ENHANCEMENT OF SPATIAL ABILITY IN GIRLS IN A SINGLE-SEX ENVIRONMENT THROUGH SPATIAL EXPERIENCE AND THE IMPACT ON INFORMATION SEEKING

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The test scores of spatial ability for women lag behind those of men in many spatial tests. On the Mental Rotations Test (MRT), a significant gender gap has existed for over 20 years and continues to exist. High spatial ability has been linked to efficiencies in typical computing tasks including Web and database searching, text editing, and computer programming. The relationships between the components of visuospatial ability and performance are complex. However, research strongly indicates that a connection exists, and further research is necessary to determine the interactions between the variables of environment, genetics, and spatial training. Spatial experience can enhance spatial skills. However, to what extent spatial skills can be enhanced in female adolescents through a spatial curriculum to reduce the gap in scores has not been fully researched, nor has the impact of spatial skill on information seeking.

This research project investigated spatial skill in adolescent females by examining (1) the extent to which the intervention of teaching a spatial curriculum in a single-sex setting could improve mental rotation test scores, and (2) the impact of spatial skills on an information seeking task in a single-sex setting. The extent to which a spatial visualization curriculum can improve MRT scores from a pretest to a posttest for girls was the first factor examined using a spatial visualization curriculum. The information seeking task used 4 tasks from a doctoral study and utilized the scholarly journal database JSTOR® (JSTOR, Ann Arbor, MI, www.jstor.org).

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INTRODUCTION

Statement of the Problem

Spatial ability, also called visuospatial ability, affects daily life in myriad ways and impacts information seeking, academic success, and educational and career choices, especially in the STEM careers of science, technology, engineering, and mathematics (Halpern & Collaer, 2005; Quaiser-Pohl & Lehmann, 2002). The test scores of spatial ability for women lag behind those of men in many spatial tests. For example, on the Mental Rotations Test (MRT), a statistically significant gender gap has existed for over twenty years and continues to exist (Voyer & Saunders, 2004). High spatial ability has been linked to efficiencies in typical computing tasks including web and database searching, text editing, and computer programming (Egan, 1988; Thomas, 1998). The relationships between visuospatial ability and performance in mathematics and science are complex. However, research strongly indicates that a connection exists, and further research is necessary to determine the interactions between the variables of environment, genetics, and spatial training. Spatial experience can enhance spatial skills (Halpern, 2000). However, to what extent spatial skills can be enhanced in female adolescents through a spatial curriculum to reduce the gap in scores has not been fully researched, nor has the impact of spatial ability on information seeking (Terlecki, Newcombe, & Little, 2007; Thomas, 1998).

This chapter outlines the background and purpose for the study, identifies the theoretical foundations for the study, provides definitions for the terms used, and discusses the assumptions and the potential significance of the study.

Background

Daily life tasks require spatial ability: navigating both in the physical world as well as the virtual world, reading graphs, maps, and diagrams, understanding multimedia instructions and animations, assembling furniture or toys, estimating space allocations (as in packing luggage or containers or moving vans), performing in many sports, estimating distances, estimating velocity and direction of oncoming objects, playing chess, dancing, and playing videogames (Brown & Parsons, 2007; Halpern, 2000; Shah & Miyake, 2005; Sherman, 1978; Terlecki, Newcombe, & Little, 2007). The medical profession research on spatial ability involves the implementation and use of virtual tools, while meteorologists research the individual differences in spatial ability and the impact on map and weather display interpretation. Researchers on visuospatial thinking work in fields as disparate as chemistry, architecture, radiology, and multimedia instruction (Shah & Miyake, 2005). Researchers have found a statistically significant relationship between spatial ability and academic success in science and mathematics (Casey, Nutall, Pezaris, & Benbow, 1995; Ferk, Vrtacnik, Blejec, & Gril, 2003). Engineering schools have found that spatial visualization skills determine how well a student can utilize *3-D* modeling programs (Sorby, 2000, 2001). Students with low spatial ability struggle with visualizing concepts in chemistry (Ferk, Vrtacnik, Blejec, & Gril, 2003). Students with low spatial ability also struggle in information seeking, text editing, and programming tasks (Egan, 1988; Greene, Gomez, & Devlin, 1986; Thomas, 1998; Vincente & Williges, 1988).

Research suggests that while some aspects of spatial ability are largely innate, some can be enhanced by practice and training. Students with problems in a variety of

areas of linguistic ability can often be identified early and remediated. However, many a student struggling with visuospatial learning disability is identified much later, often too late for effective remediation. Students such as these are often labeled “nonspecific learning disabled," and struggle with visuospatial skills (Cornoldi, Venneri, Marconato, et al., 2003).

What is striking is that much of the research, across multiple disciplines at the graduate and undergraduate level, suggests an acute awareness of the need for visuospatial training and enhancement of skills among children and young adults with low spatial ability. That awareness does not seem to translate into curricular change at the kindergarten through twelfth grade levels. While the gap is not large in all areas, it does exist. Just as a spectrum exists for visuospatial ability in girls, a spectrum exists for visuospatial ability in boys (Halpern, 2000). Remediation and enhancement of skills and abilities could help low spatial ability students of both sexes; however girls stand to gain the most.

Many career fields involve a spatial component including medicine, aviation and piloting, engineering, and designing (Shah & Miyake, 2005). Furthermore, many more places of employment use virtual reality or simulations for training purposes. Methods of communication are increasingly becoming less text-based and verbal, and utilizing more graphics and visuals (Marchionini, 1995).

A plethora of tests exists to measure aspects of spatial ability. While research results are incomplete as to the exact composition of the various facets of spatial ability (Hegarty & Waller, 2005), the Mental Rotations Test (Vandenberg & Kuse, 1978) consistently shows the greatest disparity in scores between men and women and boys

and girls, (Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995) with males on average receiving higher test scores than females. Various influences have been suggested by research studies as to the possible cause of the gender gap in MRT results, including stereotype threat (resulting from an unconscious self-identification with a dominant culture with a negative stereotype) (Steele, 1997).

