THE SPATIAL VISUALIZATION OF UNDERGRADUATES MAJORING IN PARTICULAR FIELDS OF STUDY AND THE RELATIONSHIP OF THIS ABILITY TO INDIVIDUAL BACKGROUND CHARACTERISTICS

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A Dissertation

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Doctor of Philosophy

Auburn, Alabama

March 18, 2000

UMI Number: 9958996

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ACKNOWLEDGMENTS

The writer wishes to express her sincere appreciation and gratitude to the many persons who in some way contributed to this investigation. Special gratitude is extended to Dr. Elizabeth S. Senger, the writer's major professor. Sincere thanks is also extended to Dr. Anthony J. Guarino, Dr. Dean G. Hoffman and Dr. Christopher A. Rodger as well as to Dr. Kenneth E. Easterday, who served as the writer's major professor prior to his retirement. The writer also wishes to express her gratitude to those faculty members and students of Auburn University who participated.

The writer is also deeply grateful to all of her family and friends for the support they provided throughout this study. Mr. and Mrs. James Rodrigue, the writer's parents, are extended deepest appreciation and gratitude for their constant support throughout this endeavor. Their words of encouragement and their interest in this study are immeasurable.

Finally, the writer wishes to express her deepest appreciation, gratitude, and love to her husband, Jason, who proved to be an invaluable source of strength and support. His encouragement and sacrifices for the sake of this study were truly beyond measure.

To everyone both mentioned and un-mentioned, the writer offers a heartfelt "Thank you."

DISSERTATION ABSTRACT

THE SPATIAL VISUALIZATION OF UNDERGRADUATES MAJORING IN PARTICULAR FIELDS OF STUDY AND THE RELATIONSHIP OF THIS ABILITY TO INDIVIDUAL BACKGROUND CHARACTERISTICS

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Doctor of Philosophy, March 18, 2000
(M.A.M., Auburn University, 1999)
(M.A., Louisiana State University, 1994)
(B.S., Nicholls State University, 1991)

189 Typed Pages

Directed by Dr. Elizabeth S. Senger

The main purposes of this study were to determine differences in the level of spatial visualization ability between students majoring in certain fields and to hypothesize reasons for individual differences in spatial visualization based on personal background characteristics (gender, handedness, parents' occupations, family income, musical experiences, childhood spatial experiences, hobbies, and favorite mathematics course) of these students. A total of 117 volunteer undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering at Auburn University participated.

The researcher administered two visualization tests and a background questionnaire to all students. Results indicated that the students, grouped by major, either preferred non-visual methods of problem solving or did not have a preference. With regards to level of spatial visualization, results of a one-way ANOVA indicated that the mathematics majors scored significantly lower than all of the other majors. No other differences were found between the groups. Path analyses yielded significant positive correlations between spatial visualization and each of musical experiences and favorite mathematics course. Also, childhood spatial experiences and each of gender and father's occupation were significant positively correlated. Finally, gender was significantly positively related to spatial hobbies. Significant gender differences were in favor of males.

Within the limitations of this inquiry, the researcher concluded that students in all four of the majors could benefit from more focused instruction on spatial visualization. Also, the researcher hypothesized that the mathematics majors scored significantly lower because pure mathematicians prefer to think abstractly. Path analyses results led to the conclusion that high school mathematics courses should be taught using both visual and non-visual instructional methods. Finally, elementary teachers should encourage females to "play" with spatial toys and engage in other spatial activities, such as participating in sports or music.

VITA

Rebecca Rodrigue Robichaux, daughter of James and Paulette Rodrigue, was born September 16, 1969 in Thibodaux, Louisiana. She received her elementary and secondary education in the Catholic schools of Thibodaux. Following her graduation from E. D. White Catholic High School in 1987, she attended Nicholls State University where she received the Bachelor of Science degree in 1991 with honors. While teaching in the East Baton Rouge public school system, she entered graduate school at Louisiana State University in June 1991. She graduated with a Master of Arts degree in August 1994. Rebecca began teaching computer science and mathematics in 1991 at Scotlandville Magnet High School in Baton Rouge, Louisiana. She remained there until 1995. She then taught for the U.S. Department of Defense from August 1995 until March 1997 on Andros Island, Bahamas. She resumed graduate studies at Auburn University in June 1997 and graduated with a Master of Applied Mathematics degree in June 1999. She presently holds a graduate assistantship at Auburn University teaching Developmental Studies Mathematics, supervising interns in all levels of mathematics, and working as a research assistant for the evaluation of the South Florida Annenburg Challenge. Rebecca is married to Jason Anthony Robichaux.

Style manual or journal used: Publication Manual of the American Psychological Association, Fourth Edition

Computer software used: Microsoft Word

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I. INTRODUCTION

Spatial ability has long been one of the major focuses of intense research in both the psychological and educational fields of study. This research began by those interested in clarifying the underlying structure of human intelligence. In most cases, large numbers of subjects were group tested using general intelligence paper and pencil tests, and then the obtained data were factor analyzed resulting in the identification of distinct intellectual abilities. Although researchers labeled the factors differently, a single factor was always found that corresponded specifically to spatial ability. To illustrate this point further, Thurstone (1938) continued his research by including spatial ability as one of the Primary Mental Abilities. Beginning in the 1950s and continuing into the present day, researchers in psychology, education, architecture, and engineering (Battista & Clements, 1996; Ben-Chaim, Lappan, & Houang, 1985; Bishop, 1980; Blade, 1949; Burnett & Lane, 1980; Fennema & Sherman, 1977; Guay & McDaniel, 1977; Harris, 1978; Jagacinski & Lebold, 1981; Karlins, Schuerhoff, & Kaplan, 1969; Macoby & Jacklin, 1974; Martin, 1968; McGee, 1979; Presmeg, 1986; Tapley & Bryden, 1977) began studying spatial ability and specifically, what factors, if any, may influence its development. These researchers also began investigating any possible impact or usefulness of possessing varying degrees or levels of spatial ability. Meanwhile, factor analysts continued to search for the component factors of spatial ability (Michael, Zimmerman, & Guilford, 1957; Zimmerman, 1954).

McGee (1979) determined from his research that spatial ability consisted of two factors: spatial orientation and spatial visualization. He defined spatial orientation as the ability to recognize and comprehend the relationships between the various parts of an object with respect to one's own point of view as well as from other points of view. He defined spatial visualization as the ability to mentally rotate, twist, turn or invert a three-dimensional object so that decisions can be made about that object (McGee, 1979). According to Rhoades (1981), "the ability to create a mental image of an object and then to manipulate it mentally has significant practical application in fields such as mathematics, physics, architecture, engineering and design." Eisenburg and McGinty (1977) indicated that people might choose career fields according to their strengths and abilities related to spatial sense. Hence, strong spatial visualization abilities seem imperative for individuals going into careers such as architecture and engineering since these abilities are required for such tasks as orthogonal drawing and blue-print comprehension. Because spatial visualization abilities are apparently connected with geometry and the study of space, individuals pursuing careers in mathematics would likely need to possess strong spatial skills. However, findings of other research differ. Blade and Watson (1955) tested entering freshman majoring in engineering and found that not all students interested in an engineering career possessed strong spatial skills. Additionally, Karlins, Schuerhoff, and Kaplan (1969) found that not all graduating architecture students had strong spatial skills. Those architecture students with weak spatial skills typically had low creativity also as rated by their professors.

Spatial visualization has recently become the topic of increased educational research. Once again, research has shown that the possession of a strong spatial sense appeared to enhance a student's learning of certain subjects, particularly mathematics and the sciences (Battista & Clements, 1996; Ben-Chaim, Lappan, & Houang, 1989; Bishop, 1978; Burnett & Lane, 1980; Clements & Battista, 1992; Presmeg, 1986). Based on this research, the National Council of Teachers of Mathematics (N.C.T.M.) Curriculum and Evaluation Standards (1989) stated that "spatial understandings are necessary for interpreting, understanding, and appreciating our inherently geometric world." To this end, Ben-Chaim, Lappan, and Houang (1989) suggested that students who have strong spatial skills are better prepared to handle advanced mathematical topics, such as those found in basic calculus. Studies have also indicated that spatial visualization ability served as a good predictor of school mathematics problem solving ability (Moses, 1978). Therefore, as proported by the N.C.T.M. Standards (1989), the development of spatial visualization should be a goal of all mathematics curricula. In order for mathematics teachers to promote the development of spatial visualization skills in their students, the teachers themselves need to develop their own spatial visualization skills. Teachers who feel uncomfortable with spatial concepts may tend to avoid these topics or spend as little time as possible teaching them. Martin (1968) stated that the teacher's state of mind tends to propagate itself. As a result, if students are going to acquire the spatial visualization skills they need to continue on into advanced mathematics courses, their respective teachers need to feel both comfortable with and confident in their own spatial visualization abilities. According to Ben-Chaim et al. (1989), "spatial visualization topics and activities should be explicitly taught throughout the mathematics curriculum, particularly in the middle grades." Students will then be better prepared to handle the higher mathematics topics that they will be taught at the high school and university levels.

Other research has shown that not all teachers enter their careers with the spatial visualization ability needed to teach this skill to their students, especially at the elementary or middle school levels (Battista, Wheatley, & Talsma, 1982; Martin, 1968). In one study, Martin (1968) found prospective secondary mathematics teachers possessed significantly more spatial visualization ability than prospective elementary mathematics teachers did. He concluded that this might have resulted from the number of required mathematics courses for the two degrees, i.e. fewer mathematics requirements for prospective elementary teachers than for prospective secondary mathematics teachers. However, an alternative reason for the above finding might suggest that as university freshmen, these elementary mathematics education majors did not possess the spatial visualization skills needed to progress to higher mathematics as required of secondary mathematics education majors.

A number of studies, which have investigated spatial visualization, have focused on the possibility of a gender difference in spatial ability. Some studies have shown that males outperform females on spatial visualization tests (Allen, 1974; Battista, 1990; Burnett, Lane, & Dratt, 1979; Geiringer & Hyde, 1976; Linn & Petersen, 1986; Macoby

& Jacklin, 1974; Newcombe, Bandura, & Taylor, 1983; Tartre, 1990). Several studies have shown that gender differences in mathematics achievement virtually disappeared when spatial visualization ability was factored out (Burnett, Lane, & Dratt, 1979; Fennema & Sherman, 1977; Ferrini-Mundy, 1987; Friedman, 1989; Sherman, 1967). Since this gender difference in spatial visualization has been widely accepted, some researchers have proposed that this difference has resulted in fewer females in certain careers, such as engineering and architecture, than males. According to Jagacinski and LeBold (1981), undergraduate women in engineering majors feel that they are lacking in spatial and mechanical abilities. However, in their study of spatial abilities, no difference was found between male and female engineering students (Jagacinski & LeBold, 1981). While there has been a recent trend for more and more women to enter engineering careers, the results of Jagacinski and LeBold's (1981) study indicated that males still greatly outnumber females. Although there has been a number of studies examining spatial visualization and gender, there appears to be different viewpoints concerning this issue.

Spatial visualization ability has also been studied to a lesser degree in several other contexts. Research in one such context, hemispheric specialization, has claimed that the two hemispheres of the brain serve in different intellectual capacities. Therefore, if the hemisphere which is responsible for spatial skills is less developed, the person will have less developed spatial skills (Battista, 1990; Flanery & Balling, 1979; Tobias, 1978). Persons who are considered left-handed supposedly favor the use of their right brain hemisphere, while right-handed persons favor their left brain hemisphere. Some researchers have found that left-handed persons, particularly females, did not perform as well as right-handed persons on tests of spatial ability (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973) while others have determined that left-handers outperformed righthanders (Peterson & Lansky, 1974; Yen, 1975). A second context of spatial visualization research has focused on the impact of the cultural aspects of one's environment on the development of spatial visualization ability (Baenninger & Newcombe, 1989; Belz & Geary, 1984; Berry, 1971; Bishop, 1980; Harris, 1978). Baenninger and Newcombe (1989) found a reliable relationship between spatial activity participation and spatial ability for both males and females. The more a subject had participated in spatial activities such as sports, computer games or playing with building blocks, the higher his/her spatial test performance was conceived to be (Baenninger & Newcombe, 1989). Miller and Bertoline (1991) found research that suggested humans were not born with a spatial visualization ability. Rather, spatial visualization abilities may have developed over time during different stages of life and were a result of exposure to different learning environments or life experiences.

Finally, several studies have shown that spatial visualization ability can be improved through appropriate classroom instruction and participation in teacher-monitored activities (Blade & Watson, 1955; Brinkman, 1966; Burnett & Lane, 1980; Dixon, 1997; Ferrini-Mundy, 1987; Rhoades, 1981). Therefore, if students entering university programs lack spatial visualization skills, their spatial ability may be strengthened through specific instruction; this enhanced spatial ability may then help these students succeed in their chosen careers.

Statement of the Problem

Professionals in architecture, mechanical engineering, mathematics, and mathematics education need to have strong spatial visualization skills to improve their chances of achieving optimal effectiveness in their careers. During their undergraduate years, students in these majors need to have developed spatial visualization skills (Blade, 1949; Martin, 1968; Stringer, 1975). Unfortunately, all students entering university programs in these majors may not have strong spatial visualization skills to begin with or build from (Blade & Watson, 1955; Eisenburg & McGinty, 1977; Jagacinski & Lebold, 1981; Karlins, Schuerhoff, & Kaplan, 1969; Rhoades, 1981). As a result, students across these majors have a common need for the development of spatial skills. Therefore, the requirement for something common in their respective degree programs focusing on the development of spatial visualization may need to be addressed. To develop their spatial skills, students may benefit from undergraduate degree programs that include additional course work requirements that specifically focus on such spatial skills.

Since mathematics achievement has been shown to positively correlate with spatial visualization (Aiken, 1971; Conner & Serbin, 1985; Fennema & Sherman, 1977; Pearson & Ferguson, 1989), students majoring in these four fields may require a sufficient number of mathematics courses to help further develop their spatial visualization skills. Burnett and Lane (1980) found a significant correlation between improvement in spatial ability test scores and the number of mathematics courses taken. Also, each major may need other additional required courses, which would develop specific spatial skills directly related to that respective major. In particular, architecture and engineering majors already require courses in mechanical drawing and descriptive geometry (Miller & Bertoline, 1991). Furthermore, mathematics majors may need additional course work in descriptive geometry along with other higher-level mathematics content that involves spatial topics. Mathematics education majors may benefit from methods, either as a course or within an existing course, which specifically address how to teach spatial visualization or how to enhance the spatial skills of their prospective students. Eisenburg and McGinty (1977) found that university students enrolled in advanced calculus, as required by students majoring in engineering, had higher spatial visualization skills than students enrolled in a general mathematics course for elementary teachers. Like architecture or engineering majors, prospective mathematics teachers also need to possess strong spatial visualization skills so that all concepts, not just geometric ones, can be taught from a visualization perspective. As a result students may develop a deeper understanding of numerical relationships when these relationships are placed in real contexts. These real contexts then allow the students to visualize numerical relationships through concrete objects. Because mathematics teachers have the opportunity to help develop the spatial skills of their students, the world's future architects and engineers, the teachers' spatial visualization skills need to be strong. According to Martin (1968), one of the major problems that mathematics teachers face is developing their students' ability to visualize spatial relationships.

Several studies have focused on efforts to improve the spatial skills of undergraduates during their 1st or 2nd year (Blade & Watson, 1955; Burnett & Lane, 1980; Eisenburg & McGinty, 1977; Poole & Stanley, 1972; Stringer, 1975). For example, after one year of engineering coursework, Blade and Watson (1955) found that freshman engineering majors improved their spatial skills as much as three times more than non-engineering majors. After these same engineering students were again tested to measure their spatial visualization ability at the end of their four-year degree program, results indicated their spatial ability had not declined (Blade & Watson, 1955). Unfortunately, very few studies have examined the spatial skills of mathematics education majors at any time during the students' college careers (Hill & Obenauf, 1979; Martin, 1968). Also, few studies have focused specifically on the level of the spatial visualization ability held by seniors in any of the other above mentioned majors.

Finally, Karlins, Schuerhoff, and Kaplan (1969) examined the relationship between creativity and spatial visualization skills of senior architecture majors. They found that those students who were rated high in creativity also possessed strong spatial visualization skills. Since their results revealed creativity as a positive characteristic of successful architect students, stressing the development of spatial skills in undergraduate architecture majors seems appropriate.

In general, if junior or senior level undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering were tested for spatial ability and found to possess varying levels of spatial visualization skills necessary for their career choice, then certain courses in their degree programs would need to be restructured to accommodate these levels. Such courses may need to emphasize the development of spatial skills. Additionally, this sample of undergraduates could be used for determining which background variables (gender, ethnicity, family income, handedness, parents' occupations, hobbies, childhood experiences, musical experiences, and favorite mathematics course) were highly correlated with spatial visualization. Subsequently, this information would also be useful in developing degree programs to enhance individuals' spatial ability. In conducting this study, the researcher hoped to gather evidence concerning two aspects of spatial visualization: (1) the level of spatial visualization possessed by undergraduates majoring in fields requiring this ability and (2) the relationship between certain background variables and the development of spatial visualization.

Purpose of the Study

Past research on spatial ability includes several studies that examined individual differences in spatial visualization at all age levels (Battista, 1990; Burnett, Lane, & Dratt, 1979; Fennema & Tartre, 1985; Lohman & Kyllonen, 1983; Salthouse, 1987; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Vandenburg, 1975). Furthermore, a number of studies have focused on the general nature and development of spatial visualization in students of all ages (Bishop, 1978; Brinkman, 1966; Clements, Battista, Sarama, & Swaminathan, 1997; Dodwell, 1963). However, limited research has been conducted related to the spatial ability of junior and senior undergraduate students in particular. The purposes of this study were: (1) to determine differences, if any, in the level of spatial visualization ability between students majoring in architecture, mathematics, mathematics education, and mechanical engineering, (2) to hypothesize reasons for individual differences in spatial visualization that may exist based on the background information of these students, and (3) to develop and test a causal model of the development of spatial visualization based on the findings of past research.

By focusing on junior and senior undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering, this study examined both the influences on spatial visualization and the differences in the level of spatial ability between these students, through the use of two spatial ability tests and a background information sheet on each student. The researcher expected to find no differences in the level of spatial visualization between the four majors since all had previously taken courses which would strengthen or develop an individual's spatial visualization ability, either mathematics or specific design courses. Additionally, a causal model, based on findings of previous research, was developed to determine if certain background experiences and other personal characteristics (the exogenous variables) had an influence on an individual's spatial ability (see Figure 1 for this causal model).

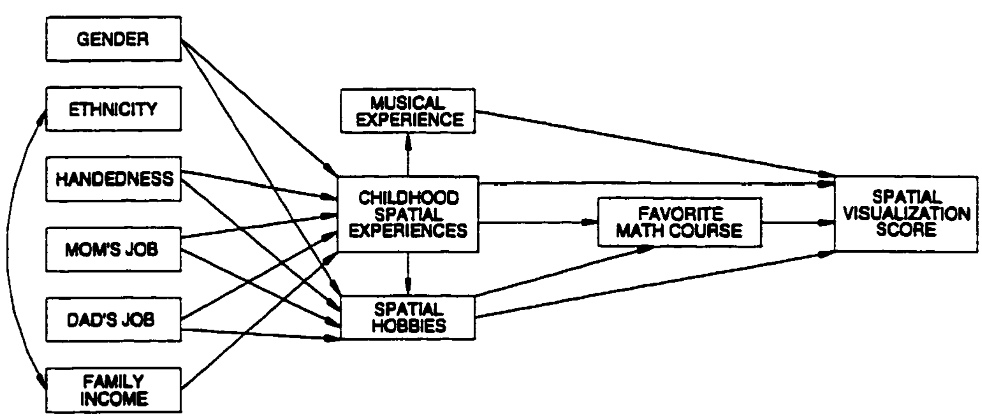


Figure 1. Path Analysis Causal Model

The following hypotheses were proposed based on previous research and the above model:

Hypothesis 1: There will be no significant differences in the level of spatial visualization between undergraduates majoring in architecture, mathematics, mathematics education, or mechanical engineering.

Rationale: All students in these majors by their junior or senior year will have had mathematics courses, orthogonal geometry, specific design courses or a combination of these courses at the college level to develop their spatial ability. Researchers have examined the possibility that specific courses, namely informal geometry or training in drawing, would enhance spatial ability (Battista, Wheatley, & Talsma, 1982; Stringer, 1975). Also, Eisenburg and McGinty (1977) suggested that people might choose career fields according to their strengths and abilities related to spatial sense.

Hypothesis 2: Spatial visualization score will be significantly positively correlated with favorite mathematics course and with the spatial experiences variables (musical experience, childhood spatial experiences, and spatial hobbies).

Rationale: A meta-analysis of research on spatial visualization has shown a reliable relationship between spatial experiences and spatial ability (Baenninger & Newcombe, 1989). Also, in a study of the relationship between mathematical, musical and spatial abilities, Mason (1986) found that differences in musical background and experience may result in differences in levels of spatial ability. Finally, researchers have examined the possibility that specific courses, namely informal geometry or training in drawing, would enhance spatial ability (Battista, Wheatley, & Talsma, 1982; Stringer, 1975).

Hypothesis 3: Favorite mathematics course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

Rationale: Wheatley, Frankland, Mitchell, and Kraft (1978) found that if a student relied more on his/her spatial ability to solve problems, then he/she may be more successful in a curriculum that also provided spatial presentations of the content and multi-sensory learning. Therefore, it follows that individuals that have had childhood spatial experiences and have or have had spatial hobbies would prefer those mathematics courses that are spatial in content, like geometry, trigonometry, and calculus.

Hypothesis 4: Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Rationale: Children who have participated in spatial activities are more likely to pursue spatial hobbies, as they grow older, in comparison to children who have not participated in such activities. Sherman (1967) suggested that males out-performed females with respect to spatial visualization because they voluntarily participated in more spatially oriented activities (hobbies) such as model building rather than playing with dolls. With respect to handedness, some researchers have suggested that left-handed persons, particularly females, did not perform as well as right-handed persons on tests of spatial ability (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973) while others have found that left-handers outperformed right-handers (Peterson & Lansky, 1974; Yen, 1975). If a certain hand preference does yield stronger spatial ability, then it seems likely that those with that hand-preference would engage in spatial hobbies. Other research has shown that father's occupation was related to differential development of spatial abilities (Belz & Geary, 1984).

Hypothesis 5: Musical experience will be significantly positively correlated with childhood spatial experiences.

Rationale: Through spatial experiences during childhood, one's ability to mentally rotate a three-dimensional object is enhanced (Harris, 1979). Harris (1978) suggested that the ability to recognize, execute or create a melodic pattern may be a spatial ability similar to the visual detection of an embedded figure or the mental rotation of a three-dimensional object. Thus, individuals having childhood spatial experiences may be more likely to have stronger musical ability than individuals having no childhood spatial experiences.

Hypothesis 6: Childhood spatial experiences will be significantly positively correlated with the demographic variables (gender, handedness, mom's job, dad's job, and family income).

Rationale: Sherman (1967) suggested that gender differences in spatial ability existed because of varied experiences; that is, environmental differences played a role in the development of spatial ability. Thus, individuals who came from different environments or who had diverse experiences would have had varying levels of spatial ability. He also suggested that males out-performed females because they voluntarily participated in more spatially oriented activities such as model building, rather than playing with dolls. Connor, Serbin, and Schackman (1977) reported that preschool boys were observed spending more time than girls engaged in activities relevant to developing spatial skills, such as playing with blocks and trucks. Vandenburg and Kuse (1979) stated that evidence existed in support of differences in spatial ability due to nurturance and culture diversity. Some researchers have suggested that left-handed persons, particularly females, did not perform as well as right-handed persons on tests of spatial ability (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973) while others have found that left-handers outperformed righthanders (Peterson & Lansky, 1974; Yen, 1975). If a certain hand preference does yield stronger spatial ability, then it seems likely that those with that hand-preference would be drawn to spatial activities as children if their environments allowed for it. Other research has shown that father's occupation was related to differential development of spatial abilities (Belz & Geary, 1984).

Significance of the Study

Researchers in the fields of architecture, education, engineering, and mathematics, are interested in those characteristics that improve the students' potential for success in those respective careers. One such characteristic includes a student's level of spatial visualization. According to Miller and Bertoline (1991), spatial visualization has been found centrally important to both engineering curriculum efforts and to the profession of engineering itself. Ben-Chaim, Lappan, and Houang (1986) reported "there has been much interest in studying this ability because spatial visualization is important in most technical-scientific occupations, and especially to the study of mathematics, science, art, and engineering." If students in these majors graduate without a strong spatial visualization ability, success in their careers may be limited. Ghiselli (1966) found that success in fields such as mathematics, architecture, and engineering "is highly predicted by one's ability to visualize and mentally manipulate objects." Architects and engineers, required to make orthogonal, assembly, and perspective drawings, who lack in their spatial visualization ability may have a lower success rate than those who do possess these skills. Similarly, mathematicians with low spatial visualization skills who are required to solve real world problems may overlook the most appropriate solution, if indeed, the most appropriate solution is spatially derived. Finally, mathematics teachers lacking in spatial visualization ability may not regard this skill highly nor have the tools necessary to adequately develop spatial ability in their own students which may in turn limit the career options that these students will later have. Some research has indicated that students generally elect to go into fields in which they feel they have the necessary skills to be successful (Eisenburg & McGinty, 1977). However, the findings of Blade and Watson (1955) did not agree with the research of Eisenburg and McGinty (1977). Blade and Watson (1955) found some students entering undergraduate programs in engineering who lacked in spatial skills. To address this, a student's spatial ability may be improved by including undergraduate course work that specifically focuses on this skill. In this way, graduates who were once poor in spatial abilities would then be better able to perform their jobs in such careers.

Psychologists have also long been interested in what experiences outside of formal education play a role in the development of one's spatial ability. There has been considerable interest in studying the possibility of a gender difference in spatial ability. According to Friedman's (1989) meta-analysis of recent research on sex differences however, by the year 2003, there may no longer be a gender difference with respect to mathematical ability. This includes problems involving spatial visualization ability, given that the females and males being compared have similar backgrounds, such as those majoring in the same field of study. Hyde (1981) suggested that the gender difference in spatial visualization skills might be a key factor as to why so few females pursue careers in engineering and other fields that demand the use of spatial visualization. In agreement with Friedman's (1989) proposed disappearance of a gender difference, Halpern (1986) stated that "the number of women entering engineering, mathematics, and science fields has been increasing dramatically over the last 20 years." This statement may imply that due to females being just as strong in spatial visualization as males, more females are now choosing careers more often that require these skills. Therefore, the possible gender difference that has long been the topic of much research may be disappearing. Although numerous studies on the development of spatial visualization ability and gender differences in that ability exist, research concerning the influences on and level of spatial visualization ability in persons entering fields requiring such ability is not as readily available. Thus, the significance of this study lay in its potential to provide: (1)

information regarding the level of spatial visualization skills of third and fourth year undergraduates majoring in fields which require such skills, and (2) evidence of the relationships between specific characteristics (gender, ethnicity, family income, handedness, parents' occupations, musical ability, hobbies, childhood play experiences, and favorite mathematics course) of students and spatial visualization ability. Such evidence and information could benefit university faculty in planning degree programs as well as middle and high school mathematics curriculum developers.

Limitations of the Study

This study was limited by the number of students currently majoring in architecture, mathematics, mathematics education, and mechanical engineering who were in their junior or senior years at Auburn University and who were willing to voluntarily participate in this research. Additionally, the subjective reporting by the students of their background information limited the study. Students may not have remembered the exact answers to some of the questionnaire items and therefore may have given incomplete or inaccurate personal information. In an attempt to prevent this from happening, students were told to describe as precisely as possible their particular situations if none of the choices corresponded exactly to what he/she had in mind. Also, students were made aware that their responses would in no way affect their academic work during the quarter of testing or any other degree requirement at a later time. Finally, other variables not under the researcher's control that may have affected the students' performance on the spatial visualization measures, such as other background influences that were not addressed in the questionnaire, limited this study.

Definition of Terms

The following terms were defined for use in this research.

Spatial Visualization Ability: Spatial visualization ability (SPVIS) was the ability to mentally rotate, twist, turn, reflect or otherwise move a three-dimensional object presented in two dimensions (McGee, 1979), as measured by the Spatial Visualization Test (Middle Grades Mathematics Project, 1983). In this study, SPVIS was a dependent variable.

Visualizer: A student was classified as a visualizer if he/she tended to solve mathematical problems using visual imagery with or without a diagram when the problem did not necessarily have to be solved visually. In this study, a visualizer score (VSCORE) was assigned to students based on their performance on the Mathematical Processing Instrument (Presmeg, 1985). VSCORE was a second dependent variable. Students were considered to be visualizers if their VSCORE was greater than 50%.

Non-visualizers: Students were classified as non-visualizers if they essentially did not solve mathematical problems using visual modes of representation. If the student's VSCORE was less than 50%, the student was considered to be a non-visualizer.

Ethnicity: The ethnicity (ETHNIC) of a student in this study was either non-minority or minority. If a student classified himself/herself as either Caucasian or Asian, he/she was considered a non-minority. If a student classified himself/herself as either African American, Hispanic, or other, he/she was considered a minority.

Handedness: The handedness (HAND) of a student was either primarily left or primarily right according to which hand the student preferred to use.

Occupations: A student's mother's occupation (MOMJOB) and the student's father's occupation (DADJOB) were defined as either spatial or non-spatial depending on whether or not the job required any amount of spatial visualization skills. Occupations that were considered spatial included the following: architecture, art, computer programmer, construction builder, any type of engineer, interior design, mathematician, mathematics educator, and scientist.

Income: A student's family income (INCOME) was the approximate income that a student's family received over a period of one year as indicated by $25,000 intervals of income on the background questionnaire.

Musical Experience: A student's musical experiences (MUSICEXP) score was determined by summing their scores on five yes/no music survey questions. If the answer to the question revealed a musical experience, the student scored one point. Since there were five music questions, the maximum musical experience score was 5 and the minimum musical experience score was 0.

Child Experience: A student's spatial child experiences (SPCHILD) was determined to be 0, 1, or 2 according to the answers to the four questions pertaining to childhood toy experiences on the background questionnaire. If the student named any of the following spatial toys as his/her favorite toy, then he/she was given a score of 2. Toys considered spatial in this investigation were building blocks (wooden blocks, plastic connecting blocks), construction sets, computer/video games, drawing kits/toys, "tinker toys", and transformer figures. If any answer to the other three questions indicated the use of one of the stated spatial toys by the student as a child, then the student was given a score of 1 for this variable; otherwise, the student was assigned a score of 0.

Spatial Hobbies: A student's spatial hobbies (SPHOBBY) was determined to be yes or no according to the list of past and present hobbies provided by the student in the background questionnaire. If a spatial hobby was found in either list, the student was assigned a value of "yes" for this variable; otherwise, the student was assigned a value of "no". The hobbies considered spatial in this inquiry were drawing, flying small aircraft, model building, participation in any kind of sport, playing computer/video games, taking photographs, and wood working.

