfamiliar images are rotated at the same rate within each group once they are encoded, the way in which the brain "chunks" received stimuli must be a crucial factor in constructing internal images. It is hypothesized that the Planning Unit suggested by Luria in some way recognizes patterns or monitors incoming stimuli in such a way that a more easily manipulated image is formed. Once constructed, it is rotated just as any other internal image from long term memory. However, because it has been encoded in a more efficient form in high spatial ability students, they are able to rotate the object much more quickly than

those of poorer spatial skill.

This may explain why the experiences mentioned by Steussy (1988) and the intervention strategies of Lord (1985, 1987) and Pallrand and Seeber (1984) are effective. If a "superstructure" is in place, it may be that as more spatial thought is experienced, the "superstructure" becomes more efficient. Consider an expert chess player. If the expert and the novice are in the middle of a game and the chess board and pieces are removed, the expert can replace most, if not all the pieces in the correct places, while the novice cannot. This probably occurs because the expert views the board and pieces in larger visual chunks that represent patterns of play (Larkin, McDermott and others, 1980). However, if the pieces are placed randomly on the board on both light and dark squares, the novice can usually equal the expert's performance. This is because no experience can be called upon by the expert to guide his memory.

Intervention strategies may create experiences which begin to shape the Planning Unit of the brain. If enough stimuli involving spatial encoding and rotation of images are experienced, the Planning Unit automatically begins to order condition-action rules

using both sequential and spatial styles. Thus, both encoding and rotation would tend to increase because the "executor" of those processes is the brain function that is really being enhanced.

Implications

The implications of a "superstructure" or "executor" unit of the brain controlling spatial thought could be significant. If an overall spatial strategy is enhanced by experiences, science teaching in many classrooms in America should change. Use and construction of three-dimensional models, computer simulations and graphic representations would need to become major parts of the curriculum. If Pallrand and Seeber (1984) and Steussy (1988) are correct in suggesting that spatial experiences enhance scientific thinking, these types of activities should be considered essential rather than optional. Textbook writers and publishers would need to incorporate labs that force students to become more spatially adept. The previously mentioned suggestions of Moses (1982) and Bishop (1978) would need to become the rule in classrooms, rather than the exception. Perhaps this is an area where teachers need to "teach less better."

The instrument developed during this project could have some interesting applications. It could be used to determine the effects spatial intervention strategies have on encoding and rotation times. Students could be pre-tested, be exposed to a year of weekly spatial intervention strategies and then post-tested. The proposed hypothesis would predict that both encoding and rotational times would decrease.

Another study could be done relating menstruation cycles to rotational and encoding performance in women. Parallel forms of the test could be developed with different alpha-numeric and PMA characters and administered to women several times a month to determine if a change in hormone levels affects spatial activity in women.

Several other studies of similar forms could be conceived to test deterioration of spatial ability due to various factors, such as nutrition or the lack of sleep. The beauty of the instrument is that it can truly analyze important functions of the brain, yet is obtainable to most high school teachers.

Recommendations

The instrument developed and tested during this project is a reliable, affordable alternative to expensive physiological testing. In order to make it more useful, it would be desirable to coordinate the use of this instrument with a brain mapping exercise. A triggering device would need to be constructed, but that process should be fairly simple, since the robotics interface used can control 16 different devices at once. Coordination with brain mapping might give added evidence of which part of the brain is responsible for increased encoding times of unfamiliar figures.

It also might be desirable to change the programming of the software so that data files can be stored for later use. Currently, only hard copy results are functional. This could increase the flexibility of the instrument's use.

Another feature that might be considered is the use of an automatic advance of the slide projector triggered by the robotics unit. Currently, the test administrator must advance the slides after hearing the audible signal that is generated by the computer.

There is much to learn about spatial rotational ability. Certainly the instrument developed during this project has shown to be a valid and reliable device capable of performing important research in the field of spatial ability.