Purpose

This research project investigated spatial ability in adolescent females by examining (1) the extent to which the intervention of teaching a spatial curriculum in a single-sex setting could improve mental rotation test scores, and (2) the impact of spatial skills on an information seeking task in a single-sex setting. Much research has been done on identifying components of spatial ability, but, to date, no agreement within or across disciplines exists for a universal definition of spatial ability as a whole. Spatial visualization is one component of spatial ability. It is important for visualizing objects in three dimensions, such as converting two dimensional chemical molecule representations to three dimensional mental representations (Hegarty & Waller, 2005; Wu & Shah, 2004). Research suggests that with practice, spatial visualization scores on many spatial tests can be increased, and that initial test scores in the low range do not necessarily indicate low aptitude in spatial visualization. However, it is not clear which interventions work on which components of spatial ability or the trajectory of the increase in spatial skills (Terlecki, Newcombe, & Little, 2007). Low scores in a visualization test could indicate a lack of experience with spatial visualization (Baenninger & Newcombe, 1995). Most of the students involved in the initial research studies on spatial ability were male (Blade & Watson, 1955). Over the years, as more

females took part in spatial visualization tests, gender gaps continued to appear, primarily in favor of males. However, females consistently score higher than males on one test of spatial ability: memory of object location (Halpern & Collaer, 2005). Some of the gender gaps were statistically insignificant; although, the gap in mental rotation scores, as tested by the pen and paper Mental Rotations Test (MRT) remains constant and statistically significant for over two decades (Voyer, Voyer, & Bryden, 1995). While mental rotation is only one facet of spatial ability, it is an important one. Mental rotation involves several kinds of rotation--mentally rotating the object or rotating one's position in relation to the object. For example, map reading, an essential skill, often requires mental rotation if one is approaching a destination from a direction other than south. Enhancing skill in mental rotation can enhance functioning in many areas (Terlecki, Newcombe, & Little, 2007). To date no information seeking or communication model fully accounts for the role of spatial ability in information seeking and communication. One information science model, Marchionini's personal information infrastructure model (1995) and one communication model, Shannon and Weaver's (1998) communication model, served as the theoretical foundations for this research project.

This study of mental rotation in girls took place in a single-sex educational setting. Stereotype threat was not evaluated as a variable, however, it must be noted that a single-sex environment is different than a co-educational environment for males and females (Salomone, 2002). Not enough research has been done to determine the effect of single-sex schooling on different age groups, different socioeconomic groups, across different racial and ethnic settings, and across rural, suburban and urban settings. Previous research suggests that differences exist, but not enough research

has been done to isolate the impact of different variables or the impact of the duration of single-sex educational experience over the short-term or the long-term.

The purpose of this study was to determine to what extent spatial ability can be improved in adolescent girls and to what extent spatial ability impacted their information seeking. This study provided spatial experience to adolescent girls through spatial curriculum instruction in a single-sex setting in a sophomore biology classroom, and also examined to what extent did mental rotation, a spatial skill, impact efficiency in information seeking tasks. This research project compared baseline measurements of skill in mental rotation based on the results of the Mental Rotations Test with the effect of the completion of a spatial curriculum on Mental Rotations Test scores, as well as the relationship between spatial ability and database information seeking tasks.

Research Questions

While spatial ability research is being conducted in discrete subject areas, many of the research findings have not been not widely published in the research journals of other disciplines, and the terms used to describe similar facets of spatial ability vary from discipline to discipline (Shah & Miyake, 2005). Engineering research focuses on the importance of developing spatial ability in undergraduate engineering students, as well as the possible influence of prior spatial experience on academic success in engineering (Sorby, 2000; 2001). Cognitive and environmental psychologists and educators conduct research on many facets of spatial ability including female underperformance on certain spatial ability tests, especially the Mental Rotations Test (Voyer & Saunders, 2004). In information science, researchers examine the impact of spatial visualization on efficiencies in information seeking (Egan, 1988; Thomas, 1998).

While this study will not directly increase the numbers of girls going into science, technology, engineering and mathematics (STEM) careers, it may lead researchers to factors that could help girls make more confident, informed choices. Most career decisions are made at the high school level (Bleeker & Jacobs, 2004). Females take fewer advanced mathematics and science courses than males in high school, and the number of math and science courses taken in high school impacts self-efficacy and success in college level mathematics and science courses (Bleeker & Jacobs, 2004). Students who struggle with visuospatial skills because of lack of spatial experiences, not necessarily a deficit of ability, may opt out of lucrative and intellectually appropriate careers because they do not think that they would be interested or successful in those fields. Students who struggle with low spatial ability may struggle in the workplace as well with the inclusion of technology in almost every workplace and almost every job task. Increasing spatial ability may improve job performance and efficiency as well.

Because high spatial ability appears to play such a critical role in academic and professional success in so many domains and subject areas, it is crucial that researchers begin to investigate interventions that will enhance and improve spatial ability in children and young adults with low spatial ability (Terlecki, Newcombe, & Little, 2007). This exploratory study examined two factors: the impact of a spatial curriculum on the ability to perform mental rotation tasks in a single-sex school, and the impact of spatial ability on an information seeking task. The extent to which a spatial visualization curriculum improved MRT scores from a pretest to a posttest for girls was the first factor examined using the spatial visualization curriculum developed by Sorby and Wysocki (2002). Sorby and Wysocki originally developed the spatial visualization curriculum to

enhance the spatial visualization skills of engineering students at Michigan Technological University. Michigan Technological University researchers subsequently developed a research project currently underway that involves training and testing larger groups of students including high school and non-engineering undergraduate students (Sorby, personal communication, November 29, 2005; June 13, 2008). The information seeking task for this research project was comprised of four tasks from a doctoral study by Thomas (1998) and utilized JSTOR® scholarly journal database (JSTOR, Ann Arbor, MI, www.jstor.org).