Major: A student's major (MAJOR) was his/her respective university major. Possible majors in this study were architecture (ARCH), mathematics (MATH), mathematics education (CTSM), and mechanical engineering (MECH).

Favorite Mathematics Course: The student's favorite high school mathematics course (FAVMATH) was classified as either geometry/trigonometry/calculus or other according to the student's answer on the background questionnaire. These three mathematics courses contain spatial content, which could enhance the development of spatial visualization.

II. REVIEW OF LITERATURE

The research literature that has focused on spatial visualization is presented in the following four sections: individual differences in spatial visualization ability and possible reasons for these differences; spatial visualization improvement; the relationship between spatial visualization and mathematics achievement, problem solving, and verbal ability; and spatial visualization in architecture, engineering and mathematics education.

Individual Differences in Spatial Visualization

The review of the related literature concerning individual differences in spatial visualization will be reviewed through the use of the following organization of sub-topics: gender differences, field dependence vs. field independence, hemispheric specialization, environmental factors and past involvement in spatial activities, speed and efficiency of mental transformations and rotations, solution strategies to spatial problems, mathematical background, and finally, musical background. Since the majority of the research concerning individual differences has focused on gender differences, this sub-topic will be presented first.

Gender Differences

Several studies have found the existence of a gender difference, while others have not. This section will first review those studies that found a gender difference (Allen, 1974; Battista, 1990; Burnett, Lane & Dratt, 1979; Fennema & Sherman, 1977; Geringer & Hyde, 1976; Linn & Petersen, 1986; Macoby & Jacklin, 1974; Nash, 1975; Pepin, Beaulieu, Matte, & Leroux, 1985; Tartre, 1990). Following this, studies that did not find a gender difference will be examined (Caplan, MacPherson, & Tobin, 1985; MacPherson, 1982). Finally, proposed hypotheses set forth by researchers in the field of spatial visualization will be discussed.

Studies that have revealed the existence of a gender difference included those using paper and pencil tests, Piaget's water level task, micro-computer games, and a sex preference testing instrument. Through this research, gender differences in spatial ability have been found starting near adolescence and continuing through the university level.

Beginning at adolescence, many researchers have agreed that a well-established gender difference exists with respect to spatial ability. In reviewing the literature, Macoby and Jacklin (1974) found higher male mean scores on tests of spatial visualization as opposed to somewhat lower female mean scores. Also, Tartre (1990) recognized that males tended to score higher than females on measures of spatial ability starting at or before puberty.

To examine gender differences in 5^{th} and 12^{th} grade students, Geiringer and Hyde (1976) used a spatial ability test and Piaget's water-level task. In the Piagetian task, students determined where the water line would be in a container when tilted at various degrees. This task determined if students understood principles of horizontality. Since past research had shown an out-performance by males over females on spatial tasks during adolescence, Geiringer and Hyde (1976) predicted different gender results for the 5^{th} and 12^{th} graders. Neither boys nor girls in the 5^{th} grade performed well on the water-level task. Also, no gender differences on the spatial tests were found for the 5^{th} grade students. With respect to the 12^{th} graders, no significant gender differences were found for the water-level task; but, a significant gender difference existed in favor of males on the spatial ability test. Thus, the results supported the idea that gender differences in spatial ability did not occur before adolescence. Contrary to this idea, Linn and Petersen (1986) did find a reliable gender difference in children ages seven and eight with respect to spatial ability through a meta-analysis of visual-spatial abilities. They also claimed that the largest gender differences with respect to spatial tasks occurred when the tasks involved the mental rotation of stimulus objects. Linn and Petersen (1986) further concluded that the apparent gender difference in spatial ability increased at age 18 and continued throughout the life span.

Using microcomputer games to measure spatial ability rather than the standard paper and pencil tests, Pepin, Beaulieu, Matte, and Leroux (1985) observed significant gender differences. Thirteen-year-old males and females earned spatial ability scores based on the results of playing a microcomputer game. The researchers noted that "the subjects selected had almost never played computer games (fewer than two times)." In agreement with Sherman's hypothesis of differential spatial experience, the authors reported that males scored significantly better than females on the computer task.

Nash (1975) conducted a study which examined the relationship between sex-role preference and gender differences in spatial ability. He measured 11-year-olds and 14-year-olds on their spatial ability as related to sex-typed attributes and sex-role preference. Subjects of both genders whose responses indicated a lower level of masculinity did not perform as well on the spatial ability test as those who were rated at a higher level of masculinity. In this study, level of masculinity was determined by the responses of each participant to 98 stereotypical sex-role items. "A higher score would mean a more masculine rating" (Nash, 1975). Regarding sex-preference, those who preferred to be male scored higher on the spatial ability test than those who preferred to be female. Results indicated a gender difference in spatial ability among those 14-year-olds with own-sex preference. Among the 11-year-olds, no sex differences were found in spatial ability. In accordance with this, McGee (1979), in his review of the literature on causes of gender differences in spatial ability, found evidence that highly masculinized males tended to score lower on tests of spatial ability as compared to other males.

In another study examining sex-roles, Jamison and Signorella (1980) tested a sample of university students using the Piagetian water-level task as a measure of spatial ability. The sample also completed the Bem Sex Role Inventory to determine the relationship between sex role and spatial ability. In the Bem Sex Role Inventory, subjects were presented 60 personality characteristics. For each characteristic, the subject was prompted for a level of how well that particular item reflected themselves. Of the 60 characteristics, 20 were stereotypically masculine, 20 were feminine and 20 were neutral. Results indicated that "males and those males and females with masculine sex-role orientations were more likely to succeed with the water-level task than females and those with feminine sex-role orientations." Furthermore, men who identified themselves with a feminine sex role performed no better on the water-level task than the women who identified with a feminine sex role. Also, masculine women did just as well as masculine men. In contrast to these results, Jamison and Signorella (1980) reported a significant sex difference in performance on the spatial task between men and women classified as androgynous in sex-role orientation.

To determine if gender differences in spatial ability existed, Fennema and Sherman (1977) tested students from four high schools. Results indicated males tended to score higher than females at all of the schools, but significantly higher scores for males over females occurred at only two schools. However, when the number of spatial related courses that the students had taken was statistically removed, the gender difference at those two schools became nonsignificant. The notion that practice and relevant experience influenced spatial ability was supported by these findings. The researchers concluded that males did not always outperform females in spatial ability, especially when those being compared had similar backgrounds and experiences.

Using four paper and pencil tests, Battista (1990) examined spatial visualization and verbal-logical thought of high school geometry students. These tests included one of each of the following: (a) spatial visualization, (b) logical reasoning, (c) geometry understandings, and (d) geometric problem solving strategies. After the data were examined, Battista (1990) found that spatial visualization ability was significantly related in the positive direction to geometry achievement and geometric problem solving for either gender. However, this did not mean that there was a significant relationship between male and female performance on all tests. Specifically on three of the tests, spatial visualization, geometry understanding, and geometric problem solving, males scored significantly higher than females. On the logical reasoning test, no significant sex difference was found. Battista (1990) concluded that male and female students differed in spatial visualization ability and in their geometry achievement, but not in their use of geometric problem-solving strategies. With respect to logical reasoning, males and females were found to have equal ability.

Focusing on university-level men and women, Allen (1974) studied gender differences in spatial ability by administering a battery of six spatial tests requiring students to report the problem-solving strategies used. Results from these tests indicated that on four of the six tests, males scored significantly higher than females. On the other two tests, males out-scored females but not significantly. Analysis of the strategies used to solve the problems revealed significant gender differences on three of the six tests. General problem-solving strategies reflected a gender difference more so than test-specific strategies. Overall, students used test-specific strategies less often. Thus, Allen (1974) concluded that in general, males and females used the same test-specific problem solving strategies. However, females resorted to guessing since use of these strategies proved unsuccessful. "Since the women marked most of the same test-specific strategies as the men, it is probable that they 'gave up' on problems only after trying unsuccessfully to solve them" (Allen, 1974). In a similar study that used university students, Burnett, Lane, and Dratt (1979) found gender differences in spatial ability favoring males. Having taken two tests of spatial ability, males significantly outperformed females according to the results.

With respect to self-assessed spatial ability, Lunneborg (1982) studied gender differences in university students. This study determined if gender differences existed when men and women judged their own spatial abilities in comparison to others of their age and sex. The students completed a survey which consisted of everyday spatial tasks one might encounter. The students had to rate themselves on a 10-point scale based on self-perceived ability to complete a spatial task. Results of this survey indicated that males rated their own spatial ability significantly greater than females on all items of the survey. In a similar study conducted by Lunneborg and Lunneborg (1984), the same results were found when another sample of university students were asked to rate themselves on spatial ability. On 9 of the 10 everyday activities which participants had to rate themselves, men judged themselves as having greater spatial ability than women did. When these ratings were correlated with other measures of spatial ability and with measures of mechanical reasoning, results indicated that certain everyday activities related more highly to spatial ability than to mechanical reasoning. The activities of "understanding of mathematics and science" and "ability to interpret graphs and charts" appeared to be most related to spatial ability. Of lesser importance in determining spatial ability were the activities of sports, driving a car, and visual games.

Newcombe, Bandura, and Taylor (1983) tested university freshmen to determine their level of spatial ability and also administered to them a questionnaire describing 81 spatial activities. Participants rated themselves on a 6-point scale as to the degree of their involvement in each activity. While males scored higher in spatial ability than females, the study revealed no gender difference with respect to their overall participation in the spatial activities.

Halpern (1986) stated that un-identical tests used on the same university-aged students produced a variety of results with respect to the size of the gender difference found, with the larger differences found on mental rotations tests. Halpern suggested that the most impressive evidence in favor of a gender difference in spatial ability was not that the difference was sometimes large or sometimes small, but that when a study did find a difference it was almost always in favor of males. Finally, she concluded, "there is ample evidence to conclude that sex-related differences in brain lateralization or sex hormones are related to spatial ability sex differences."

Harris (1981) examined the literature on gender-related variations in spatial ability. He found that in general, females required more time than males to reach a decision about a spatial task and made significantly more errors than males. Harris (1981) also recognized that in any given study, the mean differences favoring male spatial ability were always smaller than differences within each gender or within the total sample.

Hyde (1981) conducted a meta-analysis on studies claiming to have found significant gender differences to determine the magnitude of these so-called significant differences. Based on her analysis, gender differences, although statistically significant, explained less than 5% of the variance in spatial ability. In general, Hyde (1981) found small gender differences in spatial ability.

Caplan, MacPherson, and Tobin (1985; 1986) completely disagreed that gender differences with respect to spatial visualization existed. They reported no convincing support was found for biological reasons as causing the so-called differences and that the environmental evidence was severely flawed. One main reason for their belief stated when gender differences had been found they accounted for so little variance that although they may have been statistically significant, they were not practically significant. They also claimed that most of the studies that had found gender differences were out-dated and disproportionately cited in recent research. Caplan et al. (1985) stated two main problems occurred with individual studies. Many times a test may have been called a spatial ability test when in fact it measured something other than spatial ability. Secondly, when researchers reported results, these findings may have been overgeneralized. Furthermore, the recessive X-linked gene hypothesis has not had much support through real data confirming this theory. Caplan et al. (1985) emphasized that to believe that spatial ability was controlled by one gene was rather simplistic. A study by MacPherson (1982) supported the belief that no gender difference in spatial ability existed. In this study, MacPherson gave 100 high school students two spatial ability tests which did not find any significant gender difference. Caplan et al. (1985) also mentioned several other studies that did not find a gender difference or that did not result in a practically significant gender difference. Burnett (1986) responded to Caplan et al.'s (1985) article by claiming the opposite. She stated the evidence suggested that a gender difference appeared quite regularly, even in more recent studies, in tests for spatial ability, and that the magnitude of these differences reflected practical importance. Burnett (1986) claimed that recent studies of spatial ability reported that tests involving mental rotation resulted in larger gender differences than those not requiring this action. She concluded large and consistent gender differences for adult subjects needed explanation instead of denial.

Hiscock (1986) also responded to Caplan et al.'s (1985) article saying that if sex differences were found by chance as was suggested, then "one would expect to find the number of findings favoring females to be comparable to the number of findings favoring males." Actual results did not meet these expectations. Although not all studies on spatial ability have found a significant gender difference, very few studies have found a significant difference favoring females (Hiscock, 1986).

Finally, according to Linn and Hyde (1989), if a gender difference did exist, it has declined and may no longer exist. Thus, it may be that at some time there was a gender difference for various reasons, but more recently, this difference has disappeared. Linn and Hyde (1989) state that this decline is evidenced by the results of a meta-analysis of spatial visualization studies. With respect to gender differences, studies conducted prior to 1974 revealed an effect size of $d = -.30$, while studies conducted after 1974 revealed an effect size of $d = -.13$. Also, more recent findings indicated that "training tends to reduce or eliminate gender differences on mental rotations" (Linn & Hyde, 1989). Finally, the authors report that this decrease in gender differences in spatial ability are accompanied by increases in female participation and success in athletics.

Since many researchers have agreed (Allen, 1974; Battista, 1990; Burnett, Lane, & Dratt, 1979; Fennema & Sherman, 1978; Geiringer & Hyde, 1976; Linn & Petersen, 1986; Macoby & Jacklin, 1974; Nash, 1975; Pepin, Beaulieu, Matte, & Leroux, 1985; Tartre, 1990) on the presence of a gender difference in spatial ability, hypotheses have been offered to try to explain why such a gender difference may exist. Both genetic and environmental hypotheses have been proposed to explain this gender difference. According to Eliot and Fralley (1976), researchers have proposed three main hypotheses. One hypothesis stated that a sex-linked recessive gene genetically transmitted sex differences in spatial ability. A second hypothesis postulated that sex differences resulted from variations in child-rearing practices, learning opportunities, or cultural expectations. The third hypothesis supported the idea that sex differences were due to a complex interaction between both social and biological factors. Studies that have tested each of the above three hypotheses will now be discussed.

With respect to the first hypothesis, Eliot and Fralley (1976) found that O'Conner concluded that individuals inherited spatial ability, rather than acquiring it. Furthermore, this genetic trait was thought of as a sex-linked, recessive gene, which had a 50% frequency. Since this recessive gene was associated with an X chromosome, in theory, mothers with high spatial ability would pass this on to their sons. This theory also predicted fathers and sons would not have similar spatial ability, unless both parents possessed equal levels of spatial ability. Additionally, if girls had strong spatial skills, then their fathers would also. Few studies have supported this theory. After reviewing research related to the X-linked recessive gene hypothesis, McGee (1982) concluded little evidence existed in support of this hypothesis.

One of the first to provide support for the X-linked recessive gene hypothesis through empirical data, Stafford (1961) determined the spatial ability of members of 104 families and then analyzed correlations between parents and siblings and between parents only. The results agreed with the order and magnitude of the correlations proposed by the hypothesis. He found near zero mother-father and father-son correlations and a small mother-daughter correlation. With the highest and equal correlations existing between the mother-son and father-daughter pairs, the hypothesis was supported. Following this, several other researchers attempted to replicate these findings. The results of this research follow.

Hartlage (1970) tested 25 families using a paper and pencil measure of spatial visualization ability. This test was said to "represent a reasonably pure measure of spatial visualization ability." The highest correlation occurred between mothers and sons, .39, followed by a nearly as high correlation between fathers and daughters, .34. Both of these correlations reached statistical significance. Correlations between mothers and daughters and between fathers and sons were smaller and nonsignificant, .25 and .18, respectively. Thus, Hartlage (1970) concluded these significant and nonsignificant correlations provided evidence to support the X-linked recessive gene hypothesis.

Bock and Kolakowski (1973) conducted a study whose results also supported the sex-linked gene hypothesis. In their study, parents and their 12-year-old offspring participated. The researchers gave the participants a paper and pencil spatial visualization test. Subsequently, they found correlations between each parent and the offspring. Results once again indicated a statistically significant difference between the father-daughter and the father-son correlation. Here, the father-daugher correlation exceeded the father-son correlation. Bock and Kolakowski (1973) found a significantly larger mother-son correlation than mother-daughter correlation. The order and magnitude of the correlations supported the order given by the hypothesis. With regards to a gender difference, males scored significantly higher than females. Bock and Kolakowski (1973) concluded no theory of child development adequately explained why these correlations existed. Thus, the authors accepted the "hypothesis that spatial ability is substantially influenced by a recessive sex-linked gene."

Walker, Krasnoff, and Peaco (1981) tested 129 adolescents and their parents to determine their spatial ability and to investigate correlations between parents and siblings. They administered three paper and pencil tests of spatial ability to this sample. Results indicated that correlations with respect to scores on two of the three tests followed the predictions of the X-linked recessive gene hypothesis. However, the results of the third test did not adhere to the order and magnitude of the hypothesized correlations. Additionally, males significantly outperformed females overall, but not by generation. Based on this research, Walker et al. (1981) suggested that perhaps maturation, learning, and other environmental processes played a role in the development of spatial skills. They concluded in light of these and earlier studies' results, "it appears unlikely that a single recessive gene can play a determining role in all of the varieties of visual spatial perception."

In another study testing the recessive sex-linked gene theory, Bouchard and McGee (1977) did not find supporting results for this theory. They gave a spatial visualization test to persons in 200 families to determine each person's level of spatial ability and to examine the correlations between certain family member pairs. Results demonstrated a significant gender difference that favored males in each generation. However, no significant differences among the parent-offspring correlations surfaced. Consequently, these results did not support the recessive X-linked gene hypothesis. Bouchard and McGee (1977) suggested that the search for a cause of gender differences in spatial ability continue in other directions since so few studies had confirmed the theory. The authors suggested other possible causes for the gender difference such as androgenicity or maturation rate.

A study by Corley, DeFries, Kuse, and Vandenburg (1980) found results that agreed with Bouchard and McGee's findings. Corley et al. (1980) also did not find the intra-familial correlations predicted by the hypothesis. They gave a spatial ability test to 269 families and determined correlations between parents and siblings. Results provided no support for the recessive X-linked gene hypothesis. Moreover, the researchers found father-child correlations in the exact opposite direction from what was expected. Corley et al. (1980) concluded the X-linked gene hypothesis was no longer tenable. Another study conducted by Loehlin, Sharan, and Jacoby (1978) examined the X-linked gene hypothesis. They tested members of 192 families with a battery of spatial tests and found weak evidence, if any, in support of this hypothesis. The researchers found nearly equal father-daughter and mother-son correlations. However, they discovered equal and relatively high correlations between mother-daughter and father-son pairs as well. This contradicted the main thrust of the hypothesis. Leohlin et al. (1978) concluded, though, the other correlations gave modest support for the X-linked recessive gene hypothesis.

In an attempt to determine if the X-linked gene hypothesis would be supported, Fralley, Eliot, and Dayton (1978) measured the spatial ability of parents and their offspring. Families with undergraduate offspring were given two measures of spatial ability. The authors predicted that correlations between each parent and their offspring and between siblings would conform to those found in X-linked recessive gene inheritance. They also predicted high spatial ability in sons whose mothers possessed strong spatial skills. Similarly, the researchers predicted high spatial ability in fathers whose daughters were determined to have high spatial ability. Results showed that males significantly outperformed females on both measures in both groups. The resulting correlations did not, however, follow the pattern put forth by the hypothesis. Fralley et al. (1978) found that when a mother had high spatial ability, so did her son; and when a daughter had high spatial ability, so did her father. Thus, one of the predictions made held, while the other did not. Additionally, Guttman and Shoham (1979) examined patterns of family correlations with respect to spatial visualization. They tested members of 261 families with a battery of eight spatial ability tests. Again, the correlations that their data yielded did not reflect predictions made by the X-linked recessive gene hypothesis. In Guttman and Shoham's (1979) study, fathers and their sons held the highest correlation, not fathers and their daughters.

Many studies have looked at individuals with Turner's Syndrome predicting that their level of spatial ability would be similar to males since they too have only one X chromosome (Garron, 1970; Vandenburg, 1975). However, individuals with Turner's Syndrome generally did not possess high spatial visualization skills so these individuals did not support the X-linked recessive gene hypothesis (Eliot & Fralley, 1976). Vandenburg (1969) did find, however, that studies on twins indicated "that spatial abilities may have a considerable genetic component."

The second proposed hypothesis stated gender differences were the results of variations in child-rearing practices, learning opportunities, or cultural expectations. Sherman (1967) supported this hypothesis and suggested that gender differences in spatial ability existed because of varied experiences; that is, environmental differences played a role in the development of spatial ability. Thus, individuals who came from different environments or who had diverse experiences would have had varying levels of spatial ability. He also suggested that males out-performed females because they voluntarily participated in more spatially oriented activities such as model building, rather than playing with dolls. Vandenburg and Kuse (1979) stated that some evidence existed to support the hypothesis that at least part of the gender difference in spatial ability was due to nurturance and culture diversity.

Prior to Sherman's hypothesis, Farrell (1957) observed pre-school children at play and noted that of the 376 children observed, 24% of the boys played with blocks, while only 5% of the girls did so. Farrell (1957) also found that of the total recorded time spent playing with blocks, 99% of the time was reported for boys, whereas 55% was reported for girls. Both of these findings were statistically significant. Also in accordance with Sherman's hypothesis, Connor, Serbin, and Schackman (1977) reported that preschool boys were observed spending more time than girls engaged in activities relevant to developing spatial skills, such as playing with blocks and trucks. Harris (1981) also commented that in their upbringing, boys received "more opportunities, encouragement, and training than do girls to acquire visual-spatial skills." In examining the relevant literature to this hypothesis, Harris (1979) concluded enough evidence existed to support the idea that certain experiences did enhance the development of spatial ability and that males tended to have more of these experiences than females did.

Blatter (1983) examined Sherman's hypothesis by providing experiences to males and females and then testing afterwards to see if these experiences enhanced their spatial visualization. In both the control group and the experimental group, males outperformed females. Only in the experimental group, however, did the gender difference demonstrate significance. Also, both genders improved significantly as a result of the spatial experiences where the females gained significantly more than the males. Thus, females may have been lacking in spatial experiences, while males were not; but, both had room for improvement. Blatter (1983) concluded these results supported Sherman's (1967) experiential hypothesis.

The third proposed hypothesis suggesting gender differences resulted from a complex interaction between both social and biological factors was researched by Harris (1979) through a review of the literature on gender differences in spatial ability. With special attention given to possible explanations of gender differences, Harris (1979) seemed to support the third hypothesis. He stated although the socialization and environmental factors in gender differences did contribute to explaining this phenomenon, too many findings were not explained by such factors. Thus, he concluded these factors did not stand alone in an explanation of the gender difference in spatial ability, but contributed to this difference. Also, Harris (1979) stated that a component of spatial ability was inherited based on findings of studies involving the spatial ability of twins.

Field Dependence vs. Field Independence

Research has shown that the classification of a person as either field dependent or field independent played a role in that person's level of spatial ability. In this section of the literature review, the findings on field dependence vs. field independence will be discussed. First, definitions of field dependence and field independence will be stated according to Sherman (1974). Then, characteristics of persons of each field type will be suggested based on the research findings of O'Brien (1991). This section will end with results from studies that have found strong correlations between measures of field dependence and spatial orientation skills (Gardner, Jackson, & Messick, 1960; McGee, 1979; Podell & Phillips, 1959; Thurstone, 1944).

Sherman (1974) described a field-dependent person as one who is "less able to disembed a given stimulus from its surrounding; he or she is more likely to be influenced by the embedding field." Alternatively, a field-independent person was described as one who is not influenced by the background or surroundings of a stimulus object. Sherman concluded that field-independent persons have stronger spatial skills than field-dependent persons, as evidenced by strong correlations between field independent persons and high spatial visualization ability.

O'Brien (1991) conducted a study in which he focused on the cognitive styles of students enrolled in foundations of education classes. He found that males and females had distinct cognitive style differences. Males tended to be more field independent than females. The field independent subjects in this study had strong spatial visualization skills. O'Brien further stated that "evidence clearly suggests that areas of study such as engineering, mathematics, and science are preferred by field independent students." O'Brien's study provided evidence for the male dominance in careers such as architecture, engineering and mathematics. Females tended to choose careers involving social interaction, while males opted to go into fields requiring the use of their analytic abilities. Field dependent students, generally females in this study, preferred careers in social science, the humanities, counseling, teaching, and sales. Furthermore, O'Brien reported that in the academic world, the issue of field independence/dependence may be a significant factor in choice of major and career.

With regards to correlational studies by Gardner, Jackson, and Messick (1960), Thurstone (1944), and Podell and Phillips (1959), McGee (1979) noted a strong relationship was found between measures of field dependence and tests of spatial orientation skill. Specifically, in their study, Gardner et al. (1960) reported a correlation of .53 between the Embedded Figures Test and the Guilford-Zimmerman Spatial Orientation Test. Additionally, Thurstone (1944) found correlations of .43 and .41 between two forms of the Gottschaldt Figures Test and the Space Test of the Primary Mental Abilities Test battery. The Gottschaldt Figures Test was a test similar to Witkin's

Embedded Figures Test. Podell and Phillips (1959) replicated Thurstone's results in a much later study.

Hemispheric Specialization

Another individual difference found with respect to spatial visualization ability concerns hemispheric specialization, the notion that the two hemispheres of the brain serve in different intellectual capacities. This section will begin with a review of the functions and development of each hemisphere as suggested by Battista (1990), Tobias (1978) and Flanery and Balling (1979). Then opposing research concerning hand preference, hemispheric specialization and spatial ability will be discussed. Some researchers have suggested that left-handed persons, particularly females, did not perform as well as right-handed persons on tests of spatial ability (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973) while others have found that left-handers outperformed right-handers (Peterson and Lansky, 1974 ; Yen, 1975).

Battista (1990) stated that, generally, the left hemisphere of the brain was specialized for analytic/logical thought in both verbal and numerical operations; whereas, the right hemisphere was specialized for spatial tasks, artistic efforts, and body image. Harris (1979) suggested that right-hemisphere injury is associated with loss of spatial ability. Tobias (1978) reiterated this idea stating that the right hemisphere of the brain seemed to be responsible for "the abilities to perceive shapes, to remember musical phrases, to grasp things as wholes, and to remember faces." According to Tobias (1978), the left hemisphere seemed to specialize in speech and other linear or sequential tasks. Additionally she claimed, this lateralization, or brain specialization, appeared to take place earlier in females than in males. Tobias (1978) hypothesized that since girls lateralized earlier than boys, they did not experience an important stage of spatial development. She found that the development of spatial visualization ability was better enhanced when both brain hemispheres maintained their spatial capabilities for as long as possible.

Flanery and Balling (1979) tested first, third, and fifth grade children and adults for hand preference in solving tactile spatial ability problems. Flat, non-regular geometrical shapes were presented to both hands, while the subject was blindfolded, and after a certain period of time, another stimulus shape was presented to one of the hands. The subject had to say if he/she had been given that item before. Generally, the left hand was more accurate than the right, which indicated that the right hemisphere of the brain was more accurate in dealing with these spatial objects than the left hemisphere. Specifically, results of this study for the fifth grade students and the adults indicated that the left hand was significantly more accurate than the right. No significant difference was found between hands for the first and third grade students. No sex differences were found in the first, third, or fifth grade students, but a sex difference was found in the adults. Here, males tended to give more correct responses than females. Thus, Flanery and Balling (1979) concluded that the right hemisphere became progressively more specialized for tactile spatial visualization ability with increasing age and that male adults were significantly more lateralized than female adults. This followed the authors' earlier claim that "the processing of spatial information has been consistently found to be superior for the right hemisphere in adults". Their study suggested the left hand generally to be superior to the right in solving tactile spatial tasks. According to Lowery and Knirk (1982-83), researchers in general agreed that the source of spatial tasks was located in that part of the brain known as the right cerebral hemisphere. Harris (1981) suggested that "as the female's right hemisphere becomes relatively more committed to language than the male's, it becomes less efficient as a processor of spatial information."

McGee (1976) examined laterality, hand preference, and spatial ability in both left-handed and right-handed males and females. A paper and pencil test of three-dimensional spatial visualization ability was administered to 46 male and 66 female university students. Each student also completed a seven-item questionnaire to determine hand-preference. McGee's results followed what was predicted; males significantly outperformed females, overall, and left-handed females performed significantly lower than right-handed females. Since the scores on the spatial test for left-handed males and left-handed females were so divergent, when these subjects were removed from the sample, the sex difference was no longer statistically significant. Although not statistically significant, left-handed males did score higher than right-handed males, which indicated that they had stronger visualization skills than their right-handed counterparts. Due to these observations, McGee's findings showed that the function of the left cerebral hemisphere in performing spatial tasks differed for males and females. Consequently, McGee's (1979) results supported "Sherman's (1974) hypothesis of a greater relative importance of the left cerebral hemisphere to spatial functioning in females than males."

In accordance with McGee's (1976) finding that left-handed females were generally weaker than right-handed females with respect to spatial visualization, McGlone and Davidson (1973) found, in an earlier study, similar results when they tested male and female university students for level of spatial visualization. In this study, 58 right-handers and 58 left-handers, with equal numbers of males and females in each group, were given a spatial relations test. However in agreement with the aforementioned study, left-handed females tended to score the lowest on the spatial relations test. A later report by McGlone (1980) suggested that females were less hemispherically specialized with respect to both verbal and spatial tasks.

Peterson and Lansky (1974) studied left-handedness among undergraduate architectural students and professional architects. They found that, in both groups, there tended to be more left-handed individuals than would "normally" be expected. Also, after taking a test involving complex directions for drawing a maze, all the left-handed subjects performed the tasks perfectly while over 50% of the right-handers erred. These results appeared to confirm the hypothesis that both left-handedness and greater spatial ability is associated with right-hemisphere dominance. Peterson and Lansky (1974) remarked that "it appears safe to say that the left hemisphere goes more with right-handedness and verbal abilities, the right hemisphere more with left-handedness and greater spatial competence." When Yen (1975) examined spatial visualization differences in left- and right-handed high school students, she found a handedness effect on spatial ability only for males. In this study, a pencil and paper spatial ability test was given to left- and right-handed high school students. Results indicated no differences in the spatial ability among left-handed females and right-handed females. However, right-handed males outperformed left-handed males on the spatial ability test. Yen stated that "it is unlikely that handedness per se influences spatial performance." What is more likely is whatever factors affect handedness, may also affect spatial ability.

Environmental Factors and Involvement in Spatial Activities

In this section of the literature review, individual differences in spatial ability due to environmental factors and involvement in spatial activities will be addressed. First, results of studies that have focused on cultural aspects of one's environment will be discussed (Baenninger & Newcombe, 1989; Berry 1971; Bishop, 1980; Harris, 1978; Belz & Geary, 1984). Then, those studies that have examined the "educational environment" and its effect on spatial ability will be summarized (Battista, 1981; Miller & Bertoline, 1991; Bishop, 1980).