REFERENCES CITED

- Anamuah-Mensay, J. (1986). Cognitive strategies used by chemistry students solve volumetric analysis problems. *Journal of Research in Science Teaching*, 23(9), 759-762.
- Bishop, J.E. (1978). Developing student's spatial ability. *The Science Teacher*, 45(8), 20-23.
- Bower, B. (1988). Proteins linked to synaptic memory. *Science News*, 134(19), 295-296.
- Clark, M. (1989). *Biological and Health Sciences: A Project 2061 Panel Report*. Washington: American Association for the Advancement of Science.
- Cohen, H. (1983). A comparison of the effect of two types of student behavior with manipulatives on the development of projective spatial structures. *Journal of Research in Science Teaching*, 20(9), 875-883.
- Cooper, L.A. (1975). Mental transformations of random two-dimensional shapes. *Cognitive Psychology*, 7(1), 20-43.
- Dunn, R., Cavanaugh, D., Eberle, B., & Zenhausern, R. (1982). Hemispheric preference: The newest element of learning style. *American Biology Teacher*, 44(5), 291-294.
- Dunn, R. & Dunn, K. (1978). *Teaching Students Through Their Individual Learning Styles: A Practical Approach*. Reston, Virginia: Reston Publishing Company.
- Gardner, H. (1985). *Frames of Mind: The Theory of Multiple Intelligences*. New York: Basic Books, Inc.
- Grasha, A. (1981). Learning styles; the journey from Greenwich Observatory to Dalhousie University: An analysis and synthesis. Paper presented for a learning style symposium at Dalhousie University, Halifax, Nova Scotia.

- Herzberg, F. & Siegel, A.W. (1978). The development of cognitive mapping of the large-scale environment. *Journal of Experimental Child Psychology*, 26(3), 389-406.
- Holley, C.D., & Dansereau, D.F. (1984). *Spatial Learning Strategies*. New York: Academic Press.
- Kail, R., Pellegrino, J., & Carter, P. (1980). Developmental changes in mental rotation. *Journal of Experimental Child Psychology*, 29, 102-116.
- Keefe, J.W. & Monk, J.S. (1986). *Learning Style Profile*. Reston, Virginia: National Association of Secondary School Principals.
- Kermoian, R., & Campos, J.J. (1988). Locomotor experience: A facilitator of spatial cognitive development. *Child Development*, 59(4), 908-917.
- Languis, M.L. (1990). Integrating Luria's brain functioning theory and cognitive brain mapping: Differences in brain electrical activity patterns between students with high and low cognitive task performance. Presented at the Second Annual Conference on Brain and Learning, University of North Texas, Denton, Texas.
- Languis, M. & Wittrock, M. (1986). Integrating neuropsychological and cognitive research: A perspective for bridging brain-behavior relationships. In J. Obrzut and G. Hynd (Eds.), *Child Neuropsychology: Theory and Research*, Vol. 1, New York: Academic Press, 209-239.
- Larkin, J., McDermott, J., Simon, D., & Simon, H. (1980). Expert and novice performance in solving physics problems. *Science*, 208(20), 1335-1342.
- Larkin, J.H. & Rainard, B. (1984). A research methodology for studying how people think. *Journal of Research in Science Teaching*, 21(3), 235-254.

- Lawrenz, F., & Lawson, A.E. (1986). Student gain in reasoning ability as a function of teacher reasoning level and teaching style preference. *Journal of Research in Science Teaching*, 23(6), 523-530.
- Letteri, C. (1985). Teaching students how to learn: Cognitive profile analysis, augmentation, and transfer. In M. Languis (Ed.), *Learning and the Brain: Theory Into Practice*, 24(2), Columbus: The Ohio State University College of Education, 112-122.
- Lohman, D.F. (1979). *Spatial Ability: A Review and Reanalysis of the Correlation Literature* (Technical Report No. 8). Stanford, Ca: Stanford University.
- Lord, T.R. (1985). Enhancing the visual-spatial aptitude of students. *Journal of Research in Science Teaching*, 22(5), 395-405.
- Lord, T.R. (1987). Spatial teaching. *The Science Teacher*, 52(2), 32-34.
- Luria, A.R. (1970). The functional organization of the brain. *Scientific American*, 222, 66-78.
- Luria, A.R. (1980). *Higher Cortical Functions in Man*. (2nd Ed.) New York: Wiley.
- McCormack, A. (1988). *Visual/Spatial Thinking: An Element of Elementary School Science*. Monograph and Occasional Paper Series #3. Council for Elementary Science International, San Diego State University.
- McGee, M.G. (1979). *Human Spatial Abilities: Sources of Sex Differences*. New York: Prager.
- McGee, M.G. (1982). Spatial abilities: the influence of genetic factors. In M. Potegal (Ed.), *Spatial Abilities: Development and Psychological Foundations*, 199-216.
- Miller, D.C. (1989). *Topographic Brain Mapping and the Category Test: A Validation Study*. Unpublished PhD dissertation. The Ohio State University.