To further examine the role of spatial ability and information seeking, the researcher developed two research questions.

1. To what extent can spatial ability, specifically mental rotation, in 10th-grade girls be increased by providing increased spatial experience in a biology classroom?
2. Does spatial ability as measured by the Mental Rotations Test impact search efficacy while using JSTOR for database search tasks?

Definitions of Terms

Bent Twig Hypothesis --- Developed by Julia A. Sherman, the Bent Twig Hypothesis suggests that females develop a preference for a verbal/analytical approach to problem solving over spatial problem solving (Sherman, 1978). Some of that preference may be due to environmental influences. Sherman suggests that males get more spatial experience through manipulation of spatial toys, playing with trains, creating models, navigating on bicycles and in cars, playing sports, and from being encouraged to take more advanced mathematics coursework in school. Females do not receive the same encouragement in developing their spatial skills.

Mental rotation -- The ability to hold a two or three dimensional image in thought and rotate it mentally as to be seen from another angle or aspect.

Mental Rotations Test (MRT) -- The Mental Rotations Test was originally based on work by Shepard and Metzler (Shepard & Metzler, 1971) and further developed by Vandenberg and Kuse (1978). The MRT is a pencil and paper test that has consistently shown the largest gender gap when comparing tests of spatial ability (Voyer & Sanders, 2004).

Performance Factors – Variables that could cause females to perform less well or better on some spatial tasks. Some examples of performance factors are timed tests versus untimed tests, stereotype threat, or less efficient test-taking strategies.

PSAT/NMSQT® -- Preliminary Scholastic Aptitude Test/National Merit Qualifying Scholarship Test for critical reading skills, writing skills, and math problem-solving skills (College Board, New York, NY, www.collegeboard.com); also determines National Merit Scholars.

SAT® -- Scholastic Aptitude Test, reasoning and subject tests measuring critical reading, math, and writing skills needed for academic success in college (College Board, New York, NY, www.collegeboard.com).

Spatial ability – Not a unitary construct, spatial ability consists of many abilities, although no consensus exists about the composition of those abilities. It is the skill in visualizing, creating, manipulating, rotating, perceiving and remembering information in nonverbal and symbolic forms (Linn & Petersen, 1985). Some researchers focus on three major factors: spatial visualization, spatial perception, and mental rotation (Linn & Petersen, 1985). Visuospatial or visuo-spatial ability are also terms frequently used as

synonyms. Spatial ability requires representation, rotation, and inversion of objects in 3-D when they are presented in 2-D.

Spatial orientation – Visualizing images from different perspectives (Ferk, Vrtacnik, Blejec, & Gril, 2003)

Spatial perception – The determination of spatial relationships in orientation to one's own body despite distracting environmental cues (Halpern, 2000).

Spatial relations – Visualizing multiple manipulations such as rotation, reflection, and inversion including mental rotation (Ferk, Vrtacnik, Blejec, & Gril, 2003)

Spatial visualization – A multi-step process of analyzing spatial information. This process may involve mental rotation and/or spatial perception (Michael, Guilford, Fruchter, & Zimmerman, 1957). Some researchers consider spatial visualization to be visualizing 3-D objects from a 2-D representation (Ferk, Vrtacnik, Blejec, & Gril, 2003). Michael, Guilford, Fruchter, and Zimmerman (1957) provided a foundation for identifying the components of spatial ability. They identified three factors: spatial relations and orientation, visualization, and kinesthetic imagery.

STEM – Acronym for science, technology, engineering, and mathematics.

Stereotype threat – The adoption of an unconscious identification with a dominant domain riddled with negative performance stereotypes. The social and psychological pressures to avoid performing as the dominant domain does, i.e. girls underperforming in math or in the physical sciences, may inadvertently result from an unconscious emotional reaction to being judged or treated as one who fits the stereotype even if the stereotype is never mentioned. If a person identifies more with a positive stereotype in a

different dominant domain, i.e. students at a competitive school, that positive stereotype will result more frequently in a more accurate measure of performance (Steele, 1997).

Theoretical Foundation

No information science model or communications model fully accounts for the role of user spatial ability in information seeking. Because of the complexity of user cognition and information seeking behavior, it is difficult to use only one model. Two models were used and adapted for the purposes of this research project, Marchionini's (1995) personal information infrastructure and Shannon and Weaver's communication model (1998). Marchionini (1995) developed a personal information infrastructure model which consists of several components; mental models, cognitive skills, material and information resources available to individuals, and metacognition (cognitive skills, executive functioning and individual attitudes). Marchionini (1995) defines personal information infrastructure as "an individual person's collection of abilities, experience, and resources to gather, use and communicate information" (p.11). All individuals gather information and integrate the information with their own knowledge to create new knowledge. This process creates mental models from which the individual assimilates or processes new information. Different mental models can exist for different situations and kinds of information. Egan (1988) connects user interface experience with a change in the mental models of the user for computer tasks and computer systems, and writes that individual differences in the completion time needed for information tasks reflects the effectiveness of the user's mental model.

A personal information infrastructure incorporates all of the mental models, the metacognitive resources needed for thinking through plans and executing actions, and

the resources available in terms of time and money, knowledge domains, and cognitive skills. Spatial ability intersects the personal information infrastructure in the area of cognitive skills, with effect in the realm of metacognition through stereotype threat and societal sex-typed behavior expectations, and spatial ability impacts mental models through the search systems and the knowledge domain. Spatial experience can enhance spatial ability in the knowledge domain. Recognizing similar patterns of information seeking would be located within the knowledge domain portion of Marchionini's (1995) personal information infrastructure model.