Baenninger and Newcombe (1989) conducted a meta-analysis of research on spatial visualization in which subjects in each study had participated in some kind of spatial activity and were then tested. The purpose of this meta-analysis was to test a hypothesis that environment and spatial experiences have an impact on spatial ability. The authors proposed that there may be individual differences in spatial ability due to differential experiences with spatial activities as provided by varying life environments. Such activities included model building, participation in various sports, sewing clothes, and drawing three-dimensional objects. Results showed there was a reliable relationship between spatial activity participation and spatial ability for both males and females. In their study, the more a subject had participated in spatial activities, the higher his/her spatial test performance was. According to Sherman's (1967) hypothesis, males and females have differential spatial experiences due to environmental circumstances, which may partially account for the frequently found gender difference in spatial ability. Bishop (1980) also studied how environmental differences contributed to individual student differences in spatial ability. His review of the literature on environmental differences found that one's physical environment, language, occupational pursuits, and social practices influenced the level of one's spatial ability (Berry, 1971).

Harris' (1978) analysis of related literature on studies of spatial visualization with respect to environmental differences revealed several years of spatial experiences were needed before differences due to these experiences would be expressed through spatial ability test scores. He cited an example of an environmental difference where young boys were generally given more freedom to wander away from homes than young girls. Harris also noted that children with high spatial ability tended to be less restricted in their areas of play or watched over by their parents, and appeared to be more independent. He suggested perhaps boys more than girls engaged themselves in spatially relevant activities due to cultural differences in their upbringings.

Belz and Geary (1984) studied the relationship between academic achievement and a number of social/environmental background variables including ordinal birth position and father's occupation. They noted that father's occupation had received very little attention in educational research, except as a measure of socioeconomic status. The authors stated with respect to birth position, children with earlier ordinal positions and smaller family sizes have been associated with higher spatial ability. Belz and Geary

(1984) also indicated that previous research had shown that father's years of education and occupation was related to differential development of spatial abilities. In this study, data on high school seniors was obtained through school records and Scholastic Aptitude Test (SAT) scores. Analyses of this data indicated no birth order effects. The researchers also found that children with fathers in scientific occupations scored highest on both verbal and quantitative measures.

With respect to one's "educational environment", Bishop (1980) found that children taught in primary schools where manipulative materials were regularly used had higher spatial visualization than students in learning environments with little or no manipulative use. He concluded that "one aspect of the learner's environment consists of the formal education one receives, and that teaching approaches may be an important determinant of spatial abilities." Thus, individual differences in students' spatial ability may be due to varying formal education experiences. Battista (1981) further supported this idea by concluding that students with high spatial visualization ability tended to learn more than students with low spatial visualization ability when classroom instruction consisted primarily of spatial or visual presentations. He also found that students with low spatial visualization learned more when instruction drew upon both verbal and spatial methods.

Miller and Bertoline (1991) found research that suggested humans were not born with spatial visualization ability. Rather, this ability seemed to be a cognitive function developed in varying degrees through certain life experiences. Moreover, spatial visualization abilities may have developed over time during different stages of life and were a result of exposure to different learning environments. Thus, according to Miller and Bertoline, children not exposed to learning environments that promoted spatial visualization would not have had spatial abilities as well developed as children exposed to learning environments that did promote the development of spatial ability.

Speed and Efficiency of Mental Transformations and Rotations

Researchers have found that the speed and efficiency of one's mental transformations and rotations differentiated individuals with varying degrees of spatial skills (Poltrock & Agnoli, 1986; Poltrock & Brown, 1984; Salthouse, Babcock, Michell, Palmon, & Skovronek, 1990; Tapley & Bryden, 1977). After reviewing the research that has found differences in spatial ability due to speed and efficiency of mental rotations and transformations, a characterization of the mental rotations of persons with low or high spatial ability will then be considered based on the work of Carpenter and Just (1986) in the following section.

In a review of research pertaining to imagery and spatial visualization, Poltrock and Agnoli (1986) observed that important components of spatial visualization included mental image quality and efficiency in making mental rotations. If a student possessed these two components, he/she was likely to have had high spatial visualization ability. These components (mental image quality and efficiency in making mental rotations) appeared to be a source of individual differences in spatial visualization ability. As a result of their review, Poltrock and Agnoli (1986) proposed a model of the relationship between imagery cognitive components and spatial test performance. Within this model, imagery cognitive components included image generation, scanning, image quality, adding detail, rotation, and image integration. Of these components, image quality and rotation had the strongest correlations, .57 and .29, respectively, with spatial visualization ability. Poltrock and Agnoli's model was found to have an "excellent fit" to the data they obtained in their review, having a chi-square value near its expected value. In their research on individual differences in imagery and spatial ability, Poltrock and Brown (1984) found that most of the variance in spatial visualization ability was accounted for by a linear combination of measures of imagery skills. Furthermore, success on spatial ability tests required maintaining high quality images and efficiently transforming them during spatial problem solving tasks (Poltrock and Brown, 1984). Finally, Poltrock and Agnoli (1986) suggested there was strong evidence in the studies they reviewed to support the notion that "people generally use imagery to perform spatial tests."

"What is responsible for individual differences in spatial visualization ability?" was the primary question addressed by Salthouse, Babcock, Mitchell, Palmon, and Skovronek (1990). In their experiments, high-spatial and low-spatial ability male college students were administered four pencil and paper spatial visualization tests. Salthouse et al. (1990) hypothesized individual differences in spatial visualization ability might be due "to variations in transformation efficiency, and/or variations in the ability to preserve spatial information during transformations." Another factor that may have contributed to individual differences in spatial ability included the quality and accurateness of the mentally represented object. Many students had difficulty mentally copying an object and therefore did not perform as well on tests of spatial ability as those who made near perfect mental reproductions. The results of the two experiments, however, did not support the proposed hypothesis accounting for individual differences in spatial ability. The transformation efficiency of both low and high spatial students was nearly the same. Also, no differences surfaced in the precision, amount or stability of the information that was remembered while completing a spatial task. According to Salthouse et al. (1990), "the speed of executing most information-processing operations" did, however, differentiate low and high spatial ability students. Based on their results, Salthouse et al. (1990) hypothesized "spatial visualization differences are most pronounced when some information must be preserved while other information is being processed."

In a study conducted by Tapley and Bryden (1977), undergraduate university students were tested to determine if differences in spatial ability existed due to either efficiency in making mental rotations or professed solution strategies. For professed solution strategy, results indicated no major differences among the participants occurred. However, a significant gender difference with respect to response time and the degree that the stimulus object had been rotated appeared. Males were significantly faster and more accurate than females. The authors concluded these results supported the idea of a general male superiority in spatial visualization and proposed that differences in spatial ability were not necessarily contingent upon different strategies being used.

Through the use of the Cubes Comparisons Test, Carpenter and Just (1986) examined individual differences in spatial visualization. The Cubes Comparison Test required the student to determine if figures on the faces of the two cubes had the same relative position to each other. To accomplish this, students mentally, not physically, rotated one of the cubes into alignment with the other. Results indicated that high and low spatial students selected different trajectories to transform the orientation of one of the cubes into the other. Low spatial students chose a trajectory parallel to one of the standard axes, namely the x, y, or z-axis, which paralleled a side of one cube face. Alternatively, high spatial visualizers tended to choose non-standard trajectories that guaranteed only one rotation of the cube was needed. One such trajectory that passed through opposite corners of a cube illustrated the "one-rotation" method. Carpenter and Just (1986) also found that low spatial subjects often rotated a given cube face more than once within a single problem, as if they had lost track of the transformed cube, while high spatial subjects did not do this. Overall, the authors concluded, "high spatial subjects are better at generating, maintaining, and coordinating information during spatial transformations."

Solution Strategies to Spatial Problems

Some researchers have explored the solution strategies that students employed when solving spatial problems (Battista & Clements, 1996; Lohman & Kyllonen, 1983). The results of this research have shown that solution strategy differentiated between those with high and low spatial ability. In this section, these studies will be reviewed first. Then, research that has investigated the nature of the actual problems with respect to spatial ability will be considered (Clements & Battista, 1992).

In a study of elementary students' understanding of three-dimensional rectangular arrays of cubes, Battista and Clements (1996) found individual differences in spatial ability due to varying solution strategies of spatial problems involving rectangular arrays of cubes. Third, fourth, and fifth grade students were interviewed on a variety of problems in which they were asked questions about a rectangular array of cubes, such as how many cubes made up the whole rectangular solid. Then, their solution strategies were classified and tabulated. A small group from the original sample of students was then interviewed again to follow up conjectures generated by analyzing the solution strategies initially found. Five solution strategies were found that differentiated the students and their respective levels of spatial ability. These strategies were: "the student conceptualizes the set of cubes as forming a rectangular array organized into layers; the student conceptualizes the set of cubes as space-filling but does not utilize layers; the student conceptualizes the set of cubes in terms of its faces; the student uses the formula length times width times height; and other." The first strategy was used by the students with the strongest spatial ability. Then, as students moved towards the "other" category, their spatial skills decreased. This classification scheme and the results of the second interviews indicated that students had difficulty counting the cubes in the three-dimensional array because they were not able to coordinate the different views of the array and then combine them into one mental object. The authors concluded that students initially mentally viewed a three-dimensional array of cubes as an uncoordinated set of faces. After handling such a rectangular array, students eventually saw it as layers of cubes stacked on top of each other. At that point, students were able to determine the number of cubes in the array by counting the number of cubes in each layer and then multiplying by the number of layers. Until students reached that point, the formula taught to them (length times width times height) had no spatial meaning.

Lohman and Kyllonen (1983) hypothesized that when solving spatial problems, subjects used different strategies, which might lead to individual differences in measured spatial ability. Their report of previous research indicated that when solving spatial problems on the Guilford-Zimmerman Spatial Orientation Test, students, for the most part, used one of two solution strategies. Subjects either imagined themselves as being reoriented with respect to the object in the problem, or they mentally rotated the object and made comparisons by reorienting themselves. On another spatial ability test in which problems were in multiple choice format, high-ability students usually knew the answer before looking at the choices, whereas low-ability students studied the choices in order to eliminate some of them. Another difference uncovered by this review of research revealed some students solved spatial tasks in non-spatial ways. Thus, what may appear to be a high score on a spatial visualization test may in reality be an assumption based on the spatial solution strategies of the test designer rather than on the students' true spatial ability since he/she may have used other strategies.

In reviewing the literature on spatial ability, Clements and Battista (1992) found that the type of spatial problem may be a factor of individual differences in spatial performance. Generally, males performed better on tasks that involved spatial perception and rotation than females did, but problems that were characterized by a combination of visual and nonvisual solution strategies were equally as difficult for both genders. They also found several reports, which concluded that the processes underlying spatial thinking were different for males and females. Males tended to prefer nonverbal modes of thought while females tended to prefer verbal modes. Since spatial thinking may have required more nonverbal than verbal modes of thought, this agreed with the large number of studies that found gender differences in spatial ability in favor of males (Newcombe, 1982).

Mathematical Background.

Other researchers have focused on the role that mathematical background has played in one's level of spatial ability (Martin, 1968; Rhoades, 1981). Studies conducted by these researchers have revealed that the stronger one's mathematical background was, the higher his/her spatial ability was. In this section, studies that have examined spatial ability as a function of the number of mathematics classes taken prior to or during university study will be reviewed.

Having examined the backgrounds of university freshman in terms of coursework, Rhoades (1981) found individual differences in spatial visualization ability due to varying numbers of mathematics courses taken. Gathered data included the number of courses taken in several fields of study, namely mathematics, science, engineering, humanities, and others as well as scores on both spatial visualization and spatial orientation tests. The results indicated "relevant academic curricula improves performance on spatial tasks." Furthermore, only the number of mathematics courses taken explained a significant portion of the variance found in the spatial test scores. Therefore, Rhoades (1981) concluded the amount of mathematics training a student had contributed to his/her level of spatial ability. Similariy, Martin (1968) found consistent results in his study of certain education majors. His subjects included freshman students in mathematics, prospective teachers in secondary mathematics, science, art, English, social sciences, and elementary education, as well as experienced elementary and secondary mathematics teachers. Martin

(1968) found a significant difference in spatial ability between prospective female and male teachers as well as between experienced elementary and secondary teachers. Furthermore, prospective secondary mathematics teachers scored significantly higher than prospective elementary teachers, prospective social science teachers, prospective English teachers, and experienced elementary teachers. Conversely, he did not find a significant difference between the freshman mathematics students and any other group, nor between the prospective science, art and mathematics teachers. After he reviewed the degree requirements for all of the subjects in this study and compared the resultant spatial ability levels of each student, Martin (1968) concluded that more college-level course work in mathematics resulted in increased spatial ability.

Musical Background

Finally, research has been conducted which examined individual differences in spatial ability with regards to musical ability (Mason, 1986; Harris, 1978). In this last section on individual differences in spatial ability, this research will be reviewed.

In a study of the relationship between mathematical, musical and spatial abilities, Mason (1986) found that differences in musical background and experience may result in differences in levels of spatial ability. In this study, Mason tested 48 juniors in college using one musical ability test and four spatial abilities tests. The four spatial abilities tests were combined to form both scores for spatial visualization and spatial orientation. Results showed students with high mathematical ability also had high spatial visualization ability; while the students with more musical ability had more spatial orientation ability than those students with less musical ability. Mason concluded "the connection between mathematical and musical abilities may be mediated by different spatial abilities and that it may be a function of the students' formal study of each field." Harris (1978) also suggested that the ability to recognize, execute or create a melodic pattern may be a spatial ability similar to the visual detection of an embedded figure or the mental rotation of a three-dimensional object. He also acknowledged the recognition of variations on a theme may rely on abilities similar to those needed to follow a figure through several transformations.

Improvement of Spatial Visualization

The review of the related literature concerning improvement in spatial visualization will consist of the following organization of sub-topics: direct instruction of spatial relationships, activities that improve spatial ability, programmed instruction, and finally, specific course-work. Direct instruction studies make up the majority of the literature in this portion of the review and will be discussed first.

Direct Instruction

Several studies have used direct instruction on spatial relationships in an attempt to improve students' performance on tests of spatial ability (Lowery & Knirk, 1982-83). Most studies have yielded positive results (Baldwin, 1985; Ben-Chaim, Lappan, & Houang, 1985; Ben-Chaim, 1983; Ben-Chaim, Lappan, & Houang, 1988; Clements, Battista, Sarama, & Swaminathan, 1997; Conner, Serbin, & Schackman, 1977; Friedlander, 1985; Smith & Schroeder, 1979; Smith & Litman, 1979; Tillotson, 1985), although some have generated unclear conclusions (Blatter, 1983; Baenninger & Newcombe, 1989).

Connor, Serbin, and Schackman (1977) examined the response to training with respect to spatial visualization of first, third and fifth grade students. The authors predicted the training would differentially affect males and females. After dividing the students in the sample into three groups, two groups received spatial training in two different formats while the third served as a control group. Students took a pencil and paper spatial ability test after a brief training session. Results indicated no gender difference in spatial ability after training. However, as predicted, males and females did not respond similarly to the training. Boys in the two experimental groups performed equally as well; but, girls in one of the experimental groups scored significantly higher than their counterparts in the other experimental group. Thus, for boys, the type of training did not appear to matter, but for girls it did.

Through an instructional unit on area and motion, Clements, Battista, Sarama, and Swaminathan (1997) examined the improvement of spatial ability in elementary students. They employed the use of activities designed to heighten spatial ability. After pre- and post-testing, results indicated instruction had a strong positive effect on students' spatial ability and spatial-numeric connections were established. Students' spatial ability test scores improved significantly after instruction with respect to both accuracy and number of test items completed.

With respect to improvement due to instruction, Smith and Schroeder (1979) examined fourth grade girls' and boys' spatial visualization. In this study, they randomly assigned fourth grade students to either an instruction group or a non-instruction group. The non-instruction group took a paper and pencil spatial visualization test and then received 10 half-hour periods of instruction on solving two-dimensional spatial-type problems. The instruction group took the spatial visualization test after they had received the same 10 half-hour periods of instruction. Results of this study indicated no significant interaction between gender and instruction. Thus, Smith and Schroeder concluded that at the fourth grade level, boys and girls responded equally to spatial visualization instruction. Although no gender difference was found, the two groups did differ in their level of spatial ability. The fourth grade students in the instruction group scored significantly higher than those in the non-instruction group on the spatial visualization test. Thus, this study provided evidence that instruction on spatial visualization improved spatial visualization ability.

Ben-Chaim, Lappan, and Houang (1985; Ben-Chaim, 1983; Ben-Chaim, Lappan, & Houang, 1988) studied the effects of training on the spatial visualization of middle school students. The researchers administered a spatial visualization test to fifth through eighth graders before and after 3 weeks of participation in spatial visualization activities. These activities involved representing three-dimensional objects in two-dimensional drawings as well as constructing three-dimensional objects from two-dimensional representations. The students were always allowed to use manipulative materials during these activities. The findings indicated that male and females at all grade levels benefitted considerably from the participation in the activities involving spatial visualization tasks. Also, the researchers re-tested the students 4 weeks after and again 1 year after the activities had terminated. Results of this test indicated that after such time periods the effects of training were still present. Ben-Chaim et al. (1988) noted that male and female students did not respond differently to the training activities. Also, they concluded that once "spatial visualization skills have been attained, they last and even continue to develop over time" (Ben-Chaim et al., 1988).

In another study that used fifth through eighth graders, Baldwin (1985) found that students' spatial visualization ability improved through instruction based on pre- and post-test scores. In addition to regular mathematics instruction, one randomly selected class from each grade level received instruction on spatial visualization and spatial orientation for 4 weeks daily. The other classes continued with regular mathematics instruction. After analyzing the results of the post-test, Baldwin (1985) concluded that instruction in spatial skills had significantly improved the performance of female students and had significantly improved the spatial ability of all subjects, male and female, who initially had moderate spatial ability.

Additionally, Tillotson (1985) concluded, "spatial visualization ability is a trainable attribute." Tillotson gave three paper and pencil tests of spatial visualization ability to middle school students. For 8 weeks, an experimental group received instruction designed to develop spatial visualization skills. Students in the experimental group manipulated three-dimensional objects, discussed the movement of those objects, and practiced transformations with two-dimensional drawings. Testing after the 8 weeks of spatial visualization training revealed significant improvement in the spatial visualization skills by those in the experimental group, but not in the control group. Friedlander (1985) also reported significant improvement on spatial ability test scores after middle school students received instruction on a unit on similarity.

In a similar study, Smith and Litman (1979) examined early adolescent students, ages 11 to13, with respect to improved spatial visualization skills as a result of training. All students in the study received instruction, however the time of testing to assess spatial visualization ability varied. The control group took the test one day prior to receiving instruction, while the experimental group took the test one day following instruction. During one hour a day for 4 days, Smith and Litman (1979) presented students skills useful in solving two-dimensional spatial puzzles and allowed them to practice using these skills. Results indicated a significant interaction between gender and instruction. "The effects of instruction in spatial visualization were not the same for early adolescent girls and boys (Smith & Litman, 1979)." An interesting finding suggested girls in the control group outperformed boys in the control group, while boys in the experimental group outperformed girls in the experimental group. Only boys significantly improved in spatial ability as a result of instruction. Since girls outperformed boys prior to instruction, Smith and Litman (1979) concluded that the instruction acted as an equalizing factor, bringing boys' performance on a spatial ability test up to the level of the girls' performance. They viewed this as a surprising and contradictory finding when compared to other studies that have shown that males outperformed females in spatial ability initially.

In a review on spatial ability and mathematics education, Bishop (1980) reported he had used manipulative materials in a training program for high school students designed to increase their spatial ability test scores. Results of his work illustrated large gains in spatial ability as indicated by a follow-up test.

Contrary to those studies, in which training or instruction did result in improved spatial visualization skills, Blatter (1983) found no improvement in spatial visualization skills necessarily due to training. Forty-eight ninth grade students completed a spatial visualization test prior to either receiving 10 one-hour sessions of instruction on spatial relations or on regular topics covered in their literature class. Following these instructional sessions, students again took a paper and pencil spatial visualization test. Results indicated that following the training, a significant gender difference, similar to the one found using pre-test scores, still existed for the experimental group, but not for the control group. Also, Blatter (1983) reported significant gains from pre-test to post-test scores for both groups. Upon closer examination of the experimental group's scores, the author found that those lowest in initial spatial ability benefitted the most from the training. Because the control group improved significantly as well, the results yielded unclear conclusions with respect to the effects of training on spatial visualization skill.

Through a meta-analysis of research with respect to training in spatial visualization, Baenninger and Newcombe (1989) found that a training period of less than 3 weeks enhanced test-specific spatial ability. While this training did fulfill the same function as practice for the test, this treatment did not promote general spatial ability. Also, Baenninger and Newcombe (1989) suggested no gender-related differences in improvement occurred after training; that is, males and females both benefitted from training. Furthermore, Linn and Hyde (1989) remarked meta-analyses of research on spatial visualization have revealed that gender differences in spatial ability responded positively to training. Some studies have shown the amount of improvement varies with age and gender, but generally instruction aimed at improving spatial visualization did positively affect those receiving the instruction. Finally, Lowery and Knirk (1982-83) stated that spatial visualization had been taught using traditional classroom techniques as well as with specially designed manipulatives.

Activities that Improve Spatial Ability

Researchers in education have recommended that teachers incorporate certain specific spatial activities in their everyday instruction to promote the development of spatial ability, as well as certain types of interactive learning environments (West, Morris, & Nichol, 1985; Dixon, 1997). These activities will be described next.

West, Morris, and Nichol (1985) indicated activities that enhanced the development of spatial thinking included the following: building simple geometric figures and constructing more complex forms from these figures, using puzzles that relate spatial and number concepts, making various shapes with toothpicks and then drawing a picture of each shape, and constructing mobiles from a variety of cardboard shapes to increase awareness of the different perspectives a shape can have. Dixon (1997) suggested "the type of lesson used to increase students' spatial visualization affects the extent of the increase in spatial visualization." According to Dixon (1997), the most effective instructional environments included those that allowed for student-student interaction, student-teacher interaction or both through the use of dynamic activities such as those provided by The Geometer's Sketchpad (Jackwi, 1991).

Programmed Instruction

Besides direct instruction or specific spatial activities, programmed instruction has been used to facilitate the improvement of spatial ability (Brinkman, 1966). Results indicating a positive effect of the programmed instruction will be reviewed in this section.

In a study using programmed instruction, Brinkmann (1966) investigated whether or not a self-instructional program on spatial relations enhanced eighth grade students' spatial visualization ability. Having been divided into control and experimental groups, all students were administered a spatial visualization test. However, only the experimental group received instruction via the self-instructional program. A comparison of the pretest-posttest mean differences indicated the experimental group performed significantly better than the control group. The experimental group demonstrated generally constant gains. Also, on the post-test measure, this group revealed no significant gender differences. The author concluded females did not differ from males with respect to spatial ability when provided with appropriate spatial instruction.

Specific Course-Work

Researchers have examined the possibility that specific courses, namely informal geometry or training in drawing, would enhance spatial ability (Battista, Wheatley, and Talsma, 1982; Stringer, 1975). Results of these studies will be examined next.

Battista, Wheatley, and Talsma (1982) investigated whether or not a course on informal geometry taught to preservice elementary teachers enhanced their spatial ability. The researchers administered a paper and pencil spatial visualization test to the students both at the start and end of the semester during which time they were enrolled in the course. Designed specifically to enhance spatial visualization skill, this informal geometry course primarily used hands-on activities and manipulative aids. Since the students scored significantly higher on the post-test than on the pre-test, Battista, et al. (1982) concluded that the type of activities used in the course may have improved spatial visualization ability.

Using drawing training, Stringer (1975) examined improvement of spatial ability in 1st-year architecture students. Fifty-one students were randomly separated into two groups. While one group received a training course in drawing, the other group completed a typical 1st-year architecture class. All students in the sample took a spatial ability pre-test and a battery of five spatial ability tests 6 weeks after completing the courses. A comparison of the mean post-test scores revealed that on one of the five tests, the group that had received the drawing training scored significantly higher than the other group. The other four tests did not indicate significant differences between the two groups. Stringer (1975) suggested "the contribution of the drawing training specifically to the improvement in spatial visualization is indeterminable." These results appeared to agree with previous indications that the specificity of the test and the training task affected spatial ability improvement.

Spatial Visualization and Its Relation to Mathematics Achievement, Problem Solving, and Verbal Ability

The review of the related literature concerning spatial visualization and its relationship to other cognitive abilities will be presented with regards to the following three characteristics: mathematics achievement, verbal ability, and problem solving skills. The relationships between spatial visualization and each of mathematics achievement and verbal ability will be addressed first.

Mathematics Achievement and Verbal Ability

Since most of the studies in this review that have examined the relationship between verbal ability and spatial ability have also investigated the relationship between mathematics achievement and spatial ability, these two areas will be presented together in the following section (Aiken, 1971; Conner & Serbin, 1985; Fennema & Sherman, 1978; Pearson & Ferguson, 1989). Those studies that did not include verbal ability will be reviewed following the previously mentioned studies (Brown & Wheatley, 1989; Guay & McDaniel, 1977; Middaugh, 1980; Wheatley, Brown, & Solano, 1994).

In an analysis of the research on intellectual variables and mathematics achievement, Aiken (1971) found a relationship between spatial ability and mathematics achievement. However, verbal ability was considered important to both spatial ability and mathematics achievement. Aiken noted that many times geometry problems appeared to be spatial, yet were actually solved using verbal strategies instead.

In a study that examined sex-related differences in mathematics achievement, spatial visualization, and other factors, Fennema and Sherman (1977) reported similarly high correlations between mathematics achievement and spatial visualization and between mathematics achievement and verbal ability. They found mathematics achievement, as measured by a standardized mathematics test, and spatial visualization to have a correlation of .45 for females and .51 for males, all of high school age. In a subsequent study focusing on the middle school level, Fennema and Sherman (1978) found correlations between various mathematical variables and spatial visualization that ranged from .51 to .60, with no gender differences in the correlations. These mathematical variables included measures of mathematics achievement, problem solving, attitude toward mathematics, confidence in learning mathematics and perceptions of mathematics. The authors concluded that an important relationship between spatial visualization and mathematics achievement existed for males and females alike.

Conner and Serbin (1985) compared scores on tests of spatial ability, verbal ability, and mathematics achievement, along with various standardized scores and school grades of 7^{th} and 10^{th} grade students to determine the relationship, if any, between these three abilities. Results of this analysis revealed that males tended to perform better than females on mathematics measures, while females tended to outperform males on verbal measures. Additionally, males demonstrated a stronger relationship between spatial ability and mathematics achievement than females. For females only, the verbal ability test was a good indicator of mathematical ability. Results suggested verbal ability may have played a more important role than spatial ability in mathematics achievement for girls. In a subsequent study, Conner and Serbin (1985) tested 7^{th} and 10^{th} graders using a mathematics achievement test, six tests of spatial ability and a verbal ability test. Both grade levels generated positive and statistically significant correlations between four of the spatial measures and mathematics achievement. Verbal ability positively correlated with mathematical ability reaching statistical significance. Conner and Serbin (1985) concluded a usefulness of spatial visualization and spatial orientation in predicting mathematics achievement.

Researching the relationship between spatial ability and both mathematics and English achievement, Pearson and Ferguson (1989) obtained data from undergraduate students through the results of three tests of spatial ability and American College Test (ACT) mathematics and English scores. Analysis of these scores showed that spatial ability was significantly related to both mathematics and English achievement for males and females alike, high achievement being associated with stronger spatial ability. Pearson and Ferguson (1989) also found that for males, the single significant predictor of mathematics achievement was spatial ability; whereas for females, both English achievement and spatial ability were significant predictors of mathematics achievement. The study suggested that males achieved in mathematics and spatial ability only, without achieving in English. However, females' abilities did not demonstrate distinct patterns.

Using elementary school students, Guay and McDaniel (1977) researched the relationship between mathematics achievement and spatial ability without having considered verbal ability. They administered four spatial ability tests to students in grades 2 through 7. Based on previous results of the Iowa Tests of Basic Skills, students in each grade level were determined to be high or low mathematics achievers. Analysis of the data indicated the high mathematics achievers scored significantly better on the four spatial ability tests than the low mathematics achievers. This seemed to have suggested that at the elementary school level, those with high mathematics achievement also had greater spatial ability than those with low mathematics achievement.

Using a paper and pencil spatial ability test, Brown and Wheatley (1989) examined the differences in mathematical achievement of fifth grade students with low and high spatial ability. From the results of the spatial ability test, they selected six females to be interviewed while solving mathematical problems in order to assess their mathematical ability. Three of the six females possessed low spatial ability while the others were considered to have high spatial ability skills. The mathematical problems these students were asked to work involved conservation of area, linear measure, concept of one-fourth, proportional reasoning, multiplicative reasoning, and solving non-routine problems. After interview data was analyzed, Brown and Wheatley (1989) noticed the students low in spatial ability used trial and error more often to solve the mathematical problems than did those high in spatial ability. On the contrary, students high in spatial skills solved all of the problems systematically. The authors also observed students low in spatial ability counted objects one at a time. However when faced with the same tasks, students high in spatial ability counted by twos or threes. Brown and Wheatley (1989) concluded the spatial ability test was a good predictor of mathematical knowledge. One interesting finding included the fact that one of the students high in spatial ability actually had poor mathematics grades in school, but displayed a strong understanding of the mathematical ideas presented to her in the mathematical problems. She had quite creative solutions to the problems. The study suggested that spatial ability may be strongly related to mathematical understanding, but may not necessarily be a good predictor of success in a mathematics class.

In a follow-up study, Wheatley, Brown, and Solano (1994) examined the long term relationship between spatial ability and mathematical knowledge. The 10^{th} graders used in this research were the same students who were in the 5^{th} grade in the previous study. The researchers administered a paper and pencil spatial visualization test to the students and also interviewed five students while solving mathematical problems to assess these students' mathematical ability. Results indicated a moderate positive correlation between the students' spatial ability in the 5^{th} and 10^{th} grades. Additionally, the five students interviewed appeared to use spatial solution strategies when solving the mathematical problems.

Middaugh (1980) examined the relationship between spatial ability and mathematics achievement of eighth grade students using a battery of six spatial ability tests. A measure of mathematics achievement was obtained through the use of standardized test scores and mathematics grades in school. Results indicated a significant positive relationship existed between spatial ability and mathematics achievement. Also, Middaugh (1980) did not find gender differences with respect to this relationship. Thus, spatial ability was again considered a good predictor of mathematics achievement.

In a review of the literature on spatial ability, mathematics achievement, and visual imagery, Lean and Clements (1981) remarked that although many studies have found significant positive correlations between spatial ability and mathematics achievement, these correlations did not imply that "either one of the variables has priority over the other in the learning process, or that any causal relationship can be legitimately inferred." They tested 116 beginning engineering students at the University of

Technology, Lae, Papua, New Guinea who represented three distinct areas of the country and cultural environments. Students in the study took a battery of five spatial ability tests and a mathematical processing word problem test. The results indicated that spatial ability and knowledge of spatial conventions did not have a substantial influence on the mathematical performance of these engineering students. Additionally, students who preferred to solve the mathematical word problems by verbal-logical means tended to outperform those students who used more visual-spatial means. Finally, Lean and Clements (1981) concluded these results seemed to contradict the findings of other studies which suggested the use of visual-spatial processes appeared advantageous when solving mathematical word problems.