- Miller, J.D. (1989). Scientific literacy. Paper presented at the 1989 Boyd H. Bode Memorial Lecture, The Ohio State University, Columbus, Ohio, 1-14.
- Mirga, T. (1988). States and the "at risk" issues: Said aware but still "failing." *Education Week*, 7(3), 14-15.
- Moses, B. (1982). Individual differences in problem solving. *Arithmetic Teacher*, 30(4), 10-14.
- Mumaw, R.J., & Pellegrino, J.W. (1984). Individual differences in complex spatial processing. *Journal of Educational Psychology*, 76(5), 920-939.
- Mumaw, R.J., Pellegrino, J.W., Kail, R.V., & Carter, P. (1984). *Memory and Cognition*, 12(5), 515-521.
- Naour, P. (1985). Brain/behavior relationships, gender differences, and the learning disabled. In M. Languis (Ed.), *Learning and the Brain: Theory Into Practice*, 24(2), Columbus: The Ohio State University College of Education, 100-105.
- National Assessment of Educational Progress. (1988). *The Science Report Card*. Princeton, New Jersey: Educational Testing Service.
- Pallrand, G. & Seeber, F. (1984). Spatial ability and achievement in introductory physics. *Journal of Research in Science Teaching*, 21(5), 507-516.
- Pellegrino, J.W., & Kail, R.V. (1982). Process analyses of spatial aptitude. In R.J. Sternberg (Ed.), *Advances in the Psychology of Human Intelligence*. (Vol. 1). Hillsdale, New Jersey: Erlbaum, 102-114.
- Roberts, J. (1988). Technology and the at-risk student. *Electronic Learning*. November, 39-49.
- Schmidt, N. & Loher, B. (1986). *Student Satisfaction Survey: Form A*. Reston, Virginia: National Association of Secondary School Principals.

- Simmons, P. (1988). Problem Solving Behaviors of Successful and Unsuccessful Subjects Leading to a Genetics Problem Solving Model. Presented at the National Association for Research in Science Teaching Annual Meeting, Lake of the Ozarks, Missouri.
- Stewart, J., & Atkin, J. (1982). Information processing psychology: A promising paradigm for research in science teaching. *Journal of Research in Science Teaching*, 19(4), 321-332.
- Steussy, C. (1988). Path analysis: A model for the development of scientific reasoning abilities in adolescents. *Journal of Research in Science Teaching*, 26(1), 41-53.
- Thurstone, T.G. (1958). *Manual for the SRA Primary Mental Abilities*. Chicago: Science Research Associates.
- Wavering, M.J. (1986). Performance of students in grades six, nine, and twelve on five logical, spatial, and formal tasks. *Journal of Research in Science Teaching*, 23(4), 321-329.
- Witzel, S. (1986). *MB230 Robotic Workshop Instruction Manual: Version 2.1*. Woods Cross, Utah: Multibotics, Inc.
- Winn, W. (1982). The role of diagrammatic representation in learning sequences, identification, and classification as a function of verbal and spatial ability. *Journal of Research in Science Teaching*, 19(1), 79-89.
- Winn, W. (1988). Recall of the pattern, sequence, and names of concepts presented in instructional diagrams. *Journal of Research in Science Teaching*, 25(5), 375-386.