Shannon and Weaver's (1998) communication model (see Figure 2) was employed to provide a foundational model for this research project. The model, if adapted slightly, could explain the role of spatial ability in the communication process and ultimately in the information seeking process. High spatial ability is a cognitive skill that enhances efficiency in information seeking. Low spatial ability interferes with efficiency in information seeking. Thomas (1998) states that system design needs to include an analysis of communication issues. The best system design utilizes expertise from the cognitive and behavioral sciences and incorporates affective and cognitive needs of the user. Previously system design success was measured solely in terms of system performance, leaving user performance within the system out of the assessment loop. Researchers now measure system performance by examining user performance within the context of the system. Communication issues hinder or enhance user performance. Resolving or minimizing communication challenges results in more efficient systems for users. The optimal system creates a "timely flow of information [through an interface] which is relatively free of error states in both the user and the

computer…Interaction is communication, or conversation, between a system and a user" (Thomas, p. 30).

Spatial ability functions as a source of noise in Shannon and Weaver's (1998) communication model. Noise occurs when the signal being transmitted includes extraneous things that were not intended to be included by the information source. Noise can be amplified for individuals with low spatial ability, hindering their ability to search for information (called messages in Shannon and Weaver's model) and interferes with discerning salience once the user locates information. Noise can either restrict or enhance communication flow in information seeking. The restriction in information flow in information seeking can result in information poverty, not being able to access needed information. Enhancing spatial ability for individuals can increase cognitive skill, enhance salience, and reduce noise for individuals during information seeking.

Limitations of the Study

The results of this study can only be generalized to the population tested: girls enrolled in a sophomore biology class, in a single-sex, suburban, college-preparatory, private school. Students in other school settings may have different experiences from those of the population sampled in this study. Further research would be needed to see if these results are valid in other school settings. Another limitation of the study was the amount of time available for training sessions. Students working on the lessons in longer blocks of time or over a longer period of time might have different test results. Hormonal fluctuations and hormonal levels of the girls were not tested and presented another limitation to the study. Sex role inventories were not examined, although gender

beliefs of the students and their parents would have been useful information in examining stereotype threat and gender role belief prior to and at the conclusion of the study. This study also did not compare girls' results with the results of boys in either a single-sex or a coeducational setting. Students received no homework grade or incentive for their participation. This lack of incentive may have affected the students' motivation to work diligently on the workbooks in their out-of-class time.

Two different instructors taught the four sections of 10th-grade biology and the contents of the biology course differed slightly depending on the instructor. Two control groups had the same instructor. One treatment group had one biology instructor and one treatment group was taught by the second biology teacher. However, the introduction and the facilitation of the use of the spatial curriculum in the workbook and on the CD-ROM was the responsibility of the researcher. The research project did not involve biology content, although spatial ability appears to impact the comprehension of scientific models and visualizations. Students were also enrolled in different mathematics levels during the year of the research project. Some of the sophomore students took geometry at the same time they participated in this research project while others had completed geometry in their ninth grade year. Students also differed in the amount of spatial experience that they had before beginning the spatial visualization research project. Some students had more computer experience. Past research results suggest that some spatial activities improve spatial ability more than other activities.

Some students would have participated in activities which could have improved their spatial ability prior to and during the research project. Another limitation was the measurement of the duration of any increase in spatial skills and the effect of any

subsequent increase on grades in math or science or achievement and SAT test results. Any mental rotation skill increase could be permanent or transitory. Without a follow-up study, it is impossible to know the long-term benefit. The effects of test/retest could also have affected the results. Some practice effect may have been present as result of the within-subjects design of the research project. Although the results from the control group should indicate how much a test/retest effect there was, only one test (the MRT, given as a pretest and a posttest) of spatial ability was used. Other tests of spatial ability might have shown different results.

Looking at the effect of using music to prime or enhance performance in tasks requiring spatial ability or for the improvement of spatial ability was beyond the scope of this study, but some research suggests that music, particularly a Mozart sonata, can improve scores in some of the spatial ability tests (Gilleta, Vrbancic, Elias, & Saucier, 2003: Rauscher, Shaw, Levine, Ky, & Wright, 1994).

Transfer of mental rotation skill to other areas was outside the scope of this research project. It would be useful in future research, however, to determine if an increase in spatial skills results in a similar increase in mathematical skills, or better utilization of spatial skills in situations in which spatial ability would be required, such as navigation in the physical or virtual worlds, map reading, or diagram or graph interpretation. Additionally, enhancing spatial ability training through the use of stimulus color was also beyond the scope of this research project.

The spatial curriculum software was installed on classroom tablet PCs. Some students used the computers in the tablet mode and some in the laptop mode. Some used the touchpad, and some used the tablet pen to solve problems. Using the software

in the tablet mode or in the laptop mode could have impacted learning transfer from the spatial curriculum. Testing for relationships with different kinds of learning disabilities was beyond the scope of this study, although an intriguing area of research would be to examine the relationships between learning disabilities and scores on the MRT. The students attended school from rural, suburban, and urban areas, and were from racially, ethnically, and economically diverse backgrounds. This was also a limitation in the study.

Delimitations of the Study

This study confined itself to testing only sophomore students in an all-female college preparatory private high school in the Midwest in a large metropolitan area. The girls came from diverse backgrounds, including urban, rural, and suburban areas, and represented wide cultural, religious, socioeconomic ranges. The participants in this study were not confined to one socioeconomic group or one small geographic area. While the study did take place at a school in a suburban location, the students were transported to school from a wide geographic area. High school sophomore students whose research topics utilize online databases frequently for information seeking and could be considered target users of online databases.

Assumptions of the Study

1. The instruments measured mental rotation ability. The instruments were within the ability level of the students, and the questionnaires used were understandable to the sample population.
2. The girls attending the college preparatory private school had a normal range of intellectual abilities and brought diverse experiences and backgrounds to the study.

3. Standardization of research tools and classroom presentations reduced the possibility of investigator influence on test results and bias on the part of the investigator.