Problem Solving Ability

In this section of the review of literature, the relationship between spatial ability and mathematical problem solving performance will be addressed (Fennema & Tartre, 1985; Hill & Obenauf, 1979; Landau, 1984; McKee, 1983; Moses, 1978; Presmeg, 1986; Tillotson, 1985). Additionally, a study which has included other cognitive aspects, namely verbal ability and proportional reasoning skills, will be reviewed in this section (Brendzel, 1981).

In an investigation of the relationship between spatial ability and mathematical problem solving, Moses (1978) gave fifth grade students a battery of five spatial ability tests and one problem-solving test both prior to and after instruction on geometric perceptual techniques. The test determined a problem-solving score based on the number of correct responses and a visuality score based on the amount of visual processing used in solving the problems on the test. Moses (1978) randomly placed students by class in either the control group, receiving no instruction, or in the experimental group, receiving instruction. Two classes of fifth graders made up each group. Results indicated that spatial ability was significantly correlated with problem-solving performance and with visuality. However, a significant correlation was not found between problem solving performance and visuality. Moses (1978) concluded spatial ability served as a reliable predictor of problem solving performance. Also, she noted even though students with strong spatial ability usually performed well on tests of problem solving skill, their written solutions did not always indicate a highly spatial solution strategy.

Focusing on the effect of spatial visualization instruction on spatial abilities and mathematical problem solving, Tillotson (1985) found that spatial visualization ability was a good predictor of problem solving performance. The researcher administered three tests of spatial ability and a problem-solving test to 102 sixth grade students before and after an 8-week period of instruction on spatial visualization. Correlational analyses indicated a strong correlation between spatial ability and problem solving performance.

Fennema and Tartre (1985) examined the relationship between spatial ability, problem solving performance, and verbal ability. They administered a battery of tests to students in grades 6, 7, and 8 to measure spatial ability, mathematical problem solving ability and verbal ability. They also interviewed students solving mathematical word problems to investigate the extent of their use of verbal strategies, spatial problem solving strategies or both. Results indicated that girls tended to provide more verbal information when solving problems. Also, in general, students high in spatial visualization ability solved no more mathematics problems than those low in spatial visualization ability. This study suggested "although students who are discrepant in spatial visualization and verbal skills differ in the processes they use to solve problems, they do not differ in their ability to solve problems."

To study the relationship between spatial ability and mathematical problem solving performance, Landau (1984) gave middle school students tests of spatial ability and problem solving. The results indicated "there is a strong correlation between spatial ability and problem solving performance." McKee (1983) gave 9th and 10th grade students similar tests and observed comparable results. After also gathering data from school grades in mathematics classes, McKee (1983) further found significant correlations between problem solving ability and each of mathematics achievement and spatial visualization. He did not observe a significant correlation between problem solving ability and spatial orientation.

Presmeg (1986) also examined students with respect to visual and non-visual modes of problem solving. Based on interview data, she classified students as visualizers or non-visualizers. Visualizers were students who tended to use visual methods when solving mathematical problems, which could be solved by either visual or non-visual methods. Non-visualizers were students who tended not to use visual methods when solving such problems. "A visual method of solution is one which involves visual imagery, with or without a diagram, as an essential part of the method of solution, even if reasoning or algebraic methods are also employed (Presmeg, 1986)." Conversely, a non-visual method used no visual imagery, essentially. Presmeg noted that visual problem solving strategies took longer than non-visual solution strategies. Visualizers tended to forget mathematical terminology, but instead drew diagrams to represent the terminology and had trouble communicating mathematical concepts. Presmeg (1986) also found when teachers singled out students having "outstanding" mathematical achievements, these students were usually classified as non-visualizers. She proposed that this may have been due to teachers emphasizing non-visual methods of solution in many school classrooms. Furthermore, when visual methods occurred, teachers generally did not value these solutions. Non-visual teaching had the effect of leading visualizers to think that success in mathematics depended upon memorization of rules and formulae.

Hill and Obenauf (1979) researched spatial visualization and problem solving in freshman students majoring in elementary teacher education. From the randomly chosen sample of 88 students, the researchers placed half into a control group and half into an experimental group. The experimental group received instruction on spatial visualization by means of activity-based assignments. All subjects were also enrolled in a laboratory-based initial science course for elementary teacher education majors. Hill and Obernauf (1979) gave all students in this study a spatial visualization test and a mathematics/ science oriented problem solving test before and after instruction. The analysis of the obtained data demonstrated that instruction effectively improved the problem solving performance of these students. The students in the experimental group outperformed those in the control group on the problem solving post-test. No differences in spatial visualization ability occurred. Thus, although the instruction did not seem to enhance the spatial visualization ability of the students in the experimental group, their problem-solving performance was strengthened.

Hypothesizing that students who had strong spatial skills excelled in proportional reasoning problems, Brendzel (1981) investigated the relationship between these two abilities. The researcher tested 9th and 11th grade students on spatial visualization, proportional reasoning and verbal ability. The resulting data yielded a significant positive relationship between spatial ability and proportional reasoning. Brendzel (1981) concluded spatial ability was more strongly related to proportional reasoning than to field independence-dependence, gender or verbal ability.

Spatial Visualization in Architecture, Engineering, and Mathematics Education

Many researchers in non-"education" fields have recognized a proposed importance of spatial ability as it relates to performance in those respective professions. According to Bishop (1978), professionals in art, architecture, drafting, engineering, and science have found the necessity for a strong spatial visualization ability. Others have reported that successful undergraduates in science, mathematics and art possessed significantly higher spatial visualization ability, as measured by paper and pencil tests, than did undergraduates in other majors (Siemankowski and MacKnight, 1971). Harris (1981) claimed that data from the United States Employment Service indicated most scientific and technical occupations, like drafting, architecture, engineering, and mathematics, required persons demonstrating a spatial ability at or above the 90th percentile. This section of the review will focus on the related literature with regards to spatial visualization in architecture and engineering, as well as in mathematics education.

Architecture

Studies have been conducted with regards to spatial ability and architecture (Karlins, Schuerhoff, & Kaplan, 1969; Stringer, 1975). Having found that spatial ability was positively related to successful completion of architectural tasks, these studies will be reviewed in this section.

Karlins, Schuerhoff, and Kaplan (1969) studied the relationship between architectural creativity and spatial abilities. Architectural creativity was thought of as the degree of creativity a graduating architecture student possessed as determined by professors judging these students' architectural projects. Although these authors never formally defined "architectural creativity", the ratings given to the subjects in the study for this characteristic had an inter-rater reliability of .88. Thus, the professors had some underlying understanding of what this characteristic denoted even though the definition was never stated. In addition to being rated on architectural creativity, students participating in this study took tests of spatial orientation and spatial visualization. Results indicated that spatial ability was strongly related to architectural creativity, a characteristic important to the success of professional architects. Thus, Karlins et al. (1969) concluded that spatial ability seemed important to creativity in architecture.

Stringer (1975) stated in both "engineering and architectural education, formal drawing skills have traditionally been taught, both as a means of visual communication and in order to improve spatial visualization skills." He concluded that this was due to the apparent need of spatial visualization skills by architects, engineers and other designers.

Engineering

With respect to engineering, educators in this field emphasized the importance of spatial ability for success in this career (Ferrini-Mundy, 1987). In accordance with this, Estes (1942) suggested that success in engineering and other mechanical occupations depended upon the level of spatial visualization one possesses. Engineers have provided additional documentation stating the significance of visualizing and sketching in their work (Blade, 1949; Blade & Watson, 1955; Miller & Bertoline, 1991; Poole & Stanley, 1972). The results of this research will be summarized next.

Blade (1949) stated "engineers especially need to visualize because they must solve problems regarding things which they do not have actually before them or in their hands." But beyond this, engineers must have the ability to draw pictures of objects in space and mentally manipulate them to create subsequent drawings. Blade concluded that engineering teachers held the responsibility to instruct prospective engineers on how to solve problems using spatial visualization skills. Poole and Stanley (1972) suggested that instruction focus on spatial visualization and manipulation of figural material during the first year of engineering study.

Blade and Watson (1955) found that results of a spatial visualization test given after one year of engineering study served as a better predictor of engineering success than a pre-freshman visualization test. This was suggested because after one year of engineering study, all students then had similar background experiences. Whereas, prior to one year of engineering study, some students may have been lacking in spatial visualization experiences.

In a more recent study, Miller and Bertoline (1991) contended that spatial visualization and its development were considered utmost important in careers such as engineering, mathematics, and science. They also advocated that spatial visualization and perception play a major role within any university engineering program. Miller and Bertoline (1991) ended with a call for research on the need of spatial visualization in engineering and other technical fields and suggested specific evaluation materials be developed and validated to test prospective engineers on spatial visualization ability.

Mathematics Education

Many mathematics educators have investigated the role of spatial ability in the mathematics curriculum and the affects of visual vs. non-visual teaching styles (Battista, 1994; Ben-Chaim, Lappan, & Houang, 1989; Bishop, 1989; Bishop, 1980; Hershkowitz, 1989; Moses, 1982; Presmeg, 1986; Wheatley, Frankland, & Kraft, 1978). These educators have noted the importance of the development of spatial skills in students of all ages. In this final section of the review of literature, the findings of these researchers will be examined.

Battista (1994) claimed that mathematicians and mathematics educators have suggested that spatial visualization ability played a vital part in mathematical thinking. Furthermore, participation in spatial activities appeared to enhance students' mathematical thinking. Additionally, Battista stated that spatial thinking seemed connected to the conceptual learning of mathematics. Hershkowitz (1989) contended that, in general, mathematics educators and researchers have agreed spatial visualization was considered important because it helped to develop "a global and intuitive view and understanding in many areas of mathematics."

In regards to developing the students' problem solving skills, Moses (1982) commented that "the overemphasis on computation and drill in the elementary school mathematics curriculum appears to be taking its toll on the problem-solving performance of students." She advocated instead of teaching problem-solving by using conventional approaches, an alternative approach might have served students better. Conventional approaches referred to the organizing of instruction by content area, by strategy or by presenting many varied problems. Using the alternative approach, teachers stressed the creation of mental images and the translation of these images to drawings. Once students visualized these images and translations, they analyzed them in terms of the question stated in the problem. Wheatley, Frankland, Mitchell, and Kraft (1978) reiterated this idea of teaching which used visual methods by noting many times students with strong spatial skills still performed poorly in mathematics. They concluded that teaching incorporating spatial visualization capitalized on these students' strengths resulting in the promotion of mathematical success for these students where other methods have failed. The study appeared to suggest that if a student relied more on his/her spatial ability to solve problems, then he/she may be more successful in a curriculum that also provided spatial presentations of the content and multi-sensory learning.

Reporting on the role of spatial visualization in the middle school mathematics curriculum, Ben-Chaim, Lappan, and Houang (1989) indicated that teaching strategies using visualization were needed to develop the spatial visualization skills of middle school students. Certain higher-level mathematics tasks like visualizing cross sections of solids, volumes of revolution, and point projections of figures became very difficult for students who had no related concrete experiences early on during their middle school years. Thus, experiences with visualization in the middle school had become vital for success in advanced mathematics courses including Euclidean and non-Euclidean geometries and calculus. Finally, Ben-Chaim, et al. (1989) recommended "spatial visualization topics and activities be explicitly taught throughout the mathematics curriculum, particularly in the middle grades."

In his review of the literature on visualization in mathematics education, Bishop (1989) stated the whole idea of "visual aids" was based on the understanding that such aids provided an effective introduction for students to the intricate abstractions found in the study of mathematics. Manipulative materials helped students create visual images and thus promoted the process of visualization. Bishop (1989) advocated for research that examined the teachers' spatial visualization skills and the influence such ability had on both the instructional methods used and the development of the students' spatial visualization ability. Bishop (1980) concluded the area of spatial ability represented "a rich field for mathematics educators to study."

Presmeg (1986) examined the teaching styles of teachers classified as visualizers, non-visualizers, or teachers in the middle of the two extremes. She noted teachers classified as visualizers made more connections between different strands of the mathematics curriculum while instructing. These teachers also made more connections to other experiences held by their students. These other experiences included happenings in different subject areas and most importantly events in the "real world". Visual teachers used diverse teaching methods, particularly visual ones. Teachers who taught non-visually primarily used a lecture style of teaching and gave more formal and rigorous mathematical explanations. Teachers in the middle group used some lecture and some other styles of teaching similar to those used by the visualizers. Presmeg (1986) concluded that teachers in the middle group were deemed most effective as evidenced by their students' achievement. Students in classes of teachers in the middle group not only received instruction that enhanced their own visualization, but they also received instruction regarding the abstractions and generalizations found in mathematics.

In summary, the table that follows (see Table 1) indicates the occupations that require spatial visualization according to the various researchers shown. Since the majority of these researchers agreed on the need for spatial visualization skills in architecture, engineering, and mathematics, the research in this study will focus on undergraduates majoring in these respective degree programs.

Table 1

<u>Occupations Involving The Use of Spatial Visualization</u>

	Architecture	Art	Design	Drafting	Engineering	Mathematics	Mathematics Education	Science (Including Physics)
Battista (1994)							•	
Ben-Chaim, Lappan and Houang (1986)		•			•	•	•	•
Bishop (1978, 1980)	•	•		•	•	•	•	•
Blade and Watson (1955)					•			
Eisenburg and McGinty (1977)	•				•			
Ferrini – Mundy (1987)					•			
Ghiselli (1966)	•				•	•		
Harris (1981)	•			•	•	•	•	•
Karlins, Schuerhoff, and Kaplan (1969)	•							
Martin (1968)							•	
Miller and Bertoline (1991)			•		•			
O'Brien (1991)	•				•	•		
Rhoades (1981)	•		•		•	•		•
Stringer (1975)	•		•		•			

III. METHODOLOGY

This study utilized a background questionnaire and two paper and pencil visualization tests to determine the level of spatial visualization, as well as the relationship between spatial visualization and other background variables, of undergraduate students majoring in architecture, mathematics, mathematics education and mechanical engineering. The research design was correlational employing a one-way analysis of variance (ANOVA) and also utilized a causal model with path analysis to analyze the data obtained. In this chapter, the sample will be defined followed by the procedures used for collecting the data. The three data collecting instruments will be described with respect to content, reliability and validity where appropriate, scoring, and the variables that were defined by each. Finally, an explanation of how the data were analyzed in order to address each proposed hypothesis will be presented.

Sample

The sample consisted of 117 volunteer Auburn University undergraduate students majoring in architecture, mathematics (pure and applied), mathematics education, and mechanical engineering. All students were presently either in their junior or senior years of study during the summer or fall of 1999. Subgroups within this sample consisted of 50 architecture students, 19 mathematics students, 24 mathematics education students, and 24 mechanical engineering students. Within the total sample, 73 students were male while 44 were female. Of the 73 males in this study, 34 were architecture majors, 8 were mathematics majors, 9 were mathematics education majors, and 22 were mechanical engineering majors. Of the 44 females who participated, 16 were architecture majors, 11 were mathematics majors, 15 were mathematics education majors, and 2 were mechanical engineering majors. Finally, all treatment of the students in this sample was in accord with the ethical standards of the American Psychological Association and Auburn University's Human Rights Board (see Appendix A for the Human Rights Board approval letter).

Procedures for Data Collection

Three sources of data were used to investigate the influences on and differences in spatial visualization ability between the architecture, mathematics, mathematics education, and mechanical engineering majors as groups. These sources of data included paper and pencil tests of both spatial visualization (see Appendix B) and mathematical processing visualization (see Appendix C) along with a personal background questionnaire (see Appendix D). Data obtained through the Spatial Visualization Test (Middle Grades Mathematics Project, 1983) was used to measure each student's level of spatial visualization ability. The Mathematical Processing Instrument (Presmeg, 1985) was used to categorize each student as a visualizer or non-visualizer. The personal background questionnaire was used to determine which variables were significantly related to spatial visualization ability for the entire sample. These background variables included gender, ethnicity, handedness, family income, parents' occupations, musical training, hobbies, favorite high school mathematics course, and spatial childhood experiences.

At the end of the Spring 1999 quarter and at the start of the Summer 1999 quarter, the researcher contacted professors who taught junior or senior level classes in each of the four majors that were studied. Permission to ask for volunteers from their classes was granted and dates and times of when the researcher could meet with the classes were agreed upon. Participation by each professor and his/her students was voluntary. In some cases, undergraduates majoring in mathematics or mathematics education were not enrolled in a course which consisted of only majors in mathematics or mathematics education. For those students, participation in this study was requested through a brief e-mail message (see Appendix E for the actual e-mail message). Basically, this e-mail message asked these students to meet in a certain classroom at a specific time for participation in the study.

When the researcher arrived at each class, students were first given a brief explanation of the research being conducted (see Appendix F for the script of this explanation). The students were also given an information letter, which restated this explanation (see Appendix G for the actual information letter). By remaining in the classroom after this introduction, the students agreed to participate in the study. The researcher then administered the questionnaire and tests during one block of time to students enrolled in classes specific to each respective major during each of the Summer and Fall quarters of 1999.

When administering the two tests, the researcher read aloud the directions on the front page of each instrument to the students (see Appendices B and C for these directions). The Mathematical Processing Instrument (Presmeg, 1985) was administered first followed by the Spatial Visualization Test (Middle Grades Mathematics Project, 1983). The researcher chose to administer the instruments in this order to avoid any carry-over effects that the Spatial Visualization Test may have had on the Mathematical Processing Instrument. Since students were free to solve the problems in the Mathematical Processing Instrument as they preferred, no carry-over effects from this instrument to the Spatial Visualization Test were expected. To complete the questionnaire, students were instructed to create a pseudonym of their choice and then to complete the rest of the questionnaire, which was self-explanatory (see Appendix D). All student responses were anonymous; tests and questionnaires were coded using the student created pseudonyms in order to match their responses on the three sources of data. Data from these instruments were quantitatively analyzed after the testing was completed using SPSS software (Norusis, 1999).

Instruments

Quantitative methods were used to determine the level of spatial visualization ability of students majoring in architecture, mathematics, mathematics education and mechanical engineering, to determine if they preferred to use visual solution strategies when solving mathematics problems; and to determine the relationship, if any, between spatial visualization ability and various background variables. To measure the students' level of spatial visualization ability, a test constructed by the Middle Grades Mathematics Project (1983) was used. To determine what type of solution strategy the students preferred, Presmeg's (1985) Mathematical Processing Instrument was used. Finally, to obtain background data on each student, an information sheet created by the researcher was administered to them prior to their taking the two tests.

The Spatial Visualization Test (Middle Grades Mathematics Project, 1983) was used to measure spatial visualization ability (see Appendix B). This instrument was previously used by Ben-Chaim, Lappan, and Huoang (1986) to test students in grades 8 through 12 for spatial visualization. When this instrument was administered with the Differential Aptitude Space Relations Test, the results of the two measures had a correlation of .66, which provided evidence for the validity of this test. Ben-Chaim, Lappan, and Huoang (1986) had also used the test with university calculus students and with preservice elementary teachers to determine if there was a ceiling effect on the instrument. No ceiling effect was found. Moreover, one group of ninth grade students who were tested had a higher mean than this group of preservice teachers. Ben-Chaim, Lappan, and Huoang (1986) explain that "while there seems to be a developmental trend in spatial visualization skills, this trend is not solely determined by age. One's mathematical age also seems to be a factor." Reiterating this notion of mathematical age, the van Hieles contend that progress through various levels of geometric thought is more dependent on the content and instruction received than on age or maturity (Crowley, 1987). With respect to reliability, Cronbach's reliability coefficients have been found in the range of .72 to .86 for various groups of students taking the test. Thus, this test was found to be an appropriate instrument for this study as a measure of spatial visualization. The test consists of 32 multiple-choice items, which usually takes 20 to 30 minutes to complete. Due to the nature of this sample, students were given 15 minutes to complete this test. Each item involves an object made up of small unit cubes seen from a certain perspective. The student must determine which one of five other objects is the same as the one shown, but from another view. To determine each participant's score on this instrument, the researcher counted the number of correct answers out of 32 possible and converted this to a percentage. Thus, one of the dependent variables for this study, spatial visualization score, defined by the results of this instrument, was continuous on a scale of 1 to 100.

Presmeg's (1985) Mathematical Processing Instrument was used to measure preference for visual solution strategies when solving word problems (see Appendix C). This instrument was designed to measure the solution strategy preference of 9th through 12th graders, university students, and mathematics teachers. The construct validity and reliability of the instrument were tested in Cambridge, England, and in Durban, Natal, and judged to be satisfactory. The test consists of 24 word problems, each of which can be solved by either visual or non-visual methods. After completing the test, students are given a set of solutions to each problem and are to indicate which of these most accurately resembles their own. Based on this, students can be classified as visualizers, non-visualizers, or "no preference." Because of the highly selective sample used in this study and because of time constraints, the researcher administered a shorter version of the original test; the modified version consisted of every other problem for a total of 12 problems. Students were given 30 minutes to complete both parts of this shortened test. To determine each participant's visualizer score, the researcher counted the number of solutions or solution attempts that were considered visual, by the author of the instrument, out of 12 solutions possible and again converted this to a percentage. This percentage was designated as the participant's visualizer score and was considered in this study as another dependent variable on a continuous scale of 1 to 100.

The student background information sheet contained both multiple choice and free-response type questions (see Appendix D). Students were instructed to choose only one response for each multiple choice type question. These questions involved gender, college major, annual family income, ethnicity and handedness. The free-response type questions were concerned with past and present hobbies, parents' occupations, musical training, favorite high school mathematics course, and childhood toys and activities. Students were instructed to be as specific as possible in answering these questions.

Data Analysis

Four groups of volunteer undergraduate students majoring in architecture, mathematics, mathematics education, and mechanical engineering participated in this study. Each group was administered the background information sheet, the Mathematical Processing Instrument (Presmeg, 1985) and the Spatial Visualization Test (Middle

Grades Mathematics Project, 1983) consecutively within one testing session. The researcher personally administered all three data gathering instruments.

To address the first hypothesis, a one-way ANOVA was used. Hypothesis 1 stated that there will be no significant differences in the level of spatial visualization between undergraduates majoring in architecture, mathematics, mathematics education, or mechanical engineering. After determining the results of the ANOVA's omnibus *F* test, post hoc comparisons were made to determine specifically which majors differed from each other significantly. Following the ANOVA, the remaining five hypotheses were tested using path analysis, an application of multiple regression analysis in conjunction with causal theory. These hypotheses were stated as follows.

Hypothesis 2: Spatial visualization score will be significantly positively correlated with favorite mathematics course, musical experience, childhood spatial experiences, and spatial hobbies.

Hypothesis 3: Favorite mathematics course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

Hypothesis 4: Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Hypothesis 5: Musical experiences will be significantly positively correlated with childhood spatial experiences.

Hypothesis 6: Childhood spatial experiences will be significantly positively correlated with gender, handedness, mom's job, dad's job, and family income.

Additionally, the results of the path analysis were used to assess the overall fit of the proposed causal model (see Figure 2 for the path analysis model).

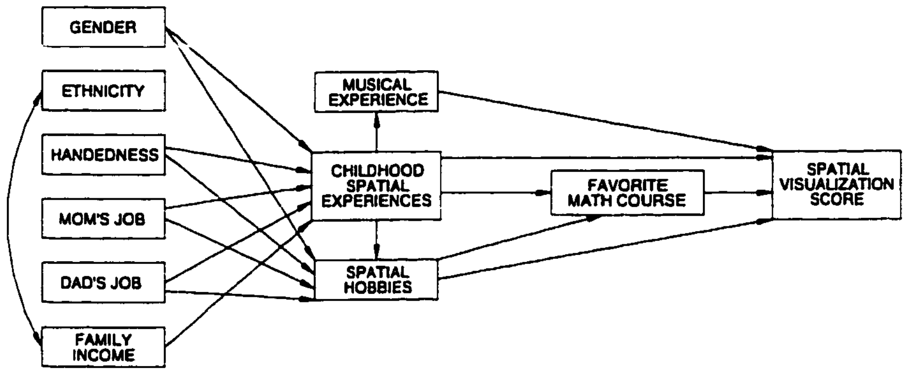


Figure 2. Path Analysis Causal Model

IV. RESULTS

The purposes of this study were: (1) to determine differences, if any, in the level of spatial visualization ability between students majoring in architecture, mathematics, mathematics education, and mechanical engineering, (2) to hypothesize reasons for individual differences in spatial visualization that may exist based on the background information of these students, and (3) to develop and test a causal model of the development of spatial visualization based on the findings of past research. Results of the statistical analyses, used to provide evidence for rejecting or accepting each of the proposed hypotheses, are presented in this chapter. The six proposed hypotheses are stated below.

Hypothesis 1: There will be no significant differences in the level of spatial visualization between undergraduates majoring in architecture, mathematics, mathematics education or mechanical engineering.

Hypothesis 2: Spatial visualization score will be significantly positively correlated with favorite mathematics course and with the spatial experiences variables (musical experience, childhood spatial experiences, and spatial hobbies).

Hypothesis 3: Favorite mathematics course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

Hypothesis 4: Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Hypothesis 5: Musical experience will be significantly positively correlated with childhood spatial experiences.

Hypothesis 6: Childhood spatial experiences will be significantly positively correlated with the demographic variables (gender, handedness, mom's job, dad's job, and family income).

The chapter begins with the frequency information for each of the background variables. Following this, descriptive statistics by academic major for each of the two continuous variables, the measures of visualization, are presented. Then, the relationship between the two continuous variables is discussed with respect to the analyses that were to follow. Fourth, results of the one-way analysis of variance (ANOVA) are presented. The findings of the path analysis, used to assess the fit of the causal model, will then be described. Finally, these results are summarized in terms of the six proposed hypotheses.

Findings

Frequencies

The sample of 117 undergraduate students consisted of 73 males (62%) and 44 females (38%). With regards to academic major, architecture majors comprised 43% of the sample, mathematics majors comprised 16%, mathematics education majors comprised 20.5%, and mechanical engineering majors made up the remaining 20.5%. Of all students who participated in this study, 9% represented minority groups (African-

American, Hispanic, or other), while the remaining 92% represented non-minority groups (Caucasian or Asian). Left-handedness was reported by 15% of the sample; the other 85% indicated a right-handed preference. In describing the mothers' occupation, 94% of the students depicted mothers whose occupations did not appear to require spatial ability; however, 6% of the mothers did have occupations appearing to require spatial ability. When the fathers' occupations were examined, 35% of the fathers worked in occupations that appeared to require spatial ability while 65% did not work in occupations requiring spatial ability. The composition of the sample with respect to family income was 8% less than $25,000; 20% between $25,000 and $50,000; 21% between $50,000 and $75,000; and 47% more than $75,000; 4% did not respond to this item. When reporting on their childhood experiences, 33% of the students indicated that their favorite toy was a spatial toy, 58% of the students mentioned that they had access to a spatial toy and described that toy, and 9% of the students did not mention any spatial toys. The composition of the sample with reference to musical experiences was 28% had no musical experience, 21% had some musical experiences (scoring a 1 or a 2), 23% had moderate musical experiences (scoring a 3), and 28% had extreme musical experiences (scoring a 4 or a 5). In listing their hobbies, 83% of the students declared a hobby that would promote the development of spatial visualization while 17% of the students did not. A spatial mathematics course, (namely, geometry, trigonometry, or calculus) was the favorite mathematics course of 67% of the students, while other mathematics courses (algebra, business mathematics, or advanced mathematics) were named as the favorite for 33% of the students.

Descriptive Statistics for Dependent Variables

The mean scores and standard deviations by MAJOR for the two dependent measures, spatial visualization and visuality, are provided in Table 2 and Table 3, respectively. On the Spatial Visualization Test (Middle Grades Mathematics Project, 1983), the architecture majors scored the highest, then the mechanical engineers, followed by the mathematics education majors. The mathematics majors scored the lowest. In regards to the Mathematical Processing Instrument (Presmeg, 1985) scores, none of the majors as groups preferred visual methods of problem solving as indicated by all four means being at or below 50% for the visuality score.

Table 2

Means and Standard Deviations for Spatial Visualization Score

Academic Major	Mean	Standard Deviation
Architecture	63.9	16.8
Mathematics	44.2	18.1
Mathematics Education	58.9	13.4
Mechanical Engineering	61.8	18.7

Table 3

Means and Standard Deviations for Visuality Score

Academic Major	Mean	Standard Deviation
Architecture	47.8	16.8
Mathematics	38.7	15.1
Mathematics Education	50.1	18.8
Mechanical Engineering	43.7	18.6

Relationship Between Dependent Measures

The two dependent measures were found to have a Pearson correlation of .25 which was statistically significant, $p = .008$. However, since these two measures were sharing only 6% of the variance, this was interpreted as not being practically significant. Because of this lack of practical significance and the finding that none of the majors preferred visual modes of problem solving, only the Spatial Visualization Test score was used in the one-way ANOVA.

Comparison of Spatial Visualization Means

A one-way ANOVA was conducted to determine differences in the spatial visualization scores by academic major. The dependent variable used in the ANOVA was SPVIS, spatial visualization score, and the independent variable was MAJOR, academic major. A Levene's Test of Equality of Error Variances was conducted to determine if the assumption of equal variances was met. An *F*-value for Levene's test of 1.03 was not significant at the .05 alpha level, p = .39. Thus, the ANOVA proceeded with equal variances assumed. Table 4 reports the degrees of freedom, mean squares, the *F*-value, and the significance level for the omnibus test. The observed power was found to be .97. Because of this power, if a difference between the groups on spatial visualization score existed, it would be detected. Also, using Eta Squared as a measure of effect size, the effect size was large having a value of .91.

Table 4

Analysis of Variance for Spatial Visualization Score

Source	*df*	Mean Square	*F*	Significance
Major	3	1848.05	6.54	.000
Error	113	282.39		

Since the observed *F*-value was statistically significant, Scheffe post hoc tests were conducted to determine which of the four majors differed significantly from each other. Table 5 presents the mean differences found by these post hoc tests.

Table 5

Mean Differences Between Majors

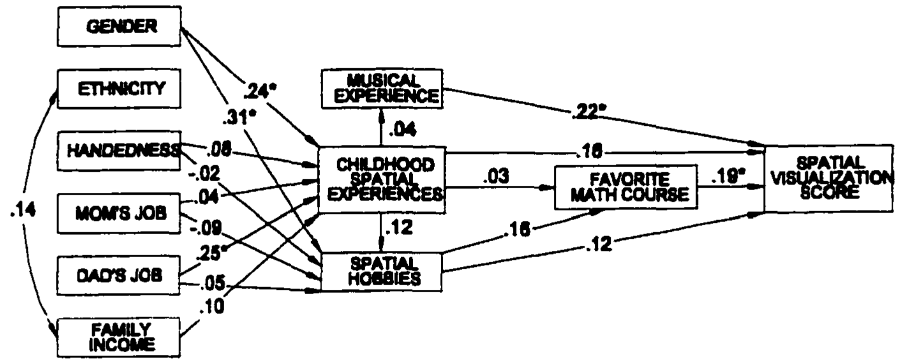
Major	Other Majors	Mean Difference
Architecture	Mathematics	19.69*
	Math. Education	4.93
	Mech. Engineering	2.03
Mathematics	Architecture	-19.69*
	Math. Education	-14.76*
	Mech. Engineering	-17.66*
Math. Education	Architecture	-4.93
	Mathematics	14.76*
	Mech. Engineering	-2.90
Mech. Engineering	Architecture	-2.03
	Mathematics	17.66*
	Math. Education	2.90

Note. * significant at the .05 level.