APPENDIX

READY.

```

5 REM *** MASTER'S THESIS PROJECT - ENCODING AND ROTATION TIMER ***
6 REM
7 REM FRED DONELSON
8 REM 787 HEDLEY PLACE, GAHANNA, OHIO 43230 PHONE 476-2630
9 REM
10 GOSUB 100:REM *** INITIALIZE AND DIMENSION ***
20 GOSUB 200:REM *** DIRECTIONS ***
30 FOR C=1 TO 143:REM*** LOOP FOR SENSING AND TIMING REACTIONS ***
40 GOSUB 500
50 GOSUB 1000
60 NEXT C
65 PRINT"*** PROGRAM IS DONE ***"
66 PRINT"  THANKS FOR YOUR HELP"
70 GOSUB 2000:REM *** EVALUATION OF ANSWERS ***
80 GOSUB 5000:REM *** STATISTICS AND PRINTOUT PACKAGE ***
85 SENSRO
90 END
100 REM *** DIMENSIONS AND VARIABLES ***
110 DIM A(145):REM **STUDENT ANSWERS (1=SAME, 2=DIFFERENT)**
120 DIM K(145):REM **KEY - THE CORRECT ANSWERS**
130 DIM T(145):REM ** REACTION TIMES IN MILLISECONDS **
135 DIM E$(145):REM - CORRECT/INCORRECT RESPONSES
150 C=0:REM - BASIC ROUTINE COUNTER
155 TMR 920
160 D=0:REM - COUNTER DURING EVALUATION LOOP
200 RETURN
500 REM * THIS ROUTINE SENSES LIGHT WHEN SLIDE IS PROJECTED *
502 PRINT"AWAITING SLIDE #":C
510 L=0
520 SENSR 7,2
530 SENSR 8,1
540 SDCNT 8,L
541 PRINTL
545 IF L>1 THEN 550
547 GOTO 540
550 RETURN
1000 PRINT "TIMING YOUR RESPONSE FOR SLIDE #":C
1020 MOTR 1,30
1030 GET A$
1040 IF A$="(F7)" THEN 1100
1050 IF A$="(F1)" THEN 1300
1060 GOTO 1030
1100 MONT 1,TM
1105 BEEP
1110 PRINT "TIMING DONE (1)"
1120 T=TM*1/1000
1125 MOTR1,0
1130 T(C)=T
1140 A(C)=1
1150 PRINT TM,T,T(C),A(C)

```

```

1160 RETURN
1300 MONT 1, TM
1305 BEEP
1310 PRINT "TIMING DONE (2)"
1320 T=TM*1/1000
1325 MOTR1,0
1330 T(C)=T
1340 A(C)=2
1350 GOTO 1150
2000 REM *** EVALUATION ROUTINE ***
2001 REM READS AND COMPARES STUDENT ANSWERS TO KEY IN DATA STATEMENTS
2005 FOR D=1 TO 143
2010 READ K(D)
2020 NEXT D
2030 DATA 2,1,1,1,2,1,1,2,1,1,1,2
2035 DATA 1,2,1,2,1,2,2,1,1,1,1,2
2040 DATA 1,2,1,2,1,1,1,2,2,1,1,2
2045 DATA 1,2,1,1,2,1,2,1,1,2,1,1
2050 DATA 1,1,2,1,2,2,1,1,2,2,1,1
2055 DATA 2,1,1,1,2,1,1,2,1,1,2,1
2060 DATA 1,2,1,1,1,2,1,1,1,1,1,1
2065 DATA 1,2,1,1,1,2,1,1,2,1,2,1
2070 DATA 1,2,2,1,1,1,1,1,1,1,2,1
2075 DATA 2,1,2,1,1,2,1,1,1,1,2,1
2080 DATA 2,1,1,1,2,1,1,2,1,2,2,1
2085 DATA 1,1,1,1,2,1,1,1,2,1,1
2205 FOR D=1 TO 143
2215 IF A(D)<>K(D) THEN 2240
2230 GOTO 2260
2240 E*(D)="WRONG"
2260 NEXT D
2300 RETURN
5000 REM ***STATISTICS AND PRINTOUT ROUTINE***
5001 REM THIS PACKAGE WILL CALCULATE BASIC STATISTICS AND PRINT OUT RESULTS
5100 REM THIS PROCEDURE ADDS REACTION TIMES FOR 0,30,60,90,120,& 150 ROTATIONS
5105 REM AND THEN AVERAGES TIME IN MILLISECONDS
5107 REM *** VARIABLES LIST ***
5108 REM ZE=ALPHA FIGURES, NO ROTATION
5109 REM ZP=PMA FIGURES, NO ROTATION
5110 REM TH=ALPHA FIGURES, 30 DEGREES
5111 REM TP=PMA FIGURES, 30 DEGREES
5112 REM SX=ALPHA,60 - SP=PMA,60
5113 REM NI=ALPHA,90 - NP=PMA,90
5114 REM TW=ALPHA,120 - WP=PMA,120
5115 REM FI=ALPHA,150 - FP=PMA,150
5116 REM ZY=ALPHA, 0, MIRROR - ZZ=PMA, 0,MIRROR
5117 REM NY=ALPHA, 90, MIRROR - NZ=PMA, 90, MIRROR