Significance of the Study

Gender differences on the Mental Rotations Test are well documented, as is the gender gap in standardized testing in mathematics, and the underrepresentation of females entering STEM careers. Mental rotation comprises only one aspect of spatial ability, but being able to rotate objects as a whole rather than in sections seems to result in more efficient problem solving and higher scores on the mathematics portion of the SAT. Early focused training on various aspects of spatial ability could enable female or male students who score initially in the low range on spatial ability tests to succeed in careers and coursework that seemed to be out of their realm of possibility previously, as well as create efficiencies in their personal information infrastructure. Historically, remediation and support have been offered primarily for reading and writing, but remediation in spatial skills has not often been incorporated in the extra support offerings. Placing an emphasis on spatial ability will require a change in the awareness of the importance of spatial skill development by preschool and kindergarten through twelfth grade educators, to give them the skills they need to make the changes. Since the majority of preschool and kindergarten through 12th grade teachers are females, it is not a population that would necessarily be strong in, or comfortable with teaching spatial skill development. While this study will not directly increase the numbers of girls going into STEM careers, it may lead to factors that could help girls make more confident, informed choices, and also guide the research toward factors that could help create efficiencies in information seeking.

Summary of the Introduction

Spatial ability impacts many areas of functioning in today's world from performance in math and science to information seeking. Individuals with high spatial ability often experience more academic success in the STEM careers and more efficient problem solving in information seeking tasks. Females often underperform on spatial ability tests, especially on tests of mental rotation when compared to males. Spatial experience can enhance spatial ability. This chapter included a discussion of the need for research in spatial skills training for female and male students low in spatial ability. Definitions of terms were outlined and limitations and delimitations of the study were identified.

This research project examined the impact of a project to improve spatial ability by classroom intervention with a spatial curriculum as well as the impact of spatial ability on information retrieval times in a database exercise. The findings of this research project could add to the knowledge base of spatial ability in information science research. A more detailed explanation of the role of spatial ability follows. Chapter 2 provides a review of the empirical research used to support this study.

CHAPTER 2

LITERATURE REVIEW

Introduction

Research on spatial ability and on gender and spatial ability and information seeking has been published in many areas. Of particular importance is the gender gap in spatial ability performance on many tests of spatial ability. Researchers analyze many factors; components of spatial ability, the impact of spatial training on spatial ability, the power of environmental influences on the development of spatial ability, and performance factors that impact spatial ability test results, in particular a test with the largest gender gap reported over decades of research, the Mental Rotations Test (MRT). Spatial ability impacts performance in many of the science, technology, engineering and mathematics (STEM) areas. In science, spatial ability impacts a student's ability to understand molecular structure; in mathematics, spatial ability can impact SAT® subject test (College Board, New York, NY, www.collegeboard.com) math test results; and spatial ability impacts efficiency in information seeking. The spatial ability research on diverse topics in all disciplines, including library and information science, appears fragmented and reflects little coordination in the communication of research results. This lack of coordination impedes the sharing of empirical research across the disciplines.

A handbook edited by Shah and Miyake (2005) summarized current research on diverse areas of visuospatial thinking. While the primary intent of the book was to bring important current research to the attention of spatial ability researchers from across the disciplines, an additional stated purpose was to enable a researcher in one discipline to

find clear definitions and explanations of spatial research in other disciplines. In this text, the authors define all spatially related terms and provide citations for supplemental research for anyone interested in pursuing topics further (Shah & Miyake, 2005). The authors omit any discussion or research on the connection between information science and spatial ability beyond geographic information systems. Empirical research on the connection between information science and spatial ability exists; however, the omission suggests that not all spatial ability research is represented in the handbook.

Theoretical Perspectives

While much research has been conducted investigating more fully the connection between spatial ability and information seeking in the areas of information retrieval, visualization, information seeking, and communication, currently no theory or model has emerged to fully account for the role of spatial ability. Copeland (2003b) writes of the difficulty in developing models for information science and suggests an engineering design instead of models based on science. Copeland writes:

> Kahneman and Tversky (1984) further suggest the implications of using scientific theories or frames to generate a model of engineering design. Framing as a technique selects and illuminates some feature of reality while omitting others…Most frames are defined by what they omit as well as by what they include; the omissions of potential problem definitions, interpretations, and solutions may be as critical as the inclusions in guiding the researcher (p.108).

One might suggest that spatial ability is part of the "counterframing" (Sniderman, Brody, & Tetlock, as cited in Copeland, 2003a, p. 17) in information science models. Researchers omit spatial ability in the development of information science models. High spatial ability impacts saliency and efficiency (Egan, 1988). Marchionini (1995) created

a structure for personal information, which can be adapted to include the impact of spatial ability on information seeking.

Marchionini's model (See Figure 1) of a personal information structure consists of "conscious and unconscious filtering and finding strategies for achieving our immediate goals and protecting ourselves from information overload" (p. 2). One might suggest that spatial ability falls under unconscious filtering in Marchionini's definition. As Marchionini further defines the personal information infrastructure, finding one subcategory into which spatial ability fits in the model becomes challenging. Marchionini (1995) defines a personal information infrastructure as:

> an individual person's collection of abilities, experience, and resources to gather, use, and communicate information…a collection of mental models for specific information systems; mental models for events, experiences, and domains of knowledge; general cognitive skills (e.g., inferencing, recognizing salience) and specific cognitive skills related to organizing and accessing information (e.g. filing rules, reading)…the level of development of a person's information infrastructure is roughly analogous to the level of his or her information literacy (p.11).