As seen in the previous table, mathematics majors differed significantly on their spatial visualization score in comparison to the other three majors. No other differences between the majors were found. Additionally, logistic regression was used post hoc to determine if the background variables of the mathematics majors were significantly different than the background variables of the other three majors. No significant differences in the background information were found.

Path Analysis Results

Spatial Visualization Score. The first equation in the structural model (see Figure 3) included the effects of the variables of favorite high school mathematics course, musical experiences, hobbies, and childhood experiences on spatial visualization score. The results of this structural equation yielded a significant squared multiple correlation of .14, $F(4, 112) = 4.48$, $p = .002$. Childhood experiences, $t(116) = 1.80$, $p = .08$, and hobbies, $t(116) = 1.28$, $p = .20$, each failed to achieve a significant correlation with spatial visualization score. However, a high spatial visualization score was significantly related to one's favorite high school mathematics course, $t(116) = 2.15$, $p = .03$, and to one's musical experiences, $t(116) = 2.48$, $p = .01$. Favorite high school mathematics course was coded 1 if the course was geometry, trigonometry, or calculus (courses promoting visualization), all other mathematics courses, including algebra, advanced mathematics or business mathematics, were coded 0.



Note. * significant at the .05 level.

Figure 3. Results of Path Analysis

Favorite High School Mathematics Course. The second structural equation assessed the effects of hobbies and childhood experiences on favorite high school mathematics course. The squared multiple correlation for the structural equation was .03, a non-significant finding, $F(2, 114) = 1.55$, $p = .22$. Thus, hobbies, $t(116) = 1.64$, $p = .10$, and childhood experiences, $t(116) = .29$, $p = .77$, were each not significantly related to one's favorite high school mathematics course.

Musical Experience. The next structural equation examined the effect of childhood experiences on musical experiences. The squared multiple correlation for this structural equation was non-significant, having a value of .001, $F(1, 115) = .14$, $p = .71$. Childhood experience was not significantly related to musical experience, $t(116) = .37$, $p = .71$.

Childhood Experiences. The fourth structural equation assessed the effects of the exogenous variables of gender, handedness, dad's job, mom's job, and family income on childhood experiences. Of the 117 cases in this investigation, 5 did not report a family income, so those cases were omitted from this part of the analysis. The results of this structural equation yielded a significant squared multiple correlation of .16, $F(5, 106) = 4.11$, $p = .002$. The variables that failed to achieve a significant correlation with childhood experiences included handedness, $t(111) = .90$, $p = .37$, mom's job, $t(111) = .48$, $p = .63$, and family income, $t(111) = 1.06$, $p = .30$. However, gender, $t(111) = 2.62$, $p = .01$, and dad's job, $t(111) = 2.78$, $p = .007$, both achieved a statistically significant correlation with childhood experiences. In defining gender, females were coded as 0; males were coded as 1. Fathers having occupations that required spatial visualization skills were coded as 1, while fathers having occupations that did not require spatial visualization skills were coded as 0.

Spatial Hobbies. The fifth equation in the structural model included the effects of the childhood experiences variable and the exogenous variables of gender, handedness, mom's job, and dad's job. The squared multiple correlation for the structural equation was .15, $F(5, 111) = 3.80$, $p = .003$. Only gender, $t(116) = .31$, $p = .001$, achieved a significant correlation with spatial hobbies. Childhood experiences, $t(116) = 1.32$, $p = .19$, handedness, $t(116) = -.16$, $p = .87$, mom's job, $t(116) = -.96$, $p = .34$, and dad's job, $t(116) = .51$, $p = .61$, all failed to achieve a significant correlation with spatial hobbies.

Ethnicity and Family Income. A Pearson correlation was calculated to determine the strength of the relationship between ethnicity and family income. Results of this calculation yielded a non-significant correlation of .14, $p = .16$.

Findings for the Hypotheses

Results for the six proposed hypotheses are summarized as follows.

Hypothesis 1

Statement. There will be no significant differences in the level of spatial visualization between undergraduates majoring in architecture, mathematics, mathematics education or mechanical engineering.

Findings. The first hypothesis was not supported in this inquiry. Mathematics majors scored significantly lower than architecture, mathematics education, and mechanical engineering majors, $F(3,113) = 6.54$, $p < .05$.

Hypothesis 2

Statement. Spatial visualization score will be significantly positively correlated with favorite mathematics course and with the spatial experiences variables (musical experience, childhood spatial experiences, and spatial hobbies).

Findings. The second hypothesis was not supported in this analysis. Students whose favorite high school mathematics course was either geometry, trigonometry or calculus were significantly more likely to have a higher spatial visualization score than those students whose favorite high school mathematics course was representative of some other branch of mathematics, $t(116) = 2.15$, $p < .05$. Also, a multifaceted musical background was significantly related to a higher spatial visualization score, $t(116) = 2.48$,

$p < .05$. However, the experiences of having played with spatial toys as a child, $t(116) = 1.80$, $p = .08$, or of participating in hobbies that required spatial visualization, $t(116) = 1.28$, $p = .20$, were not significantly correlated with a high spatial visualization score.

Hypothesis 3

Statement. Favorite mathematics course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

Findings. The findings of this research did not support the third hypothesis; students who did not have childhood spatial experiences, $t(116) = .29$, $p = .77$, or hobbies that required spatial visualization, $t(116) = 1.64$, $p = .10$, were just as likely to have a favorite high school mathematics course that promoted spatial visualization skills as those students who did have the previously mentioned experiences.

Hypothesis 4

Statement. Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Findings. The fourth hypothesis was not supported in this investigation. Males were significantly more likely to have participated in hobbies that promote spatial visualization than were females, $t(116) = -3.40$, $p < .05$. However, students who did not have childhood spatial experiences were just as likely to have participated in spatial hobbies as those students who did have childhood spatial experiences, $t(116) = 1.32$, $p = .19$. Also, right-handed students were equally likely to have spatial hobbies as left-handed students, $t(116) = -.16$, $p = .87$. Finally, students whose mothers' occupations did not require spatial visualization participated in spatial hobbies just as frequently as students whose mothers' occupations did require spatial visualization, $t(116) = -.96$, $p = .34$; the same result was found with respect to students' fathers' occupations, $t(116) = .51$, $p = .61$.

Hypothesis 5

Statement. Musical experience will be significantly positively correlated with childhood spatial experiences.

Findings. The findings of this investigation did not support this hypothesis. Students who did not indicate having had spatial experiences as a child were just as likely to have a strong musical background, $t(116) = .37$, $p = .71$, as those students who did indicate having had spatial experiences as a child.

Hypothesis 6

Statement. Childhood spatial experiences will be significantly positively correlated with the demographic variables (gender, handedness, mom's job, dad's job, and family income).

Findings. This hypothesis also was not supported in this analysis. Students were equally as likely to have had childhood spatial experiences regardless of their hand preference, $t(111) = .90$, $p = .37$, their mothers' occupations, $t(111) = .48$, $p = .63$, or their family income, $t(111) = 1.06$, $p = .29$. Still, males were significantly more likely than females to have had childhood spatial experiences, $t(111) = -2.62$, $p < .05$. Students whose fathers' occupations required the use of spatial visualization were more likely to have had childhood spatial experiences than students whose fathers' occupations did not require the use of spatial visualization $t(111) = 2.76$, $p < .05$.

V. DISCUSSION, IMPLICATIONS AND RECOMMENDATIONS

The purposes of this study were: (1) to determine differences, if any, in the level of spatial visualization ability between students majoring in architecture, mathematics, mathematics education, and mechanical engineering, (2) to hypothesize reasons for individual differences in spatial visualization that may exist based on the background information of these students, and (3) to develop and test a causal model of the development of spatial visualization based on the findings of past research.

Previous research on spatial ability has included several studies that examined individual differences in spatial visualization at all age levels (Battista, 1990; Burnett, Lane, & Dratt, 1979; Fennema & Tartre, 1985; Lohman & Kyllonen, 1983; Salthouse, 1987; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Vandenburg, 1975). Furthermore, a number of studies have focused on the general nature and development of spatial visualization in students of all ages (Bishop, 1978; Brinkman, 1966; Clements, Battista, Sarama, & Swaminathan, 1997; Dodwell, 1963). However, limited research has been conducted related to the spatial ability of junior and senior undergraduate students majoring in architecture, mathematics, mathematics education, or mechanical engineering.

In conducting this study, the researcher hoped to gather evidence concerning two aspects of spatial visualization: (1) the level of spatial visualization possessed by undergraduates majoring in fields requiring this ability, and (2) the relationship between certain background variables and the development of spatial visualization. Such evidence and information could benefit university faculty in planning degree programs as well as middle and high school mathematics curriculum developers.

Architecture majors, mathematics majors, mathematics education majors, and mechanical engineering majors were chosen to participate in this study due to the large portion of research, which indicated that persons pursuing those respective professions needed spatial visualization ability. The background variables of gender, handedness, parents' occupations, family income, hobbies, childhood experiences, musical experiences, and favorite high school mathematics course were chosen because each of these variables had been previously studied with respect to spatial visualization in other research. However, no studies have examined the effects of these variables collectively. Thus, this researcher attempted to synthesize the findings of a wide array of past research through the formation of a causal model reflecting the effects of all of the previously mentioned variables.

One hundred seventeen volunteer undergraduate students participated in this study. These students provided individualized data by completing a background information questionnaire and two paper and pencil visualization tests. The background information questionnaire developed by the researcher was used to obtain each student's gender, hand preference, parents' occupations, family income, hobbies, childhood experiences, musical experiences, and favorite high school mathematics course. The Mathematical Processing Instrument (Presmeg, 1985) was used to determine whether each group of majors preferred visual or non-visual methods of solving mathematics problems. The Spatial Visualization Test (Middle Grades Mathematics Project, 1983) was used to measure each student's level of spatial visualization. The results of the data analysis are discussed in this chapter with respect to each of the six proposed hypotheses. Following this discussion, implications and conclusions based on the results are presented. The chapter is concluded with suggestions for changes that could be made to this investigation if it were to be replicated as well as recommendations for further research in spatial visualization.

Discussion

Hypothesis 1

There will be no significant differences in the level of spatial visualization between undergraduates majoring in architecture, mathematics, mathematics education or mechanical engineering.

The mean scores of the architecture majors, mathematics education majors, and mechanical engineering majors with respect to spatial visualization were not significantly different from each other. This finding did support one of the main underlying premises of this research; the premise being that persons going into each of these careers should have well-developed spatial visualization. Furthermore, mathematics education majors should possess the same level of spatial visualization ability as architecture majors or mechanical engineering majors. Each of their mean scores was above an average score of 50%. However, these mean scores, 63.9, 61.8, and 58.9, respectively, were considered to be lower, in general, than what was expected. Higher scores were expected due to the background of these students, especially the number of mathematics courses and the orthogonal geometry/drawing course they may have had prior to their junior year. Since these students were all in their junior or senior years of study, the researcher assumed that, as a whole, these students' average score would be near 75%, halfway between average and perfect. Presumably, this was not the case since these students may have been focusing on other aspects of their fields of study through specific projects assigned during the junior or senior years; i.e. architectural design projects, mechanical and construction projects, or planning and teaching specific lessons.

Hypothesis 1 was not supported because the mean score of the mathematics majors was significantly lower than the mean scores of the other three groups. It is hypothesized that this may be due to the way in which mathematicians prefer to think, abstractly. McMillan (1962) stated that "the mathematician in his 'pure' form delights in building logical structures, such as topology or abstract algebra, which have no apparent connection with the world of physical reality." It may have been the case that the mathematics majors who participated in this study think like "pure" mathematicians. Therefore when forced to think visually (through the Spatial Visualization Test (Middle Grades Mathematics Project, 1983)), they did not perform well because this way of thinking had not been developed by choice. Alternatively, the spatial visualization skills of these mathematics majors may not have been promoted due to being taught by university mathematics professors who did not teach spatially, but rather abstractly. In accordance with this hypothesized reason for the mathematics majors' mean score, the mathematics majors had the lowest visuality score. This demonstrated that, of the four groups, mathematics majors preferred non-visual, or abstract, methods of problem solving the most. This result did not support the findings of Martin (1968) and Rhoades (1981) in which there was a significant positive relationship between mathematical background and spatial visualization ability. These researchers found that the stronger one's mathematical background was, the higher his/her spatial ability was. However, the subjects in their investigations were university freshmen or prospective teachers in any field. Therefore, the hypothesized reason (preference for abstract thought) for the significantly lower visualization scores found in this study still may be valid since these participants may be considered "pure" mathematicians.

Hypothesis 2

Spatial visualization score will be significantly positively correlated with favorite mathematics course, musical experience, childhood spatial experiences, and spatial hobbies.

Spatial visualization score was significantly related to favorite high school mathematics course and to musical experience. With respect to favorite high school mathematics course, it is hypothesized that this was the case since one's favorite mathematics course would reflect one's strengths, interests, or both. Thus, if this "favorite mathematics course" developed spatial visualization skills, such as in geometry, trigonometry, or calculus, then one's spatial visualization skills would likely be strong.

The finding that musical experiences was significantly positively related to spatial visualization score supported Mason's (1986) results which indicated that undergraduates in their junior year with more musical ability had more spatial ability than undergraduates with less musical ability. Additionally, this finding was in agreement with Harris' (1978) theory that the ability to recognize, execute, or create a melodic pattern may be a spatial ability similar to the visual detection of an embedded figure or the mental rotation of a three-dimensional object.

Childhood spatial experiences and spatial hobbies were not significantly related to spatial visualization score. With respect to childhood spatial experiences, this may have been due to a lack of statistical power, since only 9% of the participants indicated having no access to toys that promoted spatial visualization. Enough students did not reveal a spatial hobby so a significant relationship would have been found if it existed. If these results do indicate that there was no difference in the spatial visualization ability between students who had childhood spatial experiences and those that did not, then it is hypothesized that this may be due to the development of spatial visualization skills through some other means, such as in elementary or high school mathematics courses, or in specific course work received by students majoring in the areas studied here. Several studies have found that direct instruction on spatial relationships or mathematical instruction that utilized three-dimensional objects improved the spatial visualization skills of students in grades 1 through 12 (Baldwin, 1985; Ben-Chaim, Lappan, & Houang, 1985, 1988; Clements, Battista, Sarama, & Swaminathan, 1997; Conner, Serbin, & Schackman, 1977; Smith & Schroeder, 1979; Tillotson, 1985). The result mentioned above with respect to spatial hobbies failed to support the findings of Baenninger and Newcombe (1989) who found a reliable relationship between spatial activity participation and spatial visualization ability. In their study, subjects reported having participated in various activities, which included model building, playing various sports, and drawing. These same activities were those defined in this study as spatial hobbies. Again, the course work required for degrees in the areas studied in this investigation may have developed the spatial visualization ability of these students such that the development of this ability due to participation in certain hobbies was not evident.

Hypothesis 3

Favorite mathematics course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

No significant relationship was found between either childhood spatial experiences or spatial hobbies and favorite mathematics course. Thus, this hypothesis was not supported in this inquiry. As with the previous hypothesis, this non-significant result may be due to lack of power, since only 11 students did not have spatial childhood experiences. If there really was no relationship between favorite high school mathematics course and each of childhood spatial experiences and spatial hobbies, then it is hypothesized that this is due to the instruction received in high school in the student's favorite mathematics course. If a student received instruction in high school geometry, trigonometry or calculus that enhanced his/her spatial visualization skills and if the student found the course content interesting, then regardless of the experiences the student had prior to receiving this instruction, this mathematics course might be his/her favorite. Similarly, if a student was taught some other mathematics course, defined in this study to be non-spatial, such that the student became interested in the content of that course, then again, regardless of his/her previous experiences or later experiences, this course might be regarded as the student's favorite course. It is further hypothesized that, in general, if a mathematics course was taught in accord with a student's preferred mode of thought, visual or non-visual, then that mathematics course might have become that student's favorite mathematics course due to instruction and the ease of understanding brought on by this instruction. Since no prior research focused on the relationship between favorite high school mathematics course and spatial experiences, the researcher cannot state that this finding supported or did not support the results of prior research. Hypothesis 3 was proposed because of the logical relationship that would seem to exist between these variables; if a student had childhood spatial experiences, spatial hobbies, or both, then it seemed likely that the student would prefer a mathematics course which was inherently spatial. However, the type of instruction received in the course must be a factor in determining a student's favorite mathematics course.

Hypothesis 4

Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Findings with respect to Hypothesis 4 revealed a non-significant relationship between spatial hobbies and each of childhood spatial experiences, handedness, mom's job, and dad's job. Thus, regardless of a student's upbringing, as determined by his/her childhood spatial experiences and parents' occupations, that student could still have an interest in hobbies that would promote the development of spatial visualization skills. This finding does not support the findings of Sherman (1967), Berry (1971), and Vandenburg and Kuse (1979) who claimed that differences in spatial ability were due to nurturance and environmental differences during childhood. Although the variable "spatial hobbies" was not a measure of one's spatial ability, it was logically hypothesized that a child with well developed spatial skills would prefer to participate in spatial hobbies than in hobbies not promoting the use of spatial skills. However, these results did not support this idea. It may be that children, who did not have spatial experiences at home, were given opportunities to participate in spatial activities at school. Having enjoyed these activities at school, these activities later became these students' hobbies.

However, since so few students did not have childhood spatial experiences and since only seven of the moms' jobs involved the use of spatial visualization skills, these relationships may not have been statistically significant due to a lack of statistical power. This was not the case for handedness, or dad's job.

With respect to handedness, students who preferred to use their right hands were just as likely to have participated in spatial hobbies as students who preferred to use their left hands. This result did not support the previous findings of Peterson and Lansky (1974) who studied handedness in architectural students. They found that the left-handed students were more spatially inclined than the right-handed students were. However, the finding in this study was in agreement with Yen (1975) who stated that "it is unlikely that handedness per se influences spatial performance." Rather, what is more likely is whatever factors affect handedness, may also affect spatial ability, according to Yen

(1975). Since handedness in this investigation was not examined with respect to other exogenous variables, no further explanation of possible links to spatial ability can be noted.

A significant relationship was found between gender and spatial hobbies that indicated that more males participated in spatial hobbies than did females. This finding supported the research of Harris (1978) who found that males engaged themselves in spatially relevant activities more so than females, due to differences in their upbringings. However, this finding did not support the results of Newcombe, Bandura, and Taylor (1983). They investigated the involvement of university freshman in spatial activities. Their findings yielded no difference between males and females in their participation of these spatial activities. The findings of this inquiry support the notion that although the majority of the females in this study were majoring in fields promoting the use of spatial visualization skills, their "personal" hobbies were for the most part activities in which they did not have to use these skills.

Hypothesis 5

Musical experiences will be significantly positively correlated with childhood spatial experiences.

This hypothesis was not supported by the findings of this investigation. A student was equally as likely to have a strong musical background regardless of his/her childhood spatial experiences. Since previous research had indicated a positive relationship between musical ability and spatial visualization skills, it was hypothesized that if these spatial visualization skills were developed during childhood, then that child would also be likely to have developed music skills (Mason, 1986; Harris, 1978). However, this was not the case. It is postulated that this may be due to the possibility that a student with a strong musical background and who had no childhood spatial experiences might have developed his/her spatial ability in an academic setting and then showed an interest in music. Therefore, the effects of not having any childhood spatial experiences on musical background were not apparent. Alternatively, a non-significant relationship may have been found because of a lack of statistical power since very few students reported not having any spatial childhood experiences.

Hypothesis 6

Childhood spatial experiences will be significantly positively correlated with gender, handedness, mom's job, dad's job, and family income.

Gender and dad's job were significantly correlated with childhood spatial experiences, while handedness, mom's job, and family income were not significantly related to childhood spatial experiences. Thus, this hypothesis was not supported by the results of this inquiry. Again, since so few moms' jobs were classified as requiring spatial visualization skills, the researcher assumed that this non-significant finding was due to a lack of statistical power since dad's job did have a significant correlation with childhood spatial experiences. Also, these two variables were playing the same role in this inquiry; that is, if more moms' jobs would have been classified as spatial, then there would have likely been a significant correlation between childhood spatial experiences and mom's job since this was the case for dad's job. Both mom's job and dad's job were being used as a measure of the effect of having a parent whose occupation required spatial skills.

The findings with respect to gender indicated that males had significantly more childhood spatial experiences than females. The findings in regards to dad's job revealed that those students whose fathers' occupations involved spatial visualization skills had significantly more childhood spatial experiences than those students whose fathers' occupations did not require spatial visualization skills. These findings supported previous research by Sherman (1967), Conner, Serbin, and Schackman (1977), and Belz and Geary (1984). Sherman (1967) suggested that males out-performed females on spatial tasks because they voluntarily participated in more spatially oriented activities such as model building, rather than playing with dolls. Additionally, Connor, Serbin, and Schackman (1977) reported that preschool boys were observed spending more time than girls engaged in activities relevant to developing spatial skills, such as playing with blocks and trucks. Research conducted by Belz and Geary (1984) revealed that father's occupation was related to differential development of spatial abilities. In relation to this study, the development of spatial visualization skills in students who had childhood spatial experiences was different than the development of spatial visualization skills in students who had no such experiences.

The non-significant relationship between childhood spatial experiences and the remaining exogenous variables revealed that there were no differences in childhood spatial experiences due to hand preference and family income. These findings did not support previous research findings. Sherman (1967) claimed that environmental differences played a role in the development of spatial ability. Thus, individuals who came from different environments or who had diverse experiences would have had varying levels of spatial ability (Sherman, 1967). Using family income as an index of different childhood environments, this investigation did not support Sherman's (1967) claim. Additionally, Vandenburg and Kuse (1979) stated that evidence existed in support of differences in spatial ability due to nurturance and culture diversity. With respect to handedness, some researchers have suggested that left-handed persons, particularly females, did not perform as well as right-handed persons on tests of spatial ability (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973) while others have found that left-handers outperformed right-handers (Peterson & Lansky, 1974; Yen, 1975). If a certain hand preference does yield stronger spatial ability, then it seems likely that those with that hand-preference would be drawn to spatial activities as children if their environments allowed for it. In this inquiry, left-handers and right-handers were equal in terms of their childhood spatial experiences, so neither side of the research was supported.

Finally, the non-significant correlation between ethnicity and family income indicated that there was no relationship between belonging to a minority or a non-minority and one's family's financial status. Thus, students representing a variety of ethnic backgrounds appeared to have the same opportunities from a financial stance. However, since there were only 10 students in the non-minority group, this finding may have been non-significant due to a lack of statistical power. Therefore, no further explanations can be made regarding ethnicity and family income.

Implications and Conclusions

The results of this study indicated that the students majoring in architecture, mathematics education, and mechanical engineering who participated in this inquiry do have spatial visualization skills as required by their choice of major. However, the mathematics majors who participated in this study did not have the level of spatial visualization that was expected. Since the overall mean scores per major were all lower than expected, the researcher believes that possibly more direct instruction at the university level on spatial visualization may be needed. According to data from the United States Employment Service, most scientific and technical occupations, like drafting, architecture, engineering, and mathematics, require persons demonstrating a spatial ability at or above the 90^{th} percentile (Harris, 1981). If this is still the case, then more emphasis should be placed on the development of spatial skills within the undergraduate course of study. Mathematics, mathematics education, and mechanical engineering majors might also benefit from a course in projective geometry, as required by those majoring in architecture. It may also be beneficial for students to be made aware of their own problem solving preference early in their college careers. By becoming aware of this, students can start to see how visualizing the problem may actually help them solve it, regardless of the type of problem. Then, once students begin using visualization to solve problems, their own visualization skills may be strengthened.

Results of the path analyses yielded a significant correlation between the spatial visualization scores of the students in this study and their musical experiences and their favorite high school mathematics course. This may suggest that middle school educators encourage their students to learn to play musical instruments, which could in turn promote the development of the spatial visualization ability of these students. Additionally, this provides evidence, although limited, of the importance of music in the elementary, middle school and high school curricula.

Since favorite high school mathematics course was significantly correlated with spatial visualization, it may be helpful if all mathematics courses, not just those characterized as being spatial in this study (geometry, trigonometry, and calculus), were taught both visually and non-visually, as suggested by Presmeg (1986). Presmeg noted that students in mathematics classes performed best when the teacher used a combination of visual and non-visual techniques. It may be that students understand any mathematical content better when it is presented in several different ways. Also, when content is presented visually regardless of subject matter, the student may also benefit with regards to the development of his/her spatial visualization ability. Since the mathematics courses classified as spatial in this study lend themselves to be taught visually more so than other courses, this may be the reason for the high spatial visualization scores being significantly related to these spatial courses when chosen as one's favorite.

The findings of this investigation also revealed a significant correlation between gender and spatial hobbies. Although the literature on gender and spatial visualization has indicated mixed findings, the researcher expected no gender differences to be found within this study due to the targeted population. It would seem that females majoring in fields that require spatial visualization would enjoy hobbies utilizing this visualization just as much as do males. However, in the sample studied here, this was still not the case.

Females tended not to participate in hobbies requiring spatial visualization. Thus, educators should continue to encourage females to participate in activities that have been "traditionally" dominated by males such as model building and playing sports (Sherman, 1967). Additionally, classroom teachers should provide opportunities for all of their students to build models, draw, and manipulate blocks during instruction. This could allow females to participate in such activities in case they are not voluntarily participating in these activities or others, such as designing quilts or paper folding, outside of the classroom. Teachers can play an important role in the development of spatial visualization ability in their students starting at an early age by engaging them in spatially appropriate tasks (Baldwin, 1985; Ben-Chaim, Lappan, & Houang, 1985; Conner, Serbin, & Schackman, 1977).

Gender was also significantly related to childhood spatial experiences, as was father's occupation. These findings revealed that significantly more males had childhood spatial experiences than females and that those students whose fathers had spatial occupations had more childhood spatial experiences than those students whose fathers' occupations were not considered spatial. This may suggest that one's environment, as influenced by the father's occupation, might promote or not promote the development of spatial visualization skills through the child's everyday experiences within that environment (Belz & Geary, 1984; Sherman, 1967). Here again, elementary school teachers can fill in any gaps in their students' childhood experiences by allowing them to "play" with building blocks, construction sets, and spatial type puzzles. By providing these experiences, teachers could help develop the spatial skills of their students at very early ages. According to Conner, Serbin, and Schackman (1977) first, third, and fifth graders responded positively to training in spatial visualization. Also, since the results of this study indicated a gender difference with respect to childhood experiences, this could be overcome as well by the intervention of spatially oriented tasks within the elementary school setting. This significant gender difference indicated that, as children, the males who participated in this study were more involved in spatial activities than the females. Since 15 or more years have passed since these participants were children, this gender difference in childhood experiences may no longer exist. However, if this difference does still exist for their current students, then it is especially important for elementary school teachers to take an active part in the development of their students' spatial visualization skills.

Since involvement in spatial hobbies and childhood spatial experiences were not significantly related to spatial visualization skills, this may suggest that the development of spatial visualization skills occurred within some other setting, such as while attending grade school. If the students who participated in this inquiry did strengthen their spatial visualization skills during activities provided during their educational experiences, then this finding supported the claims of those researchers who found that spatial visualization skills improved after students received instruction on spatial visualization (Baldwin, 1985; Ben-Chaim, Lappan, & Houang, 1985; Clements, Battista, Sarama, & Swaminathan 1997; Conner, Serbin, & Schackman, 1977; Smith & Litman, 1979; Smith & Schroeder, 1979). This instruction involved having students manipulate three-dimensional objects. Also, students were given opportunities to solve two-dimensional spatial puzzles. Such activities seem to be beneficial for the development of spatial visualization in students of all levels. Therefore, university professors teaching architecture, mathematics, mathematics education, and mechanical engineering classes might consider using such activities during their instruction in order to continue to develop the spatial visualization skills of their students.

Additionally, since spatial hobbies and childhood spatial experiences were not significantly related to favorite high school mathematics course, this may mean that during high school, these students were taught mathematics, in general, using both visual and non-visual methods and thus received the best type of instruction (Presmeg, 1986). If these students were taught in this way, then it seems that their prior spatial experiences would not matter in terms of their favorite high school mathematics course since all mathematics courses were taught the same. Thus, students who preferred non-visual modes of instruction were satisfied by the instruction, as well as those students who preferred visual modes of instruction. Hence, this finding may provide evidence in favor of teaching methods that use both visual and non-visual techniques. The researcher has only speculated that this may be the implication of this finding. No other prior research examined the relationship between these variables. Further research in this area is necessary.

Since handedness was not significantly related to either childhood spatial experiences or spatial hobbies for the sample used in this inquiry, this may suggest that regardless of one's preferred hand, both hemispheres of the brain are equally strong. Battista (1990) stated that the right hemisphere was specialized for spatial tasks, artistic efforts and body image. Thus, being left-handed, or right-hemisphere dominant, would lead to having strong spatial visualization skills (Peterson & Lansky, 1974; Yen, 1975). However, the results found in this study suggest that the right-hemisphere, which seems to be responsible for spatial visualization skills, can be just as strong in right-handed person as in left-handed persons. Therefore, handedness appears not to account for differential development of spatial visualization or differential childhood spatial experiences and hobbies.

Since neither mom's job nor dad's job was significantly related to spatial hobbies, this result may provide evidence in favor of acquiring hobbies through some other influences, such as interaction with others or involvement in such hobbies at school. This may indicate that the environment provided to children because of their parents' occupations does not necessarily dictate what hobbies these children will pursue. Upon attending school, these children might become involved in activities, like sports, art, or music, regardless of their parents' occupations. Here again, the impact of the educational system and the importance of providing such activities at school is noted. Also, since no previous research examined the relationship between parents' occupations and their children's involvement in spatial hobbies, the researcher can only hypothesize what the implications of this finding are.

The finding that family income was not significantly related to childhood spatial experiences may suggest that these students were given spatial toys, such as building blocks, construction sets and drawing tools, as children either at home by their parents or when they attended school in kindergarten by their teacher. Therefore, it is possible for students to engage in spatial tasks as children regardless of the financial status of their families. This provides evidence in support of family income not accounting for differential development of spatial visualization, which may be considered a positive finding. The development of spatial visualization skills does not solely depend on the person's home environment as influenced by family income. Thus, once children begin attending school, if they are given opportunities to "play" with spatial toys, then their spatial visualization skills can develop to be as strong as children who are given these opportunities at home.