```

```

5118 REM FY=ALPHA,150,MIRROR - FZ=PMA,150,MIRROR
5120 ZE=(T(25)+T(31)+T(63)+T(72)+T(75)+T(112)+T(133)+T(140))/8
5125 ZY=(T(14)+T(19)+T(43)+T(46)+T(68)+T(71)+T(121)+T(128))/8
5130 ZP=(T(3)+T(20)+T(22)+T(59)+T(66)+T(101)+T(116)+T(143))/8
5135 ZZ=(T(1)+T(38)+T(41)+T(54)+T(57)+T(65)+T(93)+T(99))/8
5140 TH=(T(17)+T(50)+T(55)+T(69)+T(96)+T(100)+T(110)+T(134))/8
5150 TP=(T(11)+T(29)+T(37)+T(87)+T(105)+T(129)+T(132)+T(136))/8
5160 SX=(T(10)+T(15)+T(35)+T(48)+T(60)+T(62)+T(106)+T(108))/8
5170 SP=(T(6)+T(45)+T(84)+T(102)+T(115)+T(118)+T(122)+T(139))/8
5180 NI=(T(2)+T(7)+T(13)+T(23)+T(40)+T(49)+T(77)+T(83))/8
5185 NY=(T(12)+T(26)+T(32)+T(51)+T(58)+T(78)+T(131)+T(141))/8
5195 NP=(T(44)+T(52)+T(67)+T(70)+T(80)+T(91)+T(120)+T(127))/8
5200 NZ=(T(5)+T(14)+T(24)+T(36)+T(86)+T(90)+T(98)+T(119))/8
5210 TW=(T(79)+T(81)+T(89)+T(97)+T(113)+T(117)+T(126)+T(135))/8
5220 WP=(T(21)+T(27)+T(47)+T(64)+T(104)+T(124)+T(142)+T(123))/8
5230 FI=(T(9)+T(34)+T(39)+T(56)+T(73)+T(82)+T(92)+T(138))/8
5235 FY=(T(18)+T(28)+T(33)+T(53)+T(74)+T(95)+T(111)+T(130))/8
5245 FP=(T(4)+T(30)+T(42)+T(76)+T(85)+T(88)+T(94)+T(103))/8
5250 FZ=(T(8)+T(61)+T(107)+T(109)+T(114)+T(125)+T(137))/8
5960 OPEN 4,4
5961 FPRINT#1;
5963 PRINT#4,"          ***** ALPHA-UMERIC AND PMA MENTAL ROTATION TEST *****"
5964 PRINT#4,"          AUTHOR: FRED DONELSON, GAHANNA, OHIO"
5965 PRINT#4,"          SEPTEMBER, 1990 (COPYRIGHT PENDING)":PRINT#4,""
5966 PRINT#4,"":PRINT#4,"SUMMARY OF MENTAL ROTATION TEST"
5967 PRINT#4,""
5970 PRINT#4,"NAME ....."
5971 PRINT#4,"RESEARCH NUMBER ....."
5972 PRINT#4,"AGE ....."
5974 PRINT#4,"DATE ....."
5975 PRINT#4,""
6000 C=0:CO=0
6010 FOR C=1 TO 143
6015 IF E*(C)="WRONG" THEN 6025
6020 CO=CO+1
6025 NEXT C
6030 PRINT#4,"PERCENTAGE CORRECT = ";(CO/143)*100
6035 PRINT#4,""
6065 PRINT#4,"":PRINT#4,""
6075 PRINT#4,"ENCODING AND ROTATION TIMES (IN SECONDS)"
6076 PRINT#4,""
6080 PRINT#4,"ALPHA ENCODING      (0) = ";ZE
6085 PRINT#4,"PMA ENCODING          (0) = ";ZP
6090 PRINT#4,"AVERAGE ENCODING      (0) = ";(ZE+ZP)/2
6095 PRINT#4,""
6100 PRINT#4,"ALPHA ROTATION        (30) = ";TH
6105 PRINT#4,"PMA ROTATION          (30) = ";TP
6110 PRINT#4,"AVERAGE ROTATION      (30) = ";(TH+TP)/2
6115 PRINT#4,""
6120 PRINT#4,"ALPHA ROTATION        (60) = ";SX
6125 PRINT#4,"PMA ROTATION          (60) = ";SP
6130 PRINT#4,"AVERAGE ROTATION      (60) = ";(SX+SP)/2
6135 PRINT#4,""