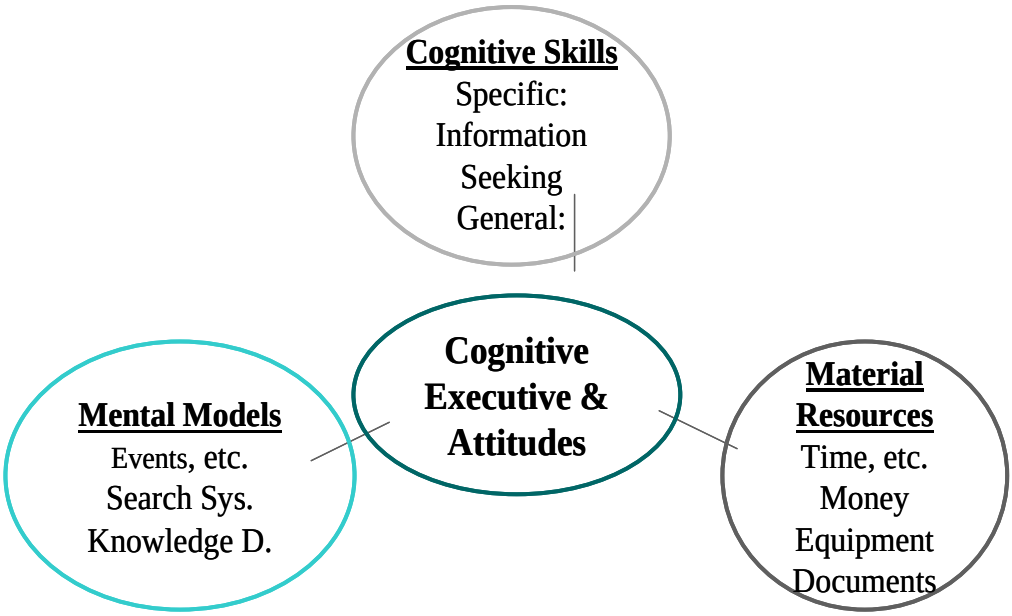

Figure 1. Personal information infrastructure components (Marchionini, 1995) Adapted with permission from G. Marchionini.

One could suggest that spatial ability impacts personal information infrastructure in many areas, including the area of (1) mental models (a model of the search system for example), (2) recognizing salience (under the cognitive skills framework), and (3) time, in terms of information seeking efficiencies (which falls under material resources). As an example, during an information seeking task, users will construct a mental model of the information space or database. A mental model of a database would consist of an estimate of the size of the database and the navigation effort required to retrieve the information needed.

Other models would be created by the user to create understanding and expectations in the information space. A cognitive skill set (spatial ability) fits in a separate section of his model. Stereotype threat for spatial ability for females would fit under the metacognitive section of Marchionini's model which includes

executive functioning and attitudes. As a result, spatial ability does not fit cleanly into any one section of Marchionini's model. Translating the model into the electronic environment, individual ability partially determines success in navigating the information space and retrieving the information needed. While technology can assist users and make a broader range of options and information sources available, it may also obstruct some users if individual differences have not been taken into account during the development process of the user interface. The users' mental models may not match the system's designer's mental model of the user interface or the information space or what Blair calls indeterminancy (Blair, 2006). Marchionini (1995) states:

> Technology augments our cognitive skills in several ways: by providing online assistance in selecting and using information sources (e.g. context-sensitive help, online reference manuals, spelling and grammar checkers, thesauri and encyclopedias, cut-and-paste tools); by broadening the proximity of personal networks (through electronic mail and bulletin boards); by extending our personal knowledge; and by changing the strategies we use for seeking and acquiring information (e.g. browsing, string search, relevance feedback) . . . adding electronic technology to our information infrastructures can have significant impacts on our cognitive activity. Electronic technology generally can amplify and augment our abilities and performance (Engelbart, 1963) as well as disorient and confuse us (Mantei, 1982) (p.15).

Electronic technology represents a grand frontier in many ways. For some users, technology can open new vistas. For others, it can represent obstacles and disorientation at every step on the trail. Low spatial ability users can find themselves disoriented and confused with some user interfaces, while high spatial ability users can be two or three times more efficient than low spatial ability users (Egan, 1998). For example, low spatial ability may interfere with the conceptualization of an accurate mental model of the database or the information source, thereby creating an inaccurate

mental model in the information seeker's personal information infrastructure. The confusion could require additional cognitive resources to resolve the disorientation as well as impact material resources by requiring more time to search or understand search results (Vincente, Hayes, & Williges, 1987). In a work situation, this confusion and disorientation could result in work inefficiencies. For example, low spatial ability could be a contributing factor in causing one cashier to work twice as slowly as the next cashier.

As Marchionini (1995) notes, electronic technology pervades contemporary life and changes how users seek, find, and utilize information. Inefficiency in information seeking due to low spatial ability can interfere with critical activities. Finding information and using the information comprise primary components of literacy (Marchionini, 1995). These inefficiencies impact more of the workforce as careers become more dependent on electronic technologies. Marchionini (1995) writes "our personal infrastructures are becoming increasingly dependent on computer technology" (p.21). This technology could increase challenges for users or eliminate them.

Marchionini (1995) discusses filters for information. He uses the term filter in a positive way, as useful for information searching, a way of refining searches. Marchionini describes filters as "sentinels" that accept, or restrict and limit information dissemination based on one's personal classification of information (p. 153). One might infer from Marchionini that filters can also unnecessarily or unintentionally restrict information seeking. Shannon and Weaver's model (1998) for communication applies when discussing filters (Figure 2). In user interfaces, Marchionini's (1995) filters could be translated as noise in the Shannon and Weaver (1998) model of communication.

Marchionini cites research (p. 32) that suggests that infrequent library users often misunderstand libraries and demonstrate inefficient search strategies due to carelessness and naiveté. It would seem to follow that another explanation is possible if one applies the concept of counterframing, that the misunderstanding and inefficiencies are due to differences in spatial ability rather than carelessness. The infrequent library users' lack of spatial skills could act as a negative filter, restricting information flow and efficiency.