Recommendations

This study examined the level of spatial visualization among students majoring in architecture, mathematics, mathematics education, and mechanical engineering. Additionally, the relationship between spatial visualization and various background variables was investigated. If this study were to be conducted again, it is suggested that certain changes be made. First, a group of undergraduates not majoring in an area that requires the use of spatial visualization skills should be included. This might help with the lack of power for certain background variables in the path analysis. Namely, students majoring in a field that does not rely on the use of spatial visualization skills might not have participated in spatial hobbies or have had as many childhood spatial experiences. If there were significant differences in the background variables between the "non-spatial majors" and the "spatial majors," this comparison could also lead to a better understanding of the backgrounds of those majoring in architecture, mathematics,

mathematics education, and mechanical engineering. Secondly, the researcher would want to have larger groups by major, in general, with the hopes of attaining greater statistical power with respect to the variables of handedness, mom's job, and ethnicity to see if the lack of statistical significance remains. Finally, the researcher would propose a similar causal model to the one proposed here, but with a path from gender to spatial visualization score. This correlation would be helpful in determining if a gender difference was present in the sample with regards to overall spatial visualization score. In the context of the present model, gender did not have a direct influence on spatial visualization score, only an indirect influence. Considering that the correlations between gender and the only two variables with which it was linked (childhood spatial experiences and spatial hobbies) were significant, the researcher recommends that a direct influence of gender on spatial visualization score be included in the model. These three changes to this investigation would make this a more powerful study and could help in verifying the results found here.

The results of this inquiry provide a rationale for future research involving spatial visualization and problem-solving preferences, visual or non-visual. One area, which could be focused on, is the relationship between musical ability and spatial visualization skills to better understand why a significant positive relationship exists between these two abilities, if indeed this relationship exists beyond the sample studied here. Further research is needed in order to provide more evidence that this relationship exists and to determine how knowledge of this relationship can help educators in developing the spatial visualization skills of their students. Perhaps there might be some way in which high school mathematics teachers could use this relationship to promote the development of spatial visualization skills in their students.

It is also recommended that studies similar to this one be conducted but with a random sample of undergraduate junior and senior students. This would allow researchers to compare the findings with respect to a very specific sample, the one used here, and a very general sample. It seems that there should be differences in the results due to choice of major and the requirements of different majors. This would help in identifying those background characteristics that are unique to students pursuing degrees in a field requiring spatial visualization skills. In this study, there was no group with which to compare the background variables of these architecture, mathematics, mathematics education, and mechanical engineering students.

Also, further longitudinal research that documents that level of spatial visualization of students as they enter school, progress through elementary, middle and high school, and as they enter a university degree program might help clarify what activities in these students lives are promoting the development of spatial visualization. This study may not have found a significant relationship between childhood spatial experiences and spatial visualization because these students may have had opportunities in school to develop this skill. By testing the same students throughout their schooling, researchers may be able to better identify specific tasks that promote spatial visualization.

It is recommended that further research also be conducted with respect to mathematics education majors specifically. Qualitative research that focused on how mathematics education majors use visualization during their student teaching might provide evidence for the need of a course on projective geometry for these future mathematics teachers. If these student teachers did not use visual methods of instruction, it may be because they themselves are not aware of their own visualization or are not confident in their teaching skills where visualization is concerned. Also, it could be that their course work in pure mathematics was with mathematicians who solve problems algebraically, not spatially, and thus, teach in this manner. Since research has indicated that students perform better when non-visual and visual methods of instruction are used, it would be beneficial to study the teaching methods used by mathematics education majors during their internship to determine if both types of instruction were being used (Presmeg, 1986).

Research that focuses on how mathematics majors think could provide support for the findings that indicated low spatial visualization scores and a preference to non-visual methods of problem solving. There appears to be a difference in the way that mathematics majors think as compared to other undergraduates in similar fields of study, such as mathematics education and mechanical engineering. This might benefit professors in understanding how their students go about solving problems and in providing their students with alternative solution strategies.

Finally, it is strongly recommended that qualitative and quantitative research be conducted together focusing on the same purposes of this investigation. A small group of undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering, approximately five of each, could be selected to participate. The researcher could administer the same spatial visualization test and background survey that was used in this inquiry to determine the level of spatial visualization and background characteristics of the sample. Then, for a period of time, the researcher could observe each of the participants while he/she was "working" on projects or tasks specific to his/her major. For example, the architecture major might be observed while designing a building or the mathematics education major might be observed while teaching a lesson. Following each observation, the researcher could interview the participant to gather more evidence of how this particular person was using spatial visualization in his/her work, if at all. Additionally, this data could be used to determine specific tasks, which each type of major engages in, that might involve the use of spatial visualization skills, provided the person has developed his/her spatial visualization skills. Following each observation, the researcher could interview the participant to clarify what was observed and to obtain answers to specific questions regarding the use of spatial visualization by the student during the observation. In conducting these observations and interviews, not only would the researcher be obtaining valuable data, but the student would also be made aware of his/her own use of spatial visualization skills and the potential importance of these skills in his/her own work. After several observation/interview sessions with each participant over a period of time, the researcher could conclude this proposed study by administering the same spatial visualization test to the students again to see if any differences in test scores occurred. If differences did occur, it may be hypothesized that when one is made aware of one's own visualization (like through one-on-one interviews) and the importance of this visualization, one's spatial visualization ability, as measured by the test, improves. The researcher was not able to investigate this possibility in the study conducted here since the participants were not aware of what was being investigated. The results might have been different had the participants known that spatial visualization was being tested.

REFERENCES

Aiken, L. R., Jr. (1971). Intellective variables and mathematics achievement: directions for research. Journal of School Psychology, 9(2), 201–212.

Allen, M. J. (1974). Sex differences in spatial problem-solving styles. Perceptual and Motor Skills, 39, 843–846.

Baenninger, M., & Newcombe, N. (1989). The role of experience in spatial test performance: A meta-analysis. Sex Roles, 20, 327–344.

Baldwin, S. L. (1985). Instruction in spatial skills and its effect on math achievement in the intermediate grades. (Doctoral dissertation, University of Northern Colorado, 1984). Dissertation Abstracts International, 46(3), 595-A.

Battista, M. T. (1981). The interaction between two instructional treatments of algebraic structures and spatial-visualization ability. Journal of Educational Research, 74(5), 337–341.

Battista, M. T. (1990). Spatial visualization and gender differences in high school geometry. Journal for Research in Mathematics Education, 21(1), 47–60.

Battista, M. T. (1994). On Greeno's environmental/model view of conceptual domains: A spatial/geometric perspective. Journal for Research in Mathematics Education, 25(1), 86–94.

Battista, M. T., & Clements, D. H. (1996). Students' understanding of three-dimensional rectangular arrays of cubes. Journal for Research in Mathematics Education, 27(3), 258–292.

Battista, M. T., Wheatley, G. H., & Talsma, G. (1982). The importance of spatial visualization and cognitive development for geometry learning in preservice elementary teachers. Journal for Research in Mathematics Education, 13(5), 332–340.

Ben-Chaim, D. (1983). Spatial visualization: Sex differences, grade level differences and the effect of instruction on the performance and attitudes of middle school boys and girls. (Doctoral dissertation, Michigan State University, 1982). Dissertation Abstracts International, 43(9), 2914–A.

Ben-Chaim, D., Lappan, G., & Houang, T. (1985). Visualizing rectangular solids made of small cubes: analyzing and effecting students' performance. Educational Studies in Mathematics, 16, 389–409.

Ben-Chaim, D., Lappan, G., & Houang, R. T. (1986). Development and analysis of a spatial visualization test for middle school boys and girls. Perceptual and Motor Skills, 63, 659–669.

Ben-Chaim, D., Lappan, G., & Houang, R. T. (1988). The effect of instruction on spatial visualization skills of middle school boys and girls. American Educational Research Journal, 25(1), 51–71.

Ben-Chaim, D., Lappan, G., & Houang, R. T. (1989). The role of visualization in the middle school mathematics curriculum. Focus on Learning Problems in Mathematics, 11(1), 49–60.

Belz, H. F., & Geary, D. C. (1984). Father's occupation and social background: relation to SAT scores. American Educational Research Journal, 21(2), 473-478.

Berry, J. W. (1971). Ecological and cultural factors in spatial perceptual development. Canadian Journal of Behavioral Science, 3(4), 324–336.

Bishop, A. J. (1980). Spatial abilities and mathematics education – A review. Educational Studies in Mathematics, 11, 257–269.

Bishop, A. J. (1989). Review of research on visualization in mathematics education. Focus on Learning Problems in Mathematics, 11(1), 7–15.

Bishop, J. E. (1978). Developing students' spatial ability. The Science Teacher, 45, 20–23.

Blade, M. F. (1949). Experiment in visualization. Journal of Engineering Drawing, 13(2), 20–21, 29–30.

Blade, M. F., & Watson, W. S. (1955). Increase in spatial visualization test scores during engineering study. Psychological Monographs, 69(12), 1–13.

Blatter, P. (1983). Training in spatial ability: A test of Sherman's hypothesis. Perceptual and Motor Skills, 57, 987–992.

Bock, R. D., & Kolakowski, D. (1973). Further evidence of sex-linked major-gene influence on human spatial visualizing ability. American Journal of Human Genetics, 25, 1–14.

Bouchard, T. J., & McGee, M. G. (1977). Sex differences in human spatial ability: not an X-linked recessive gene effect. Social Biology, 24(4), 332–335.

Brendzel, S. D. (1981). The relationship between proportional reasoning and visual spatial ability. (Doctoral Dissertation, Rutgers University The State University of New Jersey, 1981). Dissertation Abstracts International, 42(4), 1574-A.

Brinkmann, E. H. (1966). Programmed instruction as a technique for improving spatial visualization. Journal of Applied Psychology, 50(2), 179–184.

Brown, D. L., & Wheatley, G. H. (1989). Relationship between spatial ability and mathematical knowledge. In C. A. Maher, G. A. Goldin, & R. B. Davis (Eds.), Proceedings of the 11th annual meeting of psychology of mathematics education-NA, New Brunswick, NJ, 143–148.

Burnett, S. A. (1986). Sex-related differences in spatial ability: Are they trivial? American Psychologist, 41, 1012–1014.

Burnett, S. A., & Lane, D. M. (1980). Effects of academic instruction on spatial visualization. Intelligence, 4, 233–242.

Burnett, S. A., Lane, D. M., & Dratt, L. M. (1979). Spatial visualization and sex differences in quantitative ability. Intelligence, 3, 345–354.

Caplan, P. J., MacPherson, G. M., & Tobin, P. (1985). Do sex-related differences in spatial abilities exist? A multilevel critique with new data. American Psychologist, 40, 786–799.

Caplan, P. J., MacPherson, G. M., & Tobin, P. (1986). The magnified molehill and the misplaced focus: sex-related differences in spatial ability revisited. American Psychologist, 41, 1016–1018.

Carpenter, P. A., & Just, M. A. (1986). Spatial ability: An information processing approach to psychometrics. In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence, Volume 3, (pp. 221–253). New Jersey: Lawrence Erlbaum Associates.

Clements, D. H., & Battista, M .T. (1992). Geometry and spatial reasoning. In D. Grouws (Ed.), Handbook of research on mathematics teaching and learning (pp. 420–464). New York: Simon and Schuster Macmillan.

Clements, D. H., Battista, M. T., Sarama, J., & Swaminathan, S. (1997). Development of students' spatial thinking in a unit on geometric motions and area. The Elementary School Journal, 98(2), 171–186.

Conner, J. M., & Serbin, L. A. (1985). Visual-spatial skill: Is it important for mathematics? Can it be taught? In S. F. Chipman, L. R. Brush, & D. M. Wilson (Eds.), Women and mathematics: Balancing the equation (pp. 151–174). New Jersey: Lawrence Erlbaum Associates.

Conner, J. M., Serbin, L. A., & Schackman, M. (1977). Sex differences in children's response to training on a visual-spatial test. Developmental Psychology, 13(3), 293–294.

Corley, R. P., DeFries, J. C., Kuse, A. R., & Vandenburg, S. G. (1980). Familial resemblance for the identical blocks test of spatial ability: No evidence for X-linkage. Behavior Genetics, 10(2), 211–215.

Crowley, M. L. (1987). The van Hiele model of the development of geometric thought. In M. M. Lindquist & A. P. Shulte (Eds.), Learning and teaching geometry, K-12 (pp. 1–16). Reston, VA: The National Council of Teachers of Mathematics, Inc.

Dixon, J. K. (1997). Computer use and visualization in students' construction of reflection and rotation concepts. School Science and Mathematics, 97(7), 352–358.

Dodwell, P. C. (1963). Children's understanding of spatial concepts. Canadian Journal of Psychology, 17(1), 141–161.

Eliot, J., & Fralley, J. S. (1976). Sex differences in spatial ability. Young Children, 31, 487–498.

Eisenburg, T. A., & McGinty, R. L. (1977). On spatial visualization in college students. The Journal of Psychology, 95, 99–104.

Estes, S. G. (1942). A study of five tests of spatial ability. The Journal of Psychology, 13, 265–271.

Farrell, M. (1957). Sex differences in block play in early childhood education. Journal of Educational Research, 51, 279–284.

Fennema, E., & Sherman, J. A. (1977). Sex-related differences in mathematics achievement, spatial visualization and affective factors. American Educational Research Journal, 14(1), 51–71.

Fennema, E., & Sherman, J. A. (1978). Sex-related differences in mathematics achievement and related factors: A further study. Journal for Research in Mathematics Education, 7(3), 189–203.

Fennema, E., & Tartre L. A. (1985). The use of spatial visualization in mathematics by girls and boys. Journal for Research in Mathematics Education, 16(3), 184–206.

Ferrini-Mundy, J. (1987). Spatial training for calculus students: Sex differences in achievement and in visualization ability. Journal for Research in Mathematics Education, 18(2), 126–140.

Flanery, R. C., & Balling, J. D. (1979). Developmental changes in hemispheric specialization for tactile spatial ability. Developmental Psychology, 15(4), 364–372.

Fralley, J. S., Eliot, J., & Dayton, C. M. (1978). Further study of the X-linked recessive gene hypothesis for inheritance of spatial abilities. Perceptual and Motor Skills, 47, 1023–1029.

Friedlander, A. (1985). Achievement in similarity tasks: Effect of instruction, and relationship with achievement in spatial visualization at the middle grades level. (Doctoral Dissertation, Michigan State University, 1984). Dissertation Abstracts International, 45(12), 3570–3571–A.

Friedman, L. (1989). Mathematics and the gender gap: A meta-analysis of recent studies on sex differences on mathematical tasks. Review of Educational Research, 59(2), 185–213.

Gardner, R. W., Jackson, D. N., & Messick, S. J. (1960). Personality organization in cognitive controls and intellectual abilities. Pychological Issues, 2(8).

Garron, D. C. (1970). Sex-linked recessive inheritance of spatial and numerical abilities, and Turner's syndrome. Psychological Review, 77(2), 147–152.

Geiringer, E. R., & Hyde, J. S. (1976). Sex differences on Piaget's water-level task: Spatial ability incognito. Perceptual and Motor Skills, 42, 1323–1328.

Ghiselli, E. E. (1966). The validity of occupational aptitude tests. New York: Wiley.

Guay, R. B., & McDaniel, E. D. (1977). The relationship between mathematics achievement and spatial abilities among elementary children. Journal for Research in Mathematics Education, 8(3), 211–215.

Guttman, R., & Shoham, I. (1979). Intrafamilial invariance and parent-offspring resemblance in spatial abilities. Behavior Genetics, 9(5), 367–379.

Halpern, D. F. (1986). A different answer to the question, "Do sex-related differences in spatial abilities exist?" American Psychologist, 41, 1014–1015.

Harris, L. J. (1978). Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.), Asymmetrical function of the brain (pp. 405–521). London: Cambridge University.

Harris, L. J. (1979). Sex-related differences in spatial ability: A developmental psychological view. In C. B. Kopp & M. Kilpatrick (Eds.), Becoming female: Perspectives on development (pp. 133–181). New York: Plenum Press.

Harris, L. J. (1981). Sex-related variations in spatial skill. In L. S. Liben, A. H. Patterson, & N. Newcombe (Eds.), Spatial representation and behavior across the life span (pp. 83–125) New York: Academic Press.

Hartlage, L. C. (1970). Sex-linked inheritance of spatial ability. Perceptual and Motor Skills, 31, 610.

Herchkowitz, R. (1989). Visualization in geometry – Two sides of the coin. Focus on Learning Problems in Mathematics, 11(1), 61–76.

Hill, D. M., & Obenauf, P. A. (1979). Spatial visualization, problem solving, and cognitive development in freshman teacher education students. Science Education, 63(5), 665–670.

Hiscock, M. (1986). On sex differences in spatial abilities. American Psychologist, 41, 1011–1012.

Hyde, J. S. (1981). How large are cognitive gender differences? American Psychologist, 36, 892–901.

Jackiw, N. (1991). The geometer's sketchpad. Berkeley, CA: Key Curriculum Press.

Jagacinski, C. M., & LeBold, W. K. (1981). A comparison of men and women undergraduate and professional engineers. Engineering Education, 72, 213–220.

Jamison, W., & Signorella, M. L. (1980). Sex-typing and spatial ability: The association between masculinity and success on Piaget's water-level task. Sex Roles, 6(3), 345–353.

Karlins, M., Schuerhoff, C., & Kaplan, M. (1969). Some factors related to architectural creativity in graduating architecture students. The Journal of General Psychology, 81, 203–215.

Landau, M. S. (1984). The effects of spatial ability and problem presentation format on mathematical problem solving performance of middle school students.

(Doctoral Dissertation, Northwestern University, 1984). Dissertation Abstracts International, 45(2), 442-443-A.

Lean, G., & Clements, M. A. (1981). Spatial ability, visual imagery, and mathematical performance. Educational Studies in Mathematics, 12, 267–299.

Linn, M. C., & Hyde, J. S. (1989). Gender, mathematics, and science. Educational Researcher, 18(8), 17–19, 22–27.

Linn, M. C., & Petersen, A. (1986). A meta-analysis of gender differences in spatial ability: Implications for mathematics and science achievement. In J. S. Hyde & M. C. Linn (Eds.), The psychology of gender: Advances through meta-analysis (pp. 67–101). Baltimore, MD: Johns Hopkins University Press.

Loehlin, J. C., Sharan, S., & Jacoby, R. (1978). In pursuit of the "spatial gene": A family study. Behavior Genetics, 8(1), 27–41.

Lohman, D. F., & Kyllonen, P. C. (1983). Individual differences in solution strategy on spatial tasks. In R. F. Dillon & R. R. Schmeck (Eds.), Individual differences in cognition, Volume 1 (pp. 105–135). New York: Academic Press.

Lowery, B. R., & Knirk, F. G. (1982-83). Micro-computer video games and spatial visualization acquisition. Journal of Educational Technology Systems, 11(2), 155–166.

Lunneborg, P. W. (1982). Sex differences in self-assessed, everyday spatial abilities. Perceptual and Motor Skills, 55, 200–202.

Lunneborg, C. E., & Lunneborg, P. W. (1984). Contribution of sex-differentiated experiences to spatial and mechanical reasoning abilities. Perceptual and Motor Skills, 59, 107–113.

Macoby, E., & Jacklin, C. (1974). The psychology of sex differences. New York: University Press.

MacPherson, G. M. (1982). The construct validity of two tests of spatial abilities. Unpublished Master's Thesis, University of Toronto, Toronto, Canada.

Martin, B. L. (1968). Spatial visualization abilities of prospective mathematics teachers. Journal of Research in Science Teaching, 5, 11–19.

Mason, S. F. (1986). Relationships among mathematical, musical, and spatial abilities. (Doctoral Dissertation, University of Georgia, 1986). Abstract from: UMI ProQuest Digital Dissertations AAT 8613503.

McGee, M. G. (1976). Laterality, hand preference, and human spatial ability. Perceptual and Motor Skills, 42, 781–782.

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. Psychological Bulletin, 86(5), 889–918.

McGee, M. G. (1979). Human spatial abilities. New York: Praeger Publishers.

McGee, M. G. (1982). Spatial abilities: The influence of genetic factors. In M. Potegal (Ed.), Spatial abilities development and physiological foundations (pp. 199–222). New York: Academic Press.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. The Behavioral and Brain Sciences, 3, 215–227.

McGlone, J., & Davidson, W. (1973). The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. Neuropsychologia, 11, 105–113.

McKee, L. D. (1983). Figure-drawing ability in solving mathematical problems. (Doctoral Dissertation, University of Georgia, 1983). Dissertation Abstracts International, 44(2), 417–A.

McMillan, B. (1962). Mathematicians and their uses. Society for Industrial and Applied Mathematics Review, 4(2), 79–90.

Middaugh, D. J. (1980). Spatial ability and its relationship to the mathematical performance of adolescents. (Doctoral Dissertation, Kent State University, 1979). Dissertation Abstracts International, 40(10), 5349-A.

Miller, C. L., & Bertoline, G. R. (1991). Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model. Engineering Design Graphics Journal, 55(3), 5–14.

Michael, W. B., Zimmerman, W. S., & Guilford, J. P. (1951). An investigation of the nature of the spatial-relations and visualization factors in two high school samples. Educational and Psychological Measurement, 11, 561–577.

Middle Grades Mathematics Project (1983). Spatial visualization test. Department of Mathematics, Michigan State University.

Moses, B. E. (1978). The nature of spatial ability and its relationship to mathematical problem solving. (Doctoral Dissertation, Indiana University, 1977). Dissertation Abstracts International, 38(8), 4640-A.

Moses, B. E. (1982). Visualization: A different approach to problem solving. School Science and Mathematics, 82(2), 141–147.

Nash, S. C. (1975). The relationship among sex-role stereotyping, sex-role preference, and the sex difference in spatial visualization. Sex Roles, 1(1), 15–32.

National Council of Teachers of Mathematics. (1989). Curriculum and Evaluation Standards for School Mathematics. Reston: VA: The Council.

Newcombe, N. (1982). Sex-related differences in spatial ability: Problems and gaps in current approaches. In M. Potegal (Ed.), Spatial Abilities Development and Physiological Foundations (pp. 222–250). New York: Academic Press.

Newcombe, N., Bandura, M. M., & Taylor, D. G. (1983). Sex differences in spatial ability and spatial activities. Sex Roles, 9(3), 377–385.

Norusis, M. J. (1999). SPSS Professional Statistics 9.0. Chicago: SPSS, Inc.

O'Brien, T. P. (1991). Relationships among selected characteristics of college students and cognitive style preferences. College Student Journal, 25, 492–500.

Pearson, J. L., & Ferguson, L. R. (1989). Gender differences in patterns of spatial ability, environmental cognition, and math and English achievement in late adolescence. Adolescence, 24(94), 421–431.

Pepin, M., Beaulieu, R., Matte, R., & LeRoux, Y. (1985). Microcomputer games and sex-related differences: Spatial, verbal, and mathematical abilities. Psychological Reports, 56, 783–786.

Peterson, J. M., & Lansky, L. M. (1974). Left-handedness among architects: Some facts and speculation. Perceptual and Motor Skills, 38, 547–550.

Podell, J. E., & Phillips, L. (1959). A developmental analysis of cognition as observed in dimensions of Rorschach and objective test performance. Journal of Personality, 27, 439–463.

Poltrock, S. E., & Agnoli, F. (1986). Are spatial visualization ability and visual imagery ability equivalent? In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence, Volume 3 (pp. 255–296). New Jersey: Lawrence Erlbaum Associates.

Poltrock, S. E., & Brown, P. (1984). Individual differences in visual imagery and spatial ability. Intelligence, 8, 93–138.

Poole, C., & Stanley, G. (1972). A factorial and predictive study of spatial abilities. Australian Journal of Psychology, 24(3), 317–320.

Presmeg, N. C. (1985). The role of visually mediated processes in high school mathematics: A classroom investigation. Unpublished Ph.D. Dissertation, University of Cambridge, England.

Presmeg, N. C. (1986). Visualization in high school mathematics. For the Learning of Mathematics, 6(3), 42-46.

Presmeg, N. C. (1986). Visualization and mathematical giftedness. Educational Studies in Mathematics, 17, 297–311.

Rhoades, H. M. (1981). Training spatial ability. In E. Klinger (Ed.), Imagery, Volume 2, Concepts, results, and applications (pp. 247–256). New York: Prenum Press.

Salthouse, T. A. (1987). Sources of age-related individual differences in block design tests. Intelligence, 11, 245-262.

Salthouse, T. A., Babcock, R. L., Mitchell, D. R. D., Palmon, R., & Skovronek, E. (1990). Sources of individual differences in spatial visualization ability. Intelligence, 14, 187–230.

Sherman, J. A. (1967). Problem of sex differences in space perception and aspects of intellectual functioning. Psychological Review, 74(4), 290–299.

Sherman, J. A. (1974). Field articulation, sex, spatial visualization, dependency, practice, laterality of the brain and birth order. Perceptual and Motor Skills, 38, 1223–1235.

Siemankoski, F. T., & MacKnight, F. C. (1971). Spatial cognition: Success prognosticator in college science courses. Journal of Science Teaching, 1, 56–59.

Smith, W. S., & Litman, C. I. (1979). Early adolescent girls' and boys' learning of a spatial visualization skill. Science Education, 63(5), 671–676.

Smith, W. S., & Schroeder, C. K. (1979). Instruction of fourth grade girls and boys on spatial visualization. Science Education, 63(1), 61–66.

Stafford, R. E. (1961). Sex differences in spatial visualization as evidence of sex-linked inheritance. Perceptual and Motor Skills, 13, 428.

Stringer, P. (1975). Drawing training and spatial ability. Ergonomics, 18(1), 101–108.

Tapley, S. M., & Bryden, M. P. (1977). An investigation of sex differences in spatial ability: Mental rotation of three-dimensional objects. Canadian Journal of Psychology, 31(3), 122–130.

Tartre, L. A. (1990). Spatial skills, gender, and mathematics. In E. Fennema & G. C. Leder, (Eds.), Mathematics and Gender: Influences on Teachers and Students (pp. 27–59). New York: Columbia University.

Thurstone, L. L. (1938). Primary mental abilities. Chicago: University of Chicago Press.

Thurstone, L. L. (1944). A factorial study of perception. Chicago: University of Chicago Press.

Tillotson, M. L. (1985). The effect of instruction in spatial visualization on spatial abilities and mathematical problem solving. (Doctoral Dissertation, The University of Florida, 1984). Dissertation Abstracts International, 45(9), 2792–A.

Tobias, S. (1978). Overcoming math anxiety. Massachusetts: Houghton Mifflin Company.

Vandenburg, S. G. (1969). A twin study of spatial ability. Multivariate Behavioral Research, 4, 273–294.

Vandenburg, S. G. (1975). Sources of variance in performance on spatial tests. In J. Eliot & N. J. Salkind (Eds.), Children's spatial development (pp. 57–66). Springfield, MA: Thomas.

Vandenburg, S. G., & Kuse, A. R. (1979). Spatial ability: A critical review of the sex-linked major gene hypothesis. In M. A. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning (pp. 67–95). New York: Academic Press.

Walker, J. T., Krasnoff, A. G., & Peaco, D. (1981). Visual spatial perception in adolescents and their parents: The X-linked recessive hypothesis. Behavior Genetics, 11(4), 403–413.

West, R. L., Morris, C. W., & Nichol, G. T. (1985). Spatial cognition on nonspatial tasks: Finding spatial knowledge when you're not looking for it. In R. Cohen (Ed.), The development of spatial cognition (pp. 13–39). New Jersey: Lawrence Erlbaum Associates.

Wheatley, G. H., Frankland, R. L., Mitchell, R., & Kraft, R. (1978). Hemispheric specialization and cognitive development: Implications for mathematics education. Journal for Research in Mathematics Education, 9(1), 20–32.

Wheatley, G. H., Brown, D. L. & Solano, A. (1994). Long term relationship between spatial ability and mathematical knowledge. In D. Kirshner (Ed.), Proceedings of the 16th annual meeting of psychology of mathematics education-NA, Baton Rouge, LA., 225–231.

Yen, W. M. (1975). Sex-linked major-gene influences on selected types of spatial performance. Behavior Genetics, 5(3), 281–298.

Yen, W. M. (1975). Independence of hand preference and sex-linked effects on spatial performance. Perceptual and Motor Skills, 41, 311–318.

Zimmerman, W. S. (1954). Hypotheses concerning the nature of the spatial factors. Educational and Psychological Measurement, 14, 396–400.

APPENDICES

APPENDIX A

HUMAN RIGHTS BOARD APPROVAL LETTER

Auburn University

Auburn, Alabama 36849-5174

Associate Provost and
Vice President for Research
Telephone: (334) 844-4784
FAX: (334) 844-5971

Office of Human Subjects
Institutional Review Board
for the Use of Human Subjects in Research
307 Samford Hall
Telephone: (334) 844-5966
FAX: (334) 844-4391

July 8, 1999

MEMO TO: Rebecca R. Robichaux
Curriculum & Teaching

PROTOCOL TITLE: "A Comparison of Spatial Visualization & Related Variables in Undergraduate Students Majoring in Arch., Mech. Eng, Math and Math Ed."

IRB File: #99-120 EX 9907

The referenced protocol was approved "Exempt" from further review under 45 *CFR* 46.101 (b)(2) by IRB procedure on July 8, 1999. You should retain this letter in your files, along with a copy of the revised protocol and other pertinent information concerning your study. If you should anticipate a change in any of the procedures authorized in protocol #99-120, you must request and receive IRB approval prior to implementation of any revision. Please reference the above IRB File in any correspondence regarding this project.

If you will be unable to file a Final Report on your project before July 8, 2000, you must submit a request for an extension of approval to the IRB no later than July 1, 2000. If your IRB authorization expires and/or you have not received written notice that a request for an extension has been approved prior to July 8, 2000, you must suspend the project immediately and contact the Administrator of Human Subjects for assistance.

The Final Report will be required to close your IRB project file. For your convenience, a copy of that form is attached to this letter.

If you have any questions concerning this Board action, please contact Ms. Jeanna B. Sasser at 844-5966.

Sincerely,

Jeanna B. Sasser

Jeanna B. Sasser, Administrator
Institutional Review Board for the
Use of Human Subjects in Research

xc: Dr. Andrew M. Weaver
Dr. E. S. Senger

A LAND-GRANT UNIVERSITY

APPENDIX B

SPATIAL VISUALIZATION TEST

SPATIAL VISUALIZATION TEST

DO NOT WRITE ON THIS TEST BOOKLET.

READ QUESTIONS CAREFULLY.

SELECT THE ANSWER TO THE QUESTION.

MARK YOUR ANSWER ON THE ANSWER SHEET.

	A	B	C	D	E
EXAMPLE	①	●	③	④	⑤

BE SURE TO FILL THE CIRCLE COMPLETELY.

ERASE COMPLETELY WHEN NECESSARY.

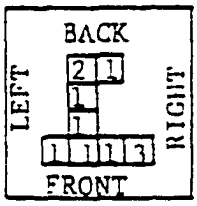
MARK ONLY IN THE RESPONSE CIRCLES PROVIDED.

MAKE NO STRAY MARKS ON THE ANSWER SHEET.

STOP: WAIT FOR INSTRUCTIONS.

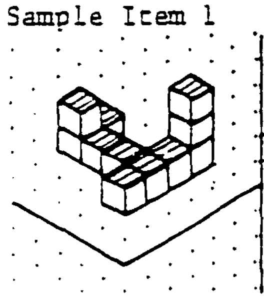
Do these sample items and then wait for further instructions.