```

```

6140 PRINT#4,"ALPHA ROTATION (90) = ";NI
6145 PRINT#4,"PMA ROTATION (90) = ";NP
6150 PRINT#4,"AVERAGE ROTATION (90) = ";(NI+NP)/2
6155 PRINT#4,""
6160 PRINT#4,"ALPHA ROTATION (120) = ";TW
6165 PRINT#4,"PMA ROTATION (120) = ";WP
6170 PRINT#4,"AVERAGE ROTATION(120) = ";(TW+WP)/2
6175 PRINT#4,""
6180 PRINT#4,"ALPHA ROTATION (150) = ";FI
6185 PRINT#4,"PMA ROTATION (150) = ";FP
6190 PRINT#4,"AVERAGE ROTATION(150) = ";(FI+FP)/2
6195 PRINT#4,"";PRINT#4,"";PRINT#4,""
7000 PRINT#4,"MIRROR IMAGE TIMES IN SEC/DEGREE ROTATION"
7005 PRINT#4,""
7010 PRINT#4,"ALPHA ENCODING (0 DIF) = ";ZY
7015 PRINT#4,"PMA ENCODING (0 DIF) = ";ZZ
7017 PRINT#4,"AVERAGE ENCODING (0 DIF) = ";(ZY+ZZ)/2
7020 PRINT#4,""
7025 PRINT#4,"ALPHA ROTATION (90 DIF) = ";NY
7030 PRINT#4,"PMA ROTATION (90 DIF) = ";NZ
7035 PRINT#4,"AVERAGE ROTATION (90 DIF) = ";(NY+NZ)/2
7040 PRINT#4,""
7045 PRINT#4,"ALPHA ROTATION (150 DIF) = ";FY
7050 PRINT#4,"PMA ROTATION (150 DIF) = ";FZ
7055 PRINT#4,"AVERAGE ROTATION(150 DIF) = ";(FY+FZ)/2;PRINT#4,""
8025 PRINT#4,""
8040 PRINT#4,"REACTION TIMES IN SECONDS"
8045 PRINT#4,"";PRINT#4,"";PRINT#4,""
8046 PRINT#4,"";PRINT#4,""
8050 C=0;FOR C=1 TO 143
8055 PRINT#4,C;T(C);E$(C)
8060 NEXT C
8065 PRINT#4,""
9000 CLOSE#4
9010 RETURN

```

READY.