Shannon and Weaver's (1998) model of communication (see Figure 2) applies in the electronic world of information seeking (Shannon & Weaver, 1998) and supports Marchionini's (1995) personal information infrastructure. Their model of communication, developed in the late 1940s assigned statistical probability to the communication process by estimating the capacity of the channel transmitting the messages and signals, as well as the probability that the message will be received without distortion at the destination. Capacity measures the amount of information transmitted per second. The information transmitted through the channel can have meaning at the destination or can be meaningless at the destination. Shannon and Weaver define information as the "measure of one's freedom of choice when one selects a message" (p. 9). This freedom of choice also increases the probability of distortion of the message in the communication process. Less freedom means less distortion in the communication process. The message of "one if by land, two if by sea" meant that only two possible communication options existed. With 26 letters in the English alphabet and multiple combinations of words for communication, the probability of distortion in the communication process increases considerably as communication becomes more

complex. Figure 2 is the common graphical representation of the model. The foundational model is an equation of statistical probability of a message.

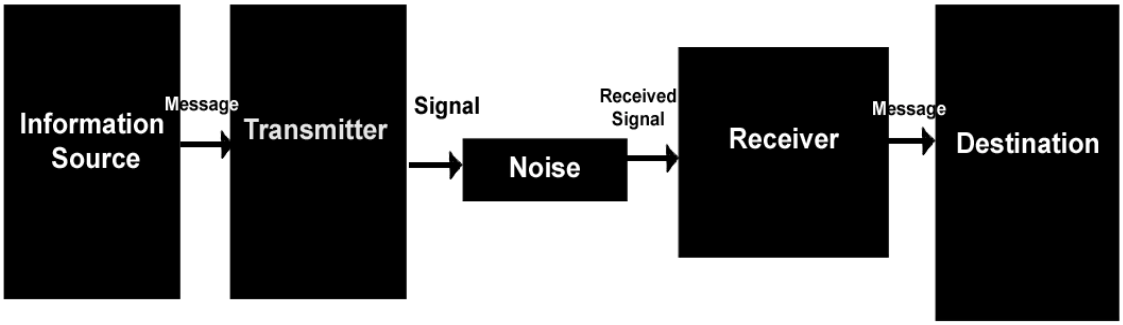

Figure 2. Shannon-Weaver Model, general model of communication (Shannon & Weaver, 1998). From *The Mathematical Theory of Communication* by C. E. Shannon and W. Weaver, 1998. Urbana: University of Illinois Press. Copyright 1998 by University of Illinois Press. Adapted with permission.

Shannon and Weaver (1998) outline three levels of communication problems. Level A problems are technical problems that concern the accuracy of the signal from sender to receiver. Level B problems are semantic problems in which the meaning of the message is not misdirected or lost on the way from the information source to the destination, or misunderstood between sender and receiver. Level C problems describe effectiveness of the communication. Will the communication result in changed behavior or have some kind of effect? The communication problem addressed in this research study is primarily at Level A, although low spatial ability impacts all three levels. Figure 3 illustrates the role of spatial ability in the Shannon and Weaver's (1998) communication model.

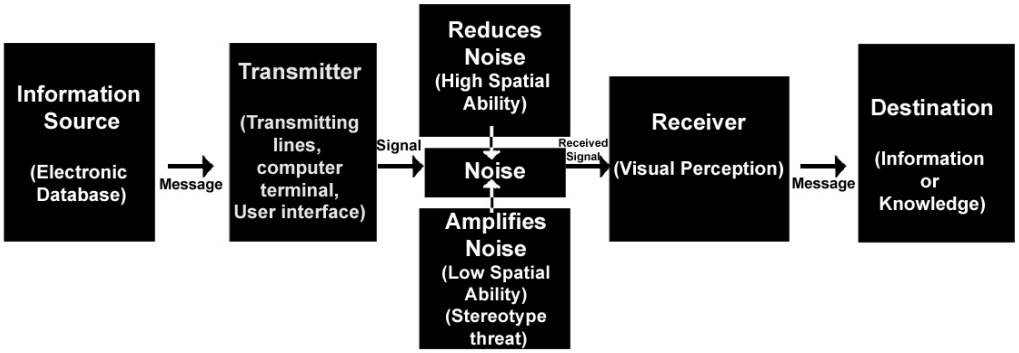

Figure 3. Shannon and Weaver's Model of Communication (1998), adapted for inclusion of the role of spatial ability. From *The Mathematical Theory of Communication*, by C. E. Shannon and W. Weaver, 1998. Urbana: University of Illinois Press. Copyright 1998 by University of Illinois Press. Adapted with permission.

The information source (the database and the user interface) selects messages to transmit based on user queries. The transmitter (the computer and the transmission lines) transmits the signal to the receiver (visual perception of the message by the user) and the receiver transmits the meaning of the message to the destination (the brain). On the way from the transmitter (computer and transmission lines) to the receiver (user's visual perception), the signal can be distorted by low spatial ability (noise). The signal could also be amplified by high spatial ability. Applying Shannon and Weaver's model as illustrated in Figure 2, the electronic database becomes the information source (material resources in the personal information infrastructure model). The transmitter becomes the line into the computer terminal (material resource), as well as, the user interface of the database (mental model), and the terminal (material resource) itself.

Marchionini's personal information infrastructure intersects Shannon and Weaver's model at the level of cognitive skills within the personal information

infrastructure when examining the communication process used creating knowledge. Spatial ability, in Shannon and Weaver's model intersects Marchionini's (1995) in the area of Noise Source (which can be a filter amplifier for a low spatial ability user, a filter for a person under stereotype threat, or a filter reducer for a high spatial ability user). The receiver in Shannon and Weaver's model translates into visual perception in cognitive skills, while destination translates into knowledge in a new mental model. Noise, according to the Shannon and Weaver model, interferes with the receiver's ability to decode the message.

Spatial ability can amplify noise or reduce noise in the creation and use of information in a personal information infrastructure. Users might find their ability to decode the information when received hindered by low spatial ability or stereotype threat. Stereotype threat results from an unconscious self-identification with a dominant culture through a negative stereotype (Steele, 1995) which creates a kind of information poverty. Users with high spatial ability and/or members of a positive stereotype dominant group are readily able to receive and decode the data quickly and move it to the destination (in Shannon and Weaver's model), or create a new mental model in their personal information infrastructure.