This is an example of the mat plan of a building. The number in each square tells how many cubes are to be placed on that square.



Use the information in the mat plan to answer the two sample items.

Sample Item 1



This is a corner view of the building above. Which corner was it drawn from?

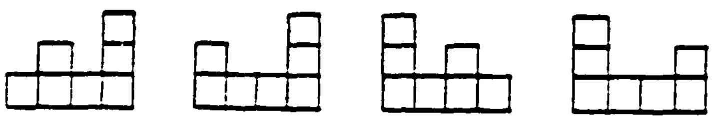
A	B	C	D
FRONT-RIGHT	BACK-RIGHT	BACK-LEFT	FRONT-LEFT

Sample 1. A (1) B (2) C (3) D (4)

Sample Item 2

These are the views of the same building, when seen straight on from the sides. Which is the FRONT VIEW?

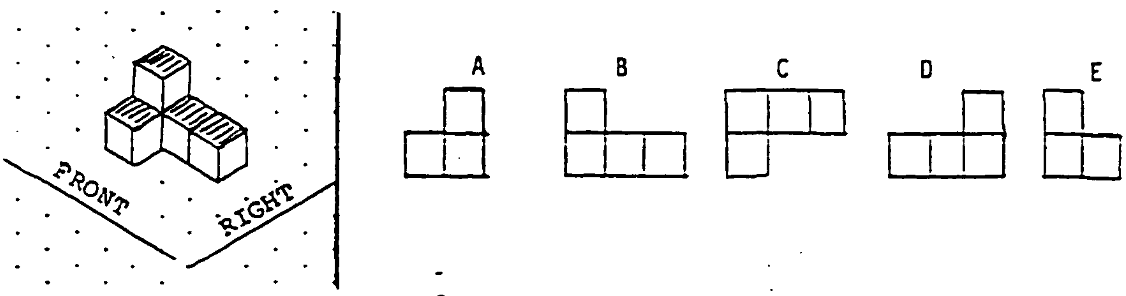
A B C D



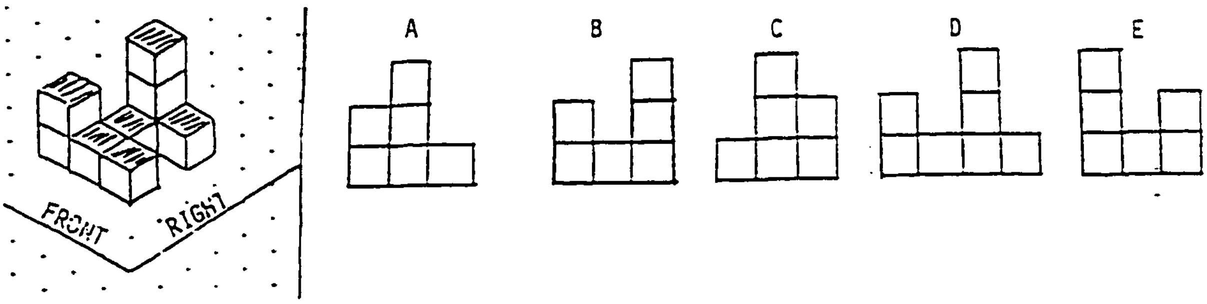
Sample 2. A (1) B (2) C (3) D (4)

STOP: Wait until you are told to begin.

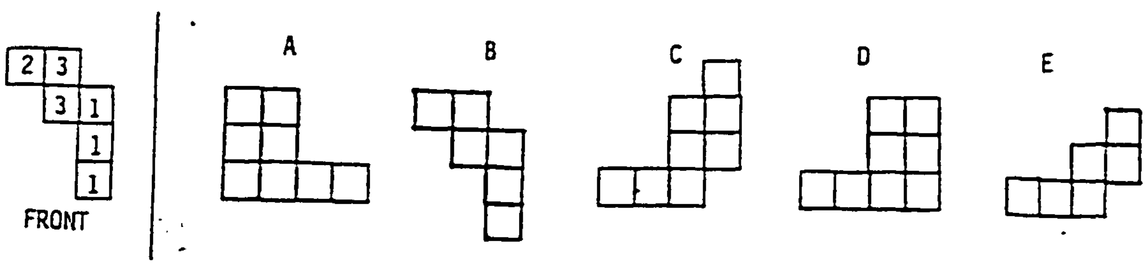
1. You are given a picture of a building drawn from the FRONT-RIGHT corner.
Find the RIGHT VIEW.



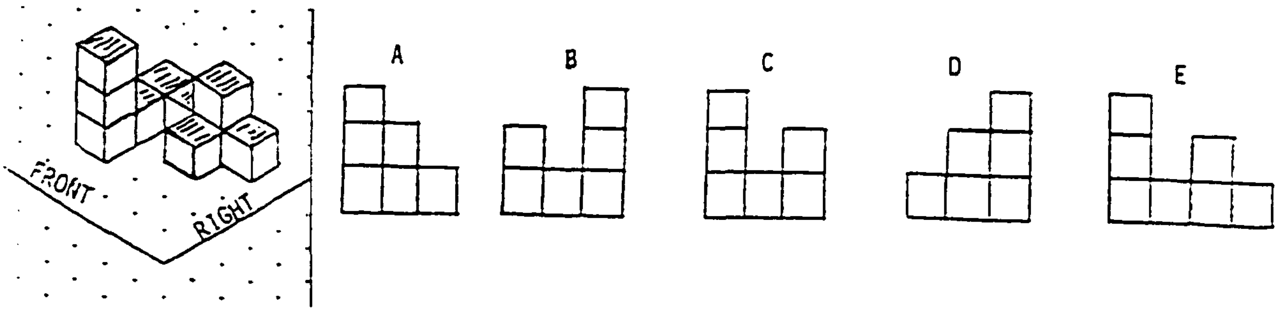
2. You are given a picture of a building drawn from the FRONT-RIGHT corner.
Find the BACK VIEW.



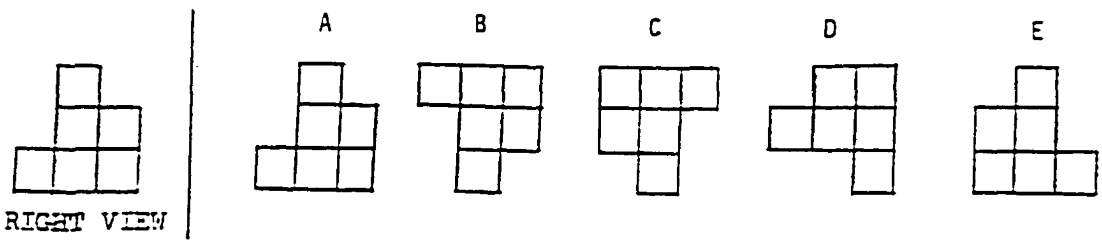
3. You are given the mat plan of a building.
Find the RIGHT VIEW.



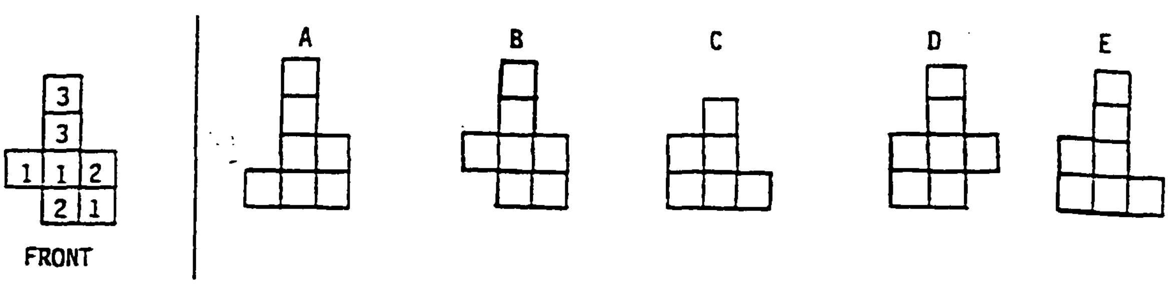
4. You are given a picture of a building drawn from the FRONT-RIGHT corner.
Find the <u>LEFT VIEW</u>.



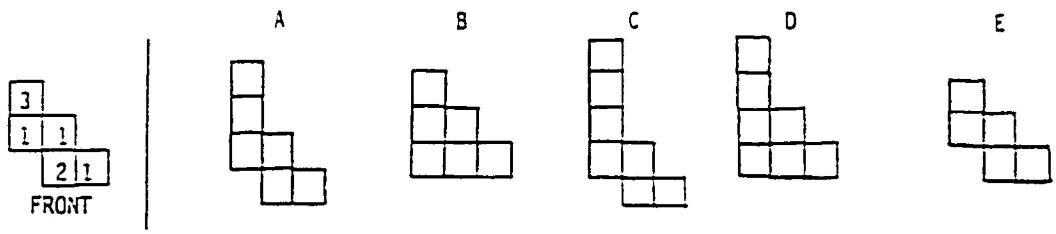
5. You are given the RIGHT VIEW of a building.
Find the <u>LEFT VIEW</u>.



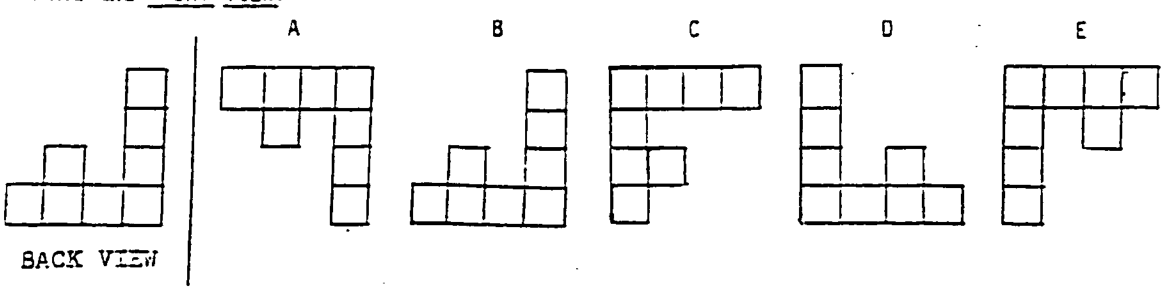
6. You are given the mat plan of a building.
Find the <u>BACK VIEW</u>.



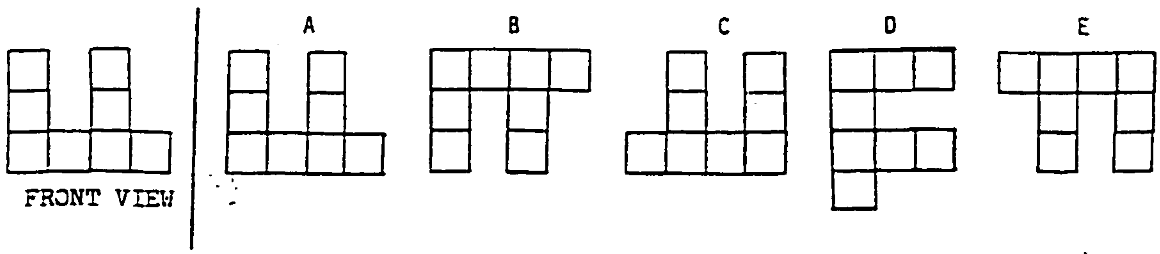
7. You are given the mat plan of a building.
Find the FRONT VIEW.



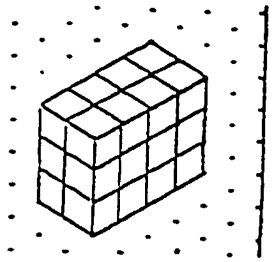
8. You are given the BACK VIEW of a building.
Find the FRONT VIEW.



9. You are given the FRONT VIEW of a building.
Find the BACK VIEW.

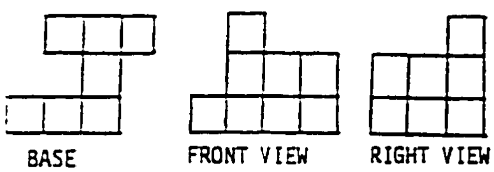


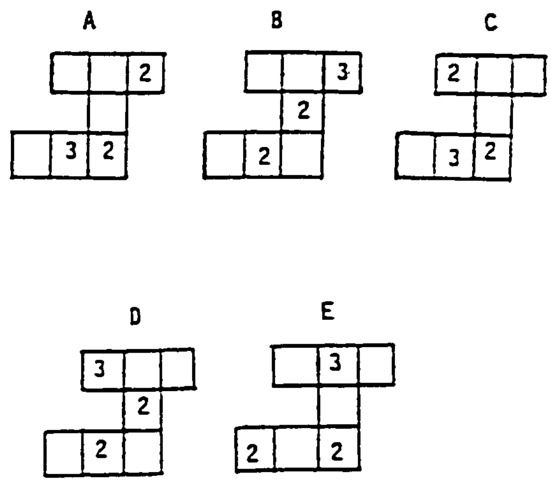
10. How many cubes are needed to build this rectangular solid ?



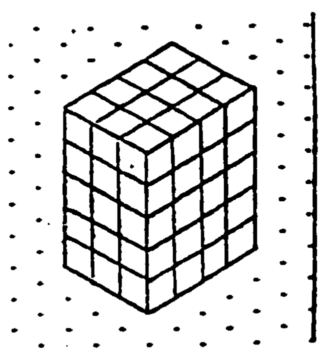
A	B	C	D	E
18	24	26	36	52

11. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building. Find the mat plan that can be completed to fit the building.



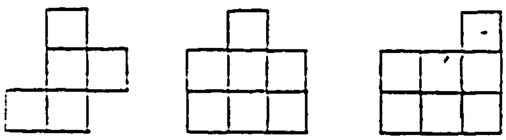


12. How many cubes are needed to build this rectangular solid?

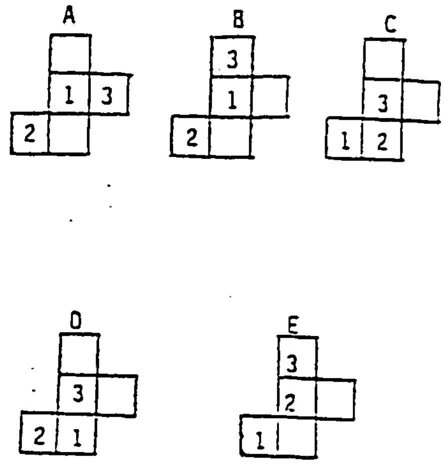


A	B	C	D	E
36	47	60	72	94

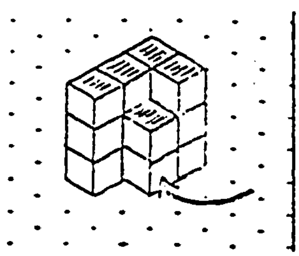
13. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building. Find the mat plan that can be completed to fit the building.



BASE FRONT VIEW RIGHT VIEW

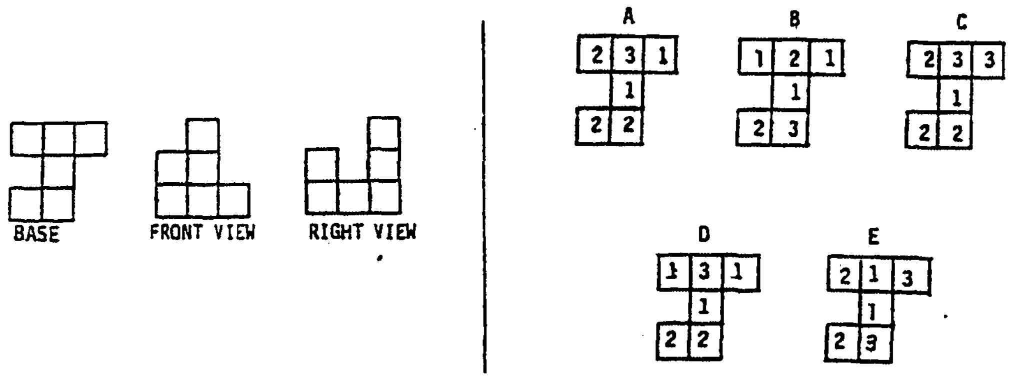


14. How many cubes touch the indicated cube face to face?

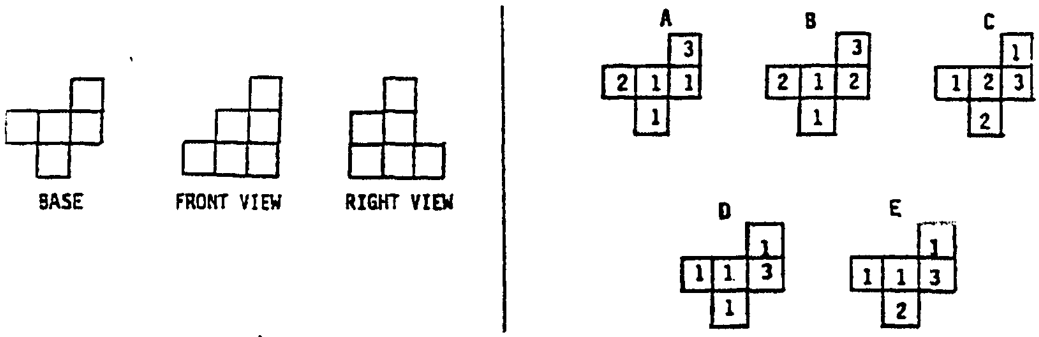


A	B	C	D	E
1	2	3	4	5

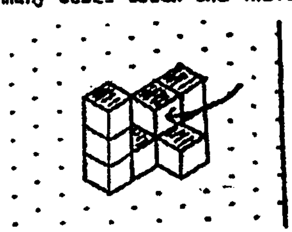
15. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building.
Find the mat plan for the building that uses the greatest number of cubes and also fits the given base and views.



16. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building.
Find the mat plan for the building that uses the least number of cubes and also fits the given base and views.

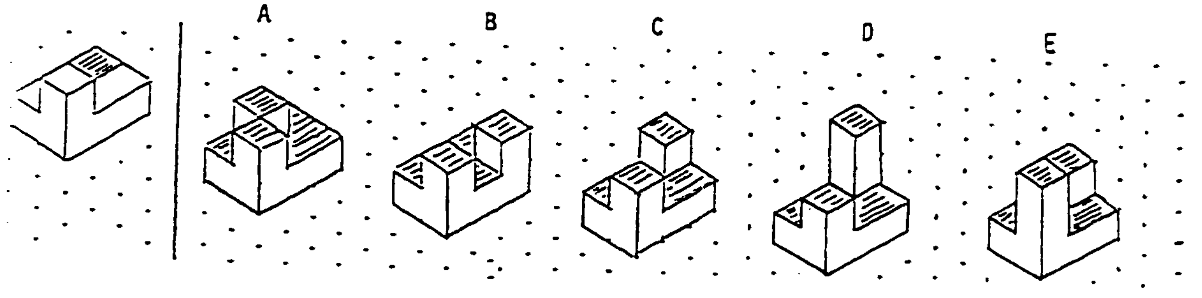


17. How many cubes touch the indicated cube face to face?

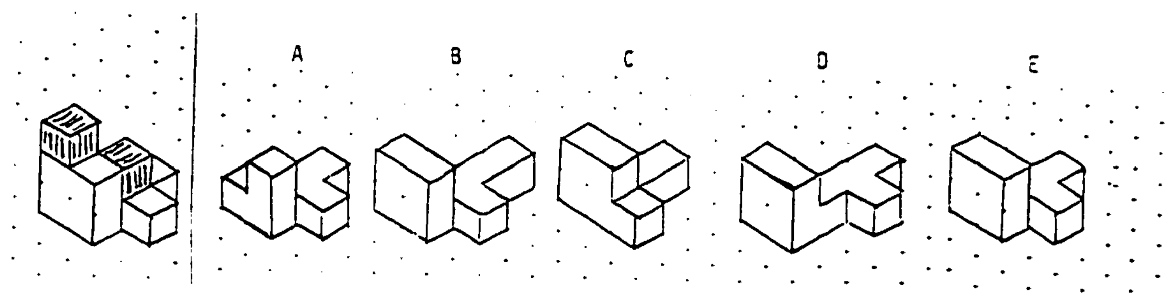


A	B	C	D	E
1	2	3	4	5

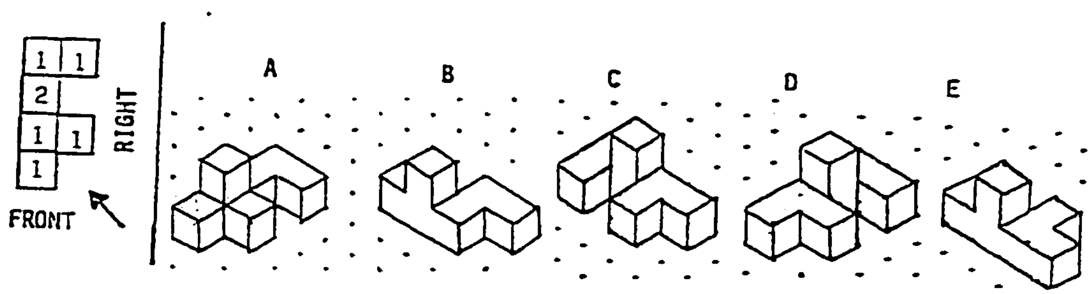
18. If a cube were added to the shaded face of the given building, what would the new building look like?



19. If the shaded cubes were removed from the given building, what would the new building look like?

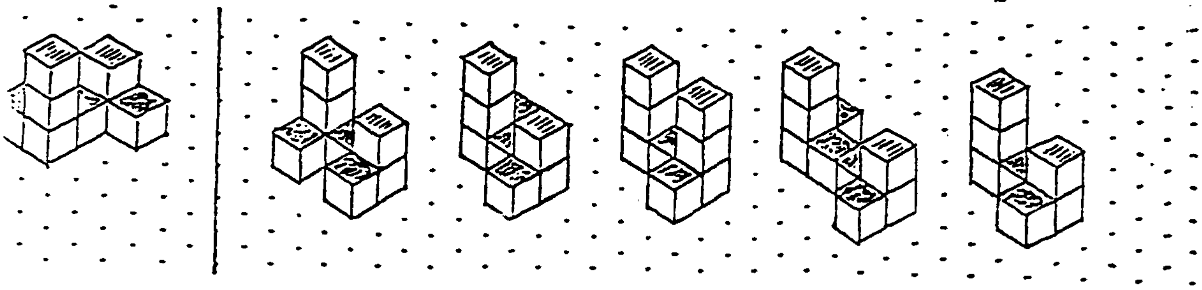


20. Find the view from the FRONT-RIGHT corner.

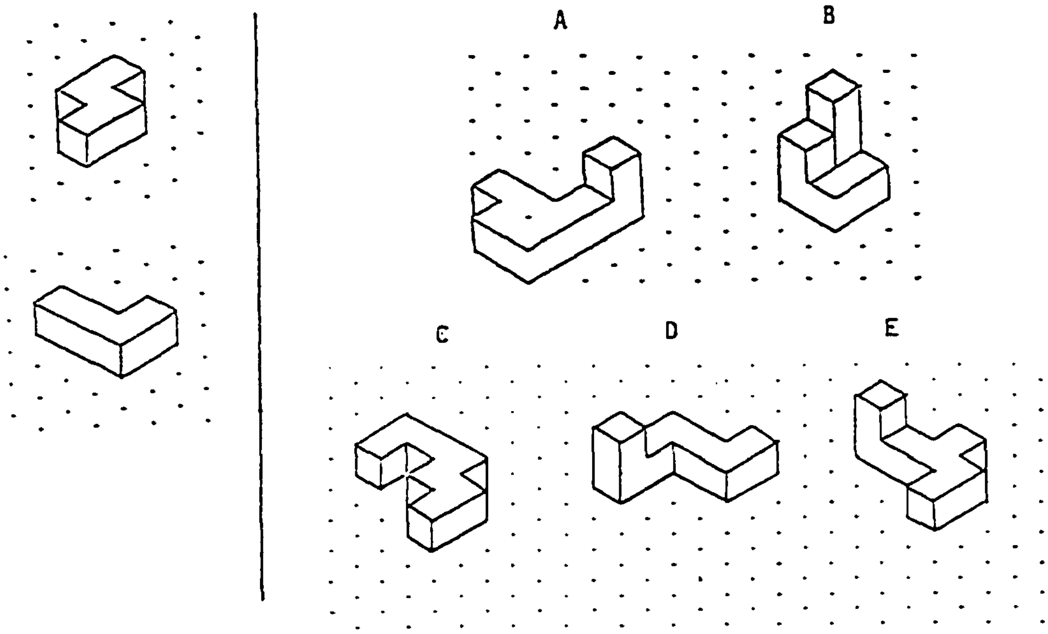


21. Find another view of the first building.

A B C D E

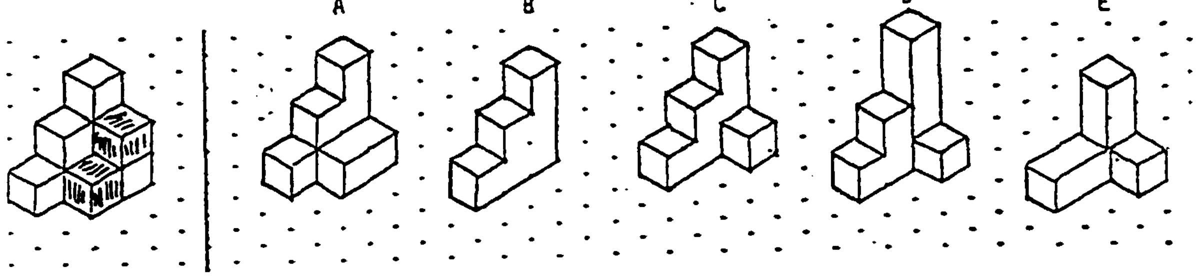


22. Which of these buildings can be made from the two pieces given?

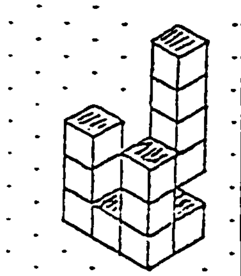


23. If the shaded cubes were removed from the given building, what would the new building look like?

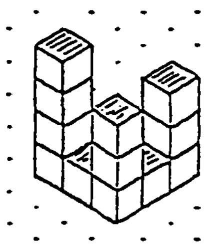
A B C D E



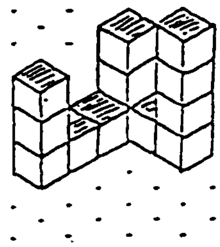
24 Find another view of the first building.



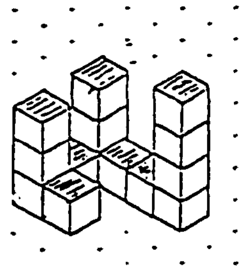
A



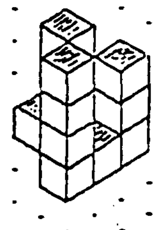
B



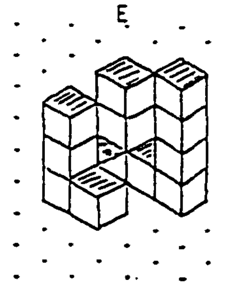
C



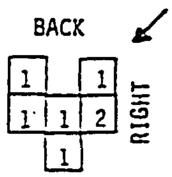
D



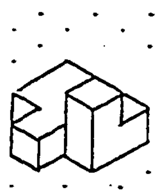
E



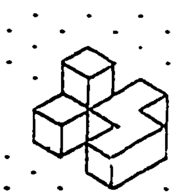
25. Find the view from the <u>BACK-RIGHT</u> corner.



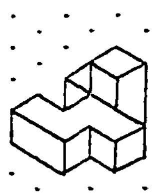
A



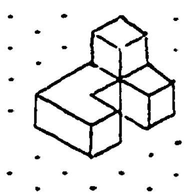
B



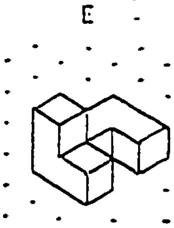
C



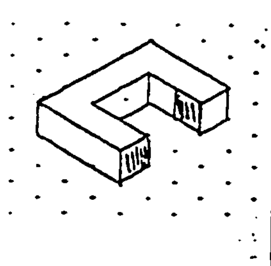
D



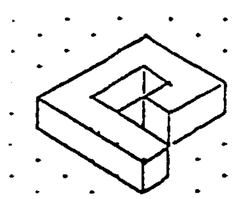
E



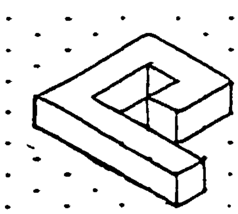
26. If a cube were added to <u>each</u> shaded face of the given building, what would the new building look like?



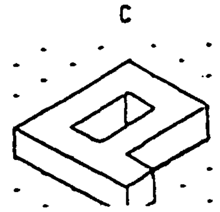
A



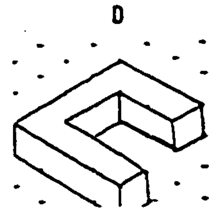
B



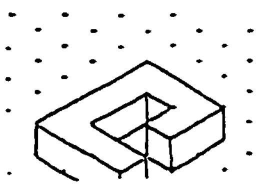
C



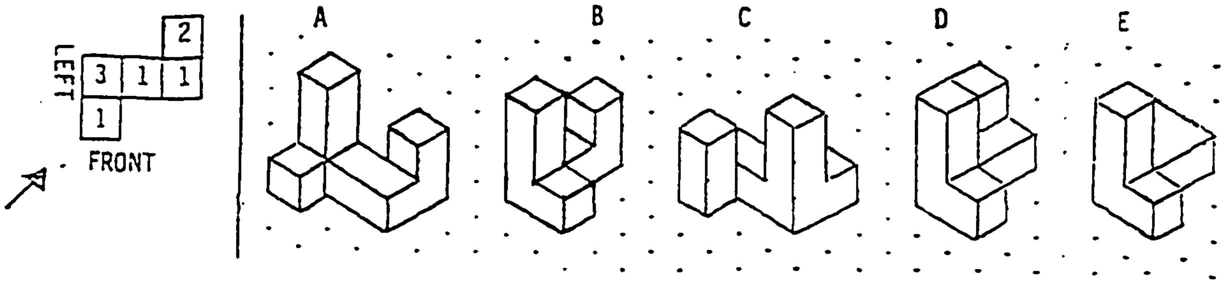
D



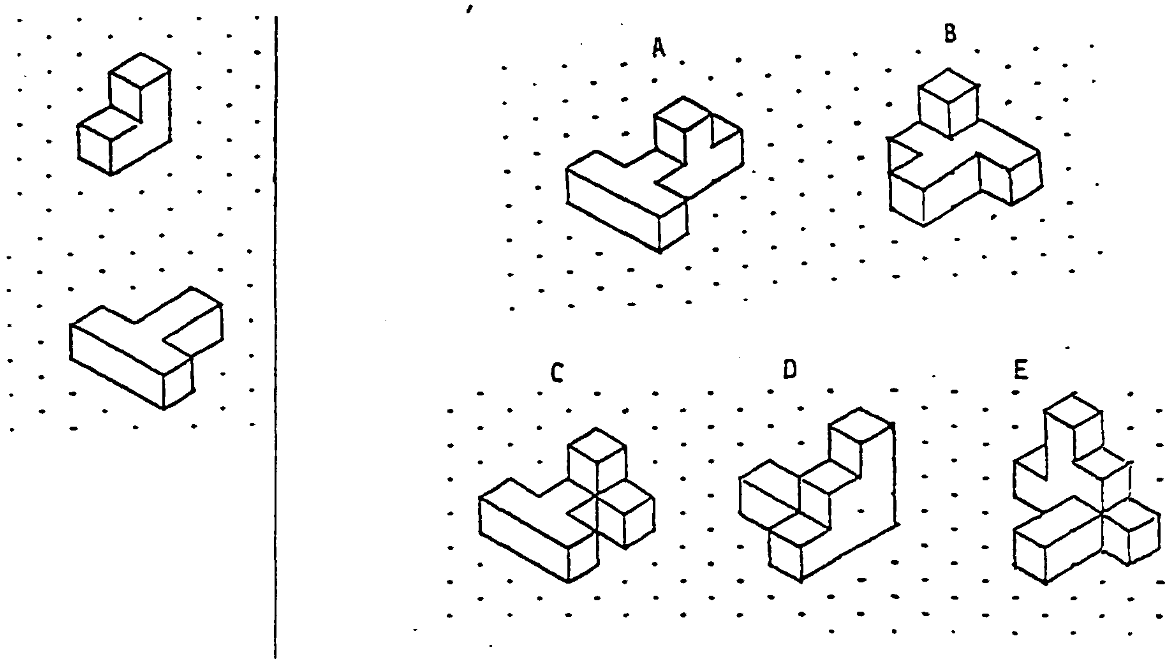
E



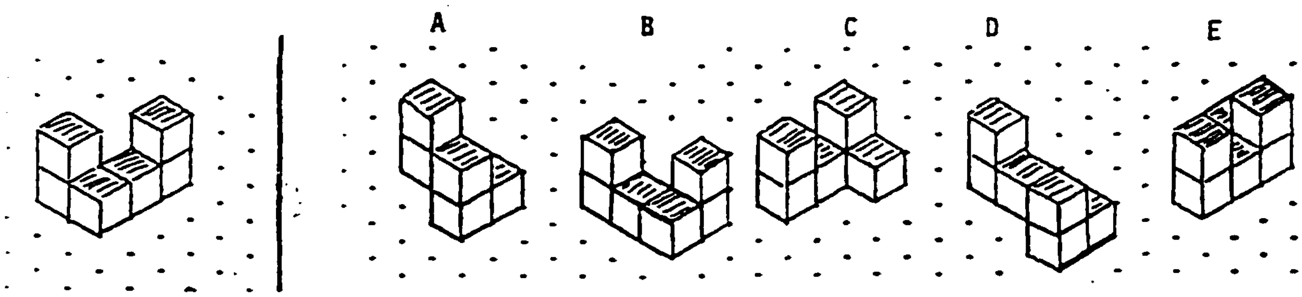
27. Find the view from the FRONT-LEFT corner.



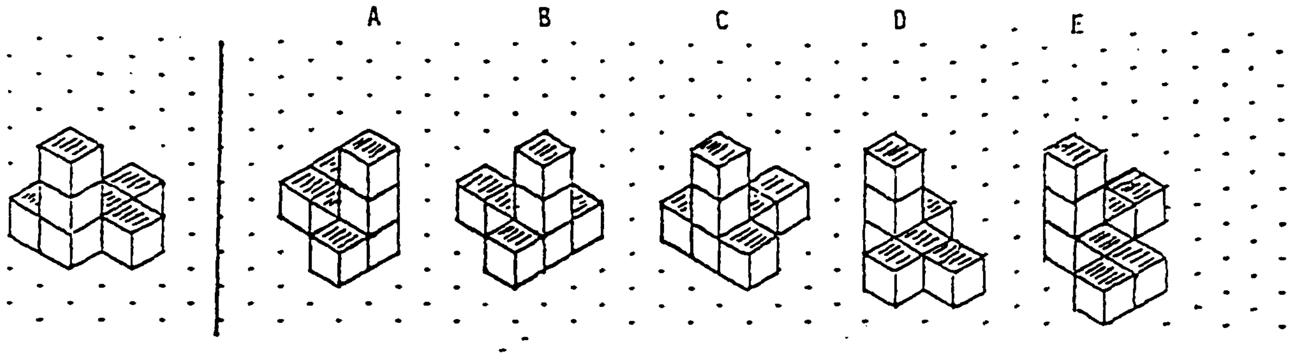
28. Which of these buildings can be made from the two pieces given?



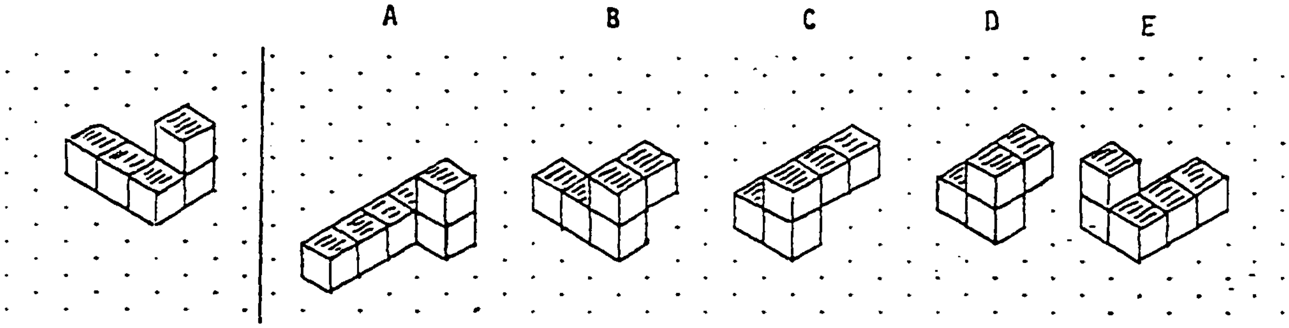
29. Find another view of the first building.



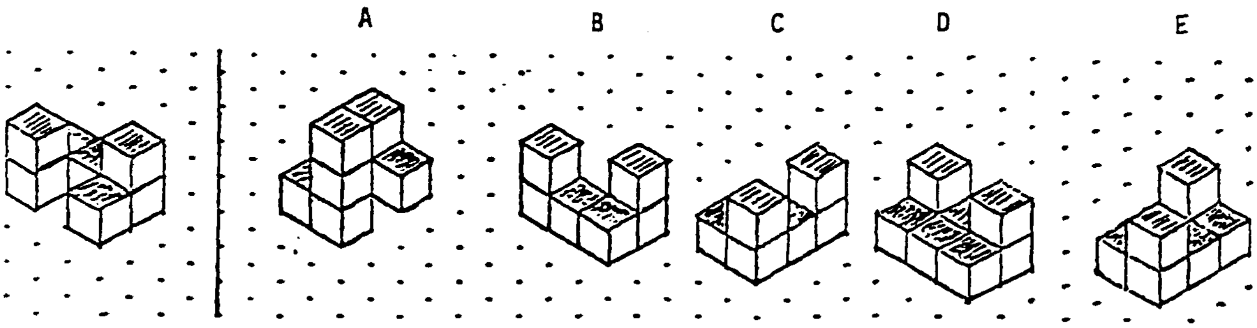
30. Find another view of the first building.



31. Find another view of the first building.



32. Find another view of the first building.



SPATIAL VISUALIZATION
TEST KEY

1.	A	18.	C
2.	C	19.	E
3.	D	20.	D
4.	B	21.	B
5.	E	22.	A
6.	C	23.	C
7.	B	24.	C
8.	D	25.	E
9.	C	26.	A
10.	B	27.	D
11.	D	28.	D
12.	C	29.	A
13.	B	30.	D
14.	C	31.	D
15.	A	32.	E
16.	E		
17.	B		

APPENDIX C

MATHEMATICAL PROCESSING INSTRUMENT

MATHEMATICAL PROCESSING INSTRUMENT

IMPORTANT:

1. **Do not** write on this problem sheet. Write your solutions on the solution sheet provided.
2. For each problem, **you are required to explain your work as much as you possible can.**
3. You are required to attempt **all** problems.

SECTION A:

A-1. One day, John and Peter visit a library together. After that, John visits the library regularly every two days, at noon. Peter visits the library every three days, also at noon. If the library opens every day, **how many days** after the first visit will it be before they are, once again, in the library together?

A-2. A straight path is divided into two unequal sections. The length of the second section is half the length of the first section. What fraction of the whole path is the first section?

A-3. At each of the two ends of a straight path a man planted a tree, and then every 5 m along the path (on one side only) he also planted another tree. The length of the path is 25 m. How many trees were planted on the path altogether?

SECTION B:

B-1. A track for an athletics race is divided into three unequal sections. The length of the whole track is 450 m. The length of the first and second sections combined is 350 m. The length of the second and third sections combined is 250 m. What is the length of each section?

B-2. A mother is seven times as old as her daughter. The difference between their ages is 24 years. How old are they?

B-3. At first, the price of one kg of sugar was three times as much as the price of one kg of salt. Then the price of one kg of salt was increased by half of its previous price, while the price of sugar was not changed. If the price of salt is now 30 cents per kg, what is the price of sugar per kg?

B-4 A saw in a sawmill saws long logs, each 16 m long, into short logs, each 2 m long. If each cut takes two minutes, how long will it take for the saw to produce eight short logs from one long log?

B-5. A passenger who had travelled half his journey fell asleep. When he awoke, he still had to travel half the distance that he had travelled while sleeping. For what part of the entire journey had he been asleep?

B-6. There was twice as much milk in one can as in another. When 20 liters of milk had been poured from both cans, then there was three times as much milk in the first can as in the second. How much milk was there originally in each can?

SECTION C:

C-1. The distance that a tourist travelled by train is 150 km longer than the course he travelled by steamer, and 750 km longer than his journey on foot. Determine the length of his entire trip if it is known that the distance he covered on foot was 1/3 of the distance he covered by steamer.

C-2. A boy walks from home to school in 30 minutes and his brother takes 40 minutes. His brother left 5 minutes before he did. In how many minutes will he overtake his brother?

C-3. Two candles have different lengths and thicknesses. The long one can burn 3 ½ hours while the short one can burn 5 hours. After burning two hours, the candles are equal in length. What was the ratio of the short candle's height to the long candle's height originally?

MATHEMATICAL PROCESSING INSTRUMENT

IMPORTANT:

On this questionnaire you are asked to consider how you did the mathematical processing problems that you were recently asked to do. Every problem has three or more possible solutions.

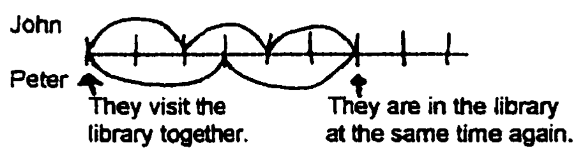
1. For every problem, you are required to indicate by placing a tick in the appropriate box on the answer sheet provided, which solution, among all the solutions presented, is the one that you used, or is very similar to the one that you used, when you first attempted the problem; whether you completed the solution or not or whether your answer is right or wrong, this does not matter.

2. If for any of the problems you think that none of the solutions presented is the one that you used, or is very similar to the one that you used, then tick the box headed "None of These". In this case, write the problem number in the space on the right-hand side of your sheet, and explain your solution as clearly as you possibly can.

SOLUTIONS:

SECTION A:

A-1 Solution 1: I solved this problem by drawing a diagram representing the days after they first visit the library.



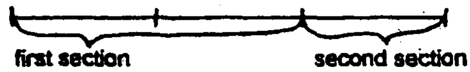
From the diagram it can be seen that, once again, they will be in the library together six days after the first visit.

A-1 Solution 2: I used the same method as for Solution 1, but I drew the diagram "in my mind" (and not on paper).

A-1 Solution 3: I solved this problem by using examples. Suppose they first visit the library together on Monday. Then after that, John will visit the library on Wednesday, Friday, Sunday, Tuesday, etc., and Peter will visit the library on Thursday, Sunday, Wednesday, etc. This means that on Sunday they will be in the library at the same time again, that is, six days after the first visit.

A-1 Solution 4: I solved this problem by saying that after the first day, John will visit the library on the third day, the fifth day, the seventh day, etc., and Peter will visit again on the fourth day, the seventh day, etc. So on the seventh day they will be in the library at the same time again; i.e. six days after the first visit.

A-2 Solution 1: I solved this problem by drawing a diagram representing the path:



From the diagram it can be seen that the first section is two-thirds of the whole path.

A-2 Solution 2: I used the same method as for Solution 1, only I drew the diagram "in my head" (and not on paper).

A-2 Solution 3: As the length of the second section is half the length of the first section, the path can be divided into three equal parts. The first section contains two parts, the second section one. Thus the first section is two-thirds of the whole path. (I did not draw or imagine any picture at all.)

A-2 Solution 4: I solved this problem by using examples.
Suppose the length of the first section is 50 m, then the length of the second section is 25 m, since the length of the second section is half the length of the first section. The length of the whole path then will be 75 m. This means that the first section (50 m) is two-thirds of the whole path.

A-3 Solution 1: I solved the problem in this way:
Every 5 m along the path a tree was planted. This means that the path was divided into 5 equal parts (25/5). Every part corresponded to one tree, but at one of the two ends of the path, the part corresponded to 2 trees. Therefore the number of trees was (4 x 1) + (1 x 2) = 6.

A-3 Solution 2: I solved the problem by imagining the path and the trees, and then counting the trees in my mind. I found there were 6 trees on the path.

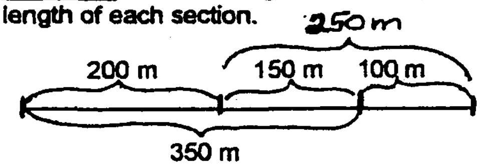
A-3 Solution 3: I solved the problem by drawing a diagram representing the path and the trees, and then counting the trees:

I found 6 trees.

SECTION B:

B-1 Solution 1: I solved this problem by imagining the track for the race and then working out the length of each section.
Length of third section = 450-350 = 100 m.
Length of first section = 450 – 250 = 200 m.
Thus length of second section = 150 m.

B-1 Solution 2: I drew a diagram which represents the track and then worked out the length of each section.



The length of the first section is 200 m, the second section is 150 m and the third section is 100 m.

B-1 Solution 3: To solve this problem I drew conclusions, with or without algebra, from the information given, and did not imagine or draw any picture at all:

The length of the whole track is 450 m.	$x + y + z = 450$
Length of first and second sections combined is 350 m.	$x + y = 350$
Conclusion: Length of third section = 450 – 350 = 100 m	$z = 100$
Length of second and third sections combined is 250 m	$y + z = 250$
Conclusion: Length of first section = 450 – 250 = 200 m	$x = 200$
Thus the length of the second section = 450 – 200 – 100 = 150	$y = 250$

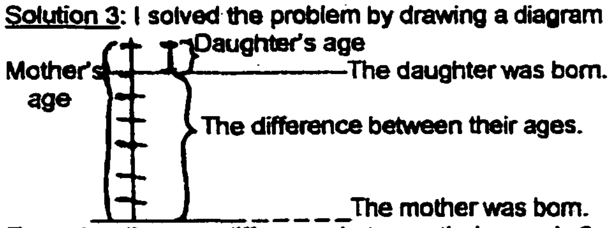
B-2 Solution 1: I solved this problem by trial and error:

Daughter's age:	Mother's age:	
2 years	26 years	No
3 years	27 years	No
4 years	28 years	Yes

Thus the daughter's age is 4 years and the mother's 28 years.

B-2 Solution 2: I solved this problem by using symbols and equations.
e.g. Let daughter's age be x years. Then mother's age is 7x years.
Difference between their ages is 6x years. Therefore 6x = 24. So x = 4.
Thus the daughter's age is 4 years and the mother's age is 28 years.

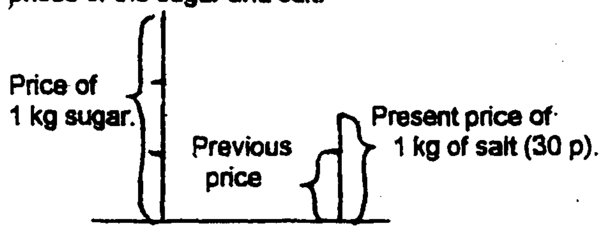
B-2 Solution 3: I solved the problem by drawing a diagram representing their ages:



From the diagram, difference between their ages is 6 equal parts; this difference is 24 years. Thus, each part represents 4 years, so the daughter's age is 4 years and the mother's age is 28 years.

B-2 Solution 4: I imagined a diagram as in Solution 3, and then reasoned that 6 parts represent 24 years, so one part represents 4 years (with or without using symbols). Thus the daughter's age is 4 years and the mother's age is 28 years.

B-3 Solution 1: I solved this problem by drawing a diagram which represented the prices of the sugar and salt.



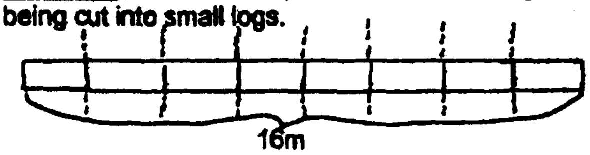
In the diagram it can be seen that after the price of salt was increased, the price of 1 kg of sugar was twice the price of 1 kg of salt (now 30 p). Thus the price of 1 kg of sugar is 60 p.

B-3 Solution 2: I used the same method as for Solution 1 but I drew the diagram "in my head" (and not on paper).

B-3 Solution 3: I solved the problem by reasoning:
The price of 1 kg of salt is now 30 p. This is 1½ times the previous price; thus the previous price was 20 p per kg. Thus the price of sugar is 3x20 p, i.e. 60 p per kg.

B-3 Solution 4: I solved the problem using symbols and equations,
e.g. Suppose the previous price of salt was x p per kg.
Then the price of sugar was 3x p per kg.
After the increase, price of salt = 1 ½ p per kg.
Thus the price of sugar is twice the present price of salt, i.e. price of salt is 60 p per kg.

B-4 Solution 1: To solve this problem, I drew a diagram representing the long log being cut into small logs.

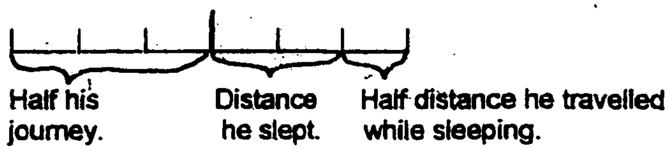


From the diagram, 7 cuts are needed to produce 8 short logs. Thus time required = 7x2 = 14 minutes.

B-4 Solution 2: As in Solution 1, but I "saw" the diagram in my mind.

B-4 Solution 3: I solved the problem reasoning:
If the long log were more than 16m long, one would need 8 cuts to produce 8 short logs. But the last cut is not needed, so 7 cuts are required.
Time taken = 7x2 = 14 minutes.

B-5 Solution 1: I drew a diagram representing the distance travelled.



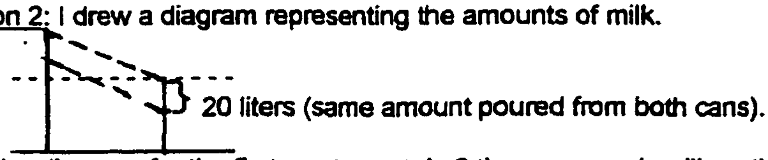
From the diagram: if the whole distance is 6 parts, he slept for 2 parts, i.e. 1/3 of the entire journey.

B-5 Solution 2: As in Solution 1, but I "saw" the diagram in my mind.

B-5 Solution 3: I solved this problem using symbols and equations,
e.g. Let the distance for which he slept be x units.
When he awoke, the remaining distance was ½ x units.
Then (x + ½ x) units constitutes half the journey.
So the whole journey was 2(x + ½ x) = 3x units.
Thus, he slept for 1/3 of the journey.

B-6 Solution 1: I solved this problem using symbols and equations,
e.g. Let original amounts of milk be x liters and 2x liters.
Amounts after pouring out are (x-20) and (2x-20) liters.
Then 3(x-20) = 2x-20, so x = 40.
Thus the original amounts of milk were 40 liters and 80 liters.

B-6 Solution 2: I drew a diagram representing the amounts of milk.

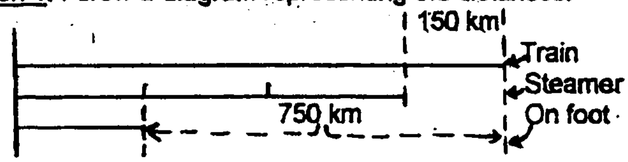


From the diagram, for the first can to contain 3 times as much milk as the second after pouring, amount remaining in second can must be 20 liters. Thus original amounts were 40 liters and 80 liters.

B-6 Solution 3: As in Solution 2, but I "saw" the diagram in my mind.

SECTION C:

C-1 Solution 1: I drew a diagram representing the distances.

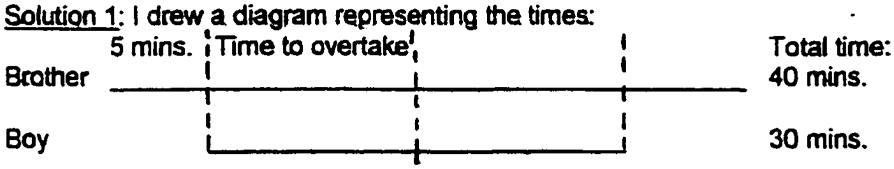


From the diagram it is clear that two thirds of the journey by steamer = 750-150 = 600 km. Thus length of journey by steamer is 900 km, by train 1050 km and on foot 300 km, and thus length of entire trip is 2250 km.

C-1 Solution 2: As in Solution 1, but I imagined the diagram.

C-1 Solution 3: I solved this problem using symbols and equations.
e.g. Let distance on foot by x km.
Then distance by steamer is 3x km and by train (x+750) km.
Thus 3x + 150 = x + 750, so x = 300.
So distance on foot is 300 km, by steamer 900 km and by train 1050 km, and thus length of entire trip is 2250 km.

C-2 Solution 1: I drew a diagram representing the times:



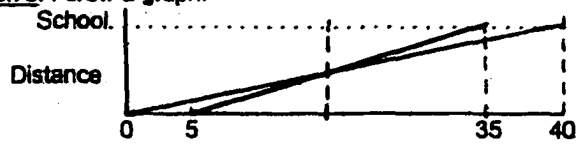
From the diagram, the boy will arrive at school 5 mins. before his brother; thus the two halves of the figure must be symmetrical, so he will overtake his brother halfway, i.e. after 15 mins.

C-2 Solution 2: As in Solution 1, but I imagined the diagram.

C-2 Solution 3: I used symbols and equations, e.g.
Let distance to school be d units and let the boy overtake his brother in x mins. Then his brother has walked for (x+5) mins. The boy's speed is d/30 units per min., and his brother's, d/40. When he overtakes, they have gone the same distance. Thus d/30(x) = d/40(x+5), and thus x =15.
The boy overtakes his brother in 15 mins.

C-2 Solution 4: I solved this problem by calculating their times to reach the halfway point. It tales the boy 15 mins. and his brother 20 mins. But the brother left 5 mins. earlier; thus they will reach the halfway point together.
The boy overtakes his brother in 15 mins.

C-2 Solution 5: I drew a graph:

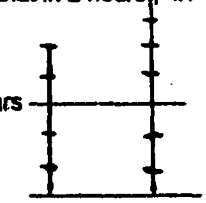


By symmetry the graphs intersect midway. Thus the boy overtook his brother in 15 minutes.

C-3 Solution 1: I reasoned from the data given:
After 2 hours, fraction of tall candle used up was 4/7; thus 3/7 remained.
At this time, fraction of short candle used up was 2/5; thus 3/5 remained.
But these heights were equal.
Thus 3/7 times the length of tall candle = 3/5 times length of short candle.
Therefore required ratio = 5/7.

C-3 Solution 2: I reasoned as in Solution 1, but used algebraic symbols and equations.

C-3 Solution 3: I drew a diagram representing the lengths of the candles, after reasoning that in 2 hours, 4/7 of the long candle and 2/5 of the short one were used up.



It can be seen from the diagram that the required ratio is 5/7.

C-3 Solution 4: As in Solution 3, but I imagined the diagram.

C-3 Solution 5: I imagined or drew on paper a diagram similar to that in Solution 3, and then reasoned as follows:
After 2 hours, the short candle had 3 hours left to burn and the long one, 1½ hours. The heights were equal; thus the short candle was twice as thick as the long candle. Therefore, the required ratio was 5/(3 ½ x2), i.e. 5/7.

C-3 Solution 6: I reasoned as in Solution 5, but I drew or imagined no picture at all.

Classification of Solutions from the Mathematical Processing Instrument According to their Visuality

Key: V = visual method of solution
N = nonvisual method of solution

	Problem Number	Solution numbers: 1	2	3	4	5	6
Section A							
	A-1	V	V	N	N		
	A-2	V	V	N	N		
	A-3	N	V	V			
Section B							
	B-1	V	V	N			
	B-2	N	N	V	V		
	B-3	V	V	N	N		
	B-4	V	V	N			
	B-5	V	V	N			
	B-6	N	V	V			
Section C							
	C-1	V	V	N			
	C-2	V	V	N	N	V	
	C-3	N	N	V	V	V	N

APPENDIX D

BACKGROUND INFORMATION QUESTIONNAIRE

Background Information: **PSUEDONYM : ___________**

For each of the following items, please check ONE response:

Gender: ___ **Female**
___ **Male**

Major : ______ **Engineering**
______ **Architecture**
______ **Mathematics**
______ **Math. Education**

Overall GPA: __________

Composite ACT: __________

Math ACT: __________

Annual Family Income :
_____ **less than $25,000**
_____ **$25,000 - $50,000**
_____ **$50,000 - $75,000**
_____ **more than $75,000**

Ethnicity :
_____ **African American**
_____ **Asian**
_____ **Caucasian**
_____ **Hispanic**
_____ **Other**

Handedness: _____ **Primarily Left**
_____ **Primarily Right**

Answer each of the following as precisely as possible.

Mother's Occupation (before retirement, if applicable) :

____

Describe as detailed as you can the work that your Mother does in this occupation:

____

____

Father's Occupation (before retirement, if applicable):

____

Describe as detailed as you can the work that your Father does in this occupation:

____

____

Do you have any siblings (yes or no)? ______
If yes, how many? ________
How many are older than you? ______________________________

What was your favorite high school MATH course (i.e. algebra, geometry, advanced math, business math, trigonometry, calculus, etc.) with respect to content?

____

Did you at one time or do you currently play one or more musical instruments (yes or no; consider your voice to be a "musical instrument")? __________________________

If yes, which instruments did you or do you play? __________________________

____

For how many years were you trained in playing each instrument? _______________

____

Were you ever a member of a musical group (concert band, choir, orchestra, rock group)? ___________ If yes, which one(s)? ___________________________________

Describe any other details of your musical experiences, not already mentioned.

____

____

List your past and present hobbies: (Try to be as specific as possible.)

PAST	PRESENT
____________________	________________________
____________________	________________________
____________________	________________________
____________________	________________________
____________________	________________________
____________________	________________________

As a young child, what was your favorite toy? __________________________

____

As a young child, what was your favorite "play activity"? __________________

____

While growing up, did you have access to any type of "building blocks " (yes or no)? _______

If yes, explain what kind of building blocks you had access to. _______________

____

APPENDIX E

STUDENT RECRUITING EMAIL MESSAGE

E-mail invitation for individual Math / Math Ed. Majors to participate in research study

Please allow me to introduce myself. My name is Rebecca R. Robichaux and I am a Doctoral student in Mathematics Education. I am contacting you today to discuss your participation in a research study.

You have been identified by either one of your former professors, your advisor, or by a class roll search to be an excellent candidate for participation in this research study involving the Mathematics Techniques used in problem solving by juniors or seniors in your respective major.

You are being formally requested through this E-mail to participate in this study by attending a brief research session to be held in Room 137B of the Math Annex on

____________________.

Please forward this message back to me with one of the following responses identified:

______ I will meet at the above stated time and location.

______ I would rather meet at the following time:____________________.

______ I would rather not participate.

Thank-you in advance for your help and cooperation in this matter.

Rebecca R. Robichaux

APPENDIX F

SUMMARY SCRIPT FOR PARTICIPATION IN STUDY

"Script" to Prospective Volunteers in Study

Hi, my name is Rebecca Robichaux. I'm a doctoral student in Math Education and am interested in studying the ways that senior and junior undergraduates in certain fields, like architecture, mechanical engineering, mathematics, and mathematics education, solve various types of math problems and puzzles. I'm hoping that you'll help me with this study by providing data through completion of a mathematical processing instrument, a cube puzzles instrument and a questionnaire of background information. This will take at most 55 minutes of your time.

Your instructor has been supportive of my study in allowing me to use class time to do this. (This statement will not be used for those math and math ed. majors being recruited through email.)

Please take a minute to read over this information letter, which states what I've just briefly explained.

Thank-you for agreeing to participate. We'll start with the Mathematical Processing Instrument. After everyone has completed it, we'll continue on with the cube puzzles, which will be timed.

APPENDIX G

INFORMATION SHEET

Auburn University

Auburn University, Alabama 36849-5212

Curriculum and Teaching
5040 Haley Center

Telephone: (334) 844-4434
ATTNet: 221-4434

INFORMATION LETTER
For Participation in a Study of Mathematics Techniques

You are respectfully invited to participate in a study of mathematics techniques. The goal of this study will be to determine if there are any differences in the mathematics techniques used by students majoring in Architecture, Mechanical Engineering, Mathematics, and Mathematics Education during their junior or senior years of enrollment. You have been identified as an excellent candidate for study due to your choice in and progress within your respective major. The information and results obtained from this study will be beneficial to researchers who are interested in better understanding the mathematics techniques used by college students majoring in the above areas.

If you decide to participate in this study, you will be required to complete a short background information sheet and to complete two different mathematical techniques instruments. This work will be completed either during class-time or at a more convenient time to be determined by yourself *(60 minutes maximum)*. Participation in this study will neither expose yourself to any academic or otherwise personal risks nor will it entitle you to any sort of compensation for your time.

All information obtained in connection with this study will remain anonymous. You may discontinue participation at any time without penalty. Your decision of whether or not to participate will not jeopardize your current or future standings with Auburn University.

If you have any questions regarding this study, please contact:
Rebecca R. Robichaux (334) 844-6883
robicrr@mail.auburn.edu
5068 Haley Center
Auburn University, AL 35237

For more information regarding your rights as a participant, you may contact the Office of Human Subjects, Ms. Jeanna Sasser, at (334) 844-5966.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. IF YOU DECIDE TO PATICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

Rebecca R. Robichaux
Investigator's Signature

JMAN SUBJECTS
=FICE OF RESEARCH
ROJECT # 99-120 EX 9907
PROVED 7/8/99 TO 7/8/2000

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