In expanding Marchionini's (1995) model to account for the impact of spatial ability on personal information infrastructure, spatial ability moderates three components of Marchionini's model; cognitive skills, mental models, and material resources (Vincente, Hayes, & Williges, 1987). Spatial ability, a cognitive skill, that influences a user's perception of a search system and can impact material resources by increasing

or decreasing the time needed to complete an information seeking task (Egan, 1988). An illustration of this model appears in Figure 4.

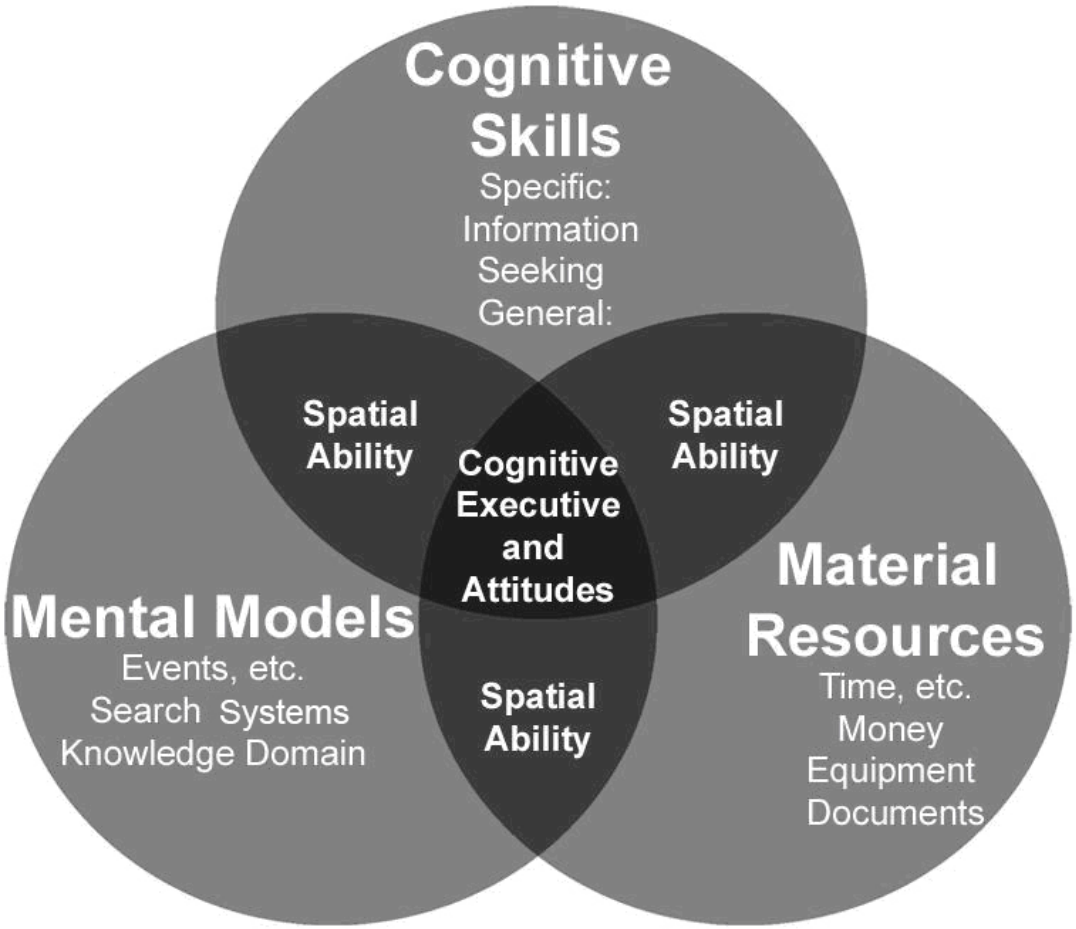

Figure 4. Personal information infrastructure, adapted for inclusion of spatial ability (Marchionini, 1995, adapted).Adapted with permission (G. Marchionini, personal communication, 2007).

Spatial Ability

The research on spatial ability varies and encompasses investigations of a variety of components including mental rotation and spatial visualization, and performance factors related to differences in spatial ability, including prior experience, gender, stereotype threat, and environmental factors. Halpern (2000) published a review of empirical evidence of sex differences research. One section of her review

discussed visual-spatial abilities (she identified five) and some of the apparent contradictions in the evidence for and against sex differences. In her conclusion she states that the effect sizes of sex differences in spatial ability tests depend on the type of test used for assessment, the population tested, the spatial ability tested, how the findings on distinct abilities were grouped together in the results, and the testing conditions (timed versus untimed, scoring of responses). Some spatial ability tests show little or no sex differences, however, mental rotation produces the largest magnitude of sex differences. Halpern cites a calculation published by Voyer, Voyer, and Bryden (1995) in their meta-analysis that states that it would take 178,205 studies of no effect of sex differences in spatial ability to counter the studies that found sex differences of statistical significance. A discussion of two components of spatial ability that impacted this research study follows: mental rotation and spatial visualization.

Components of Spatial Ability

Hegarty and Waller (2005) examined individual differences in spatial abilities in a literature review. Their examination of the research suggested that spatial ability exists not as a single ability or skill, but rather a complex interaction between several components. Hegarty and Waller (2005) discussed factor-analytic research, which attempted to identify the components of spatial ability research. Mental rotation, the ability to hold a two or three dimensional image in thought and rotate it mentally as to be seen from another angle or aspect seems unrelated to any linguistic ability (Linn and Petersen, 1985). Several meta-analyses produced over the last 20 years provide evidence that the most consistent and largest spatial ability gender performance gap appears through the analysis of test scores recorded when using the Mental Rotations

Test (Voyer & Saunders, 2004). While researchers have not been able to differentiate all components of spatial ability, the research seems to indicate that the spatial components of spatial visualization (defined as a multi-step process of analyzing spatial information that may involve mental rotation and/or spatial perception) and spatial orientation, previously thought to be separate components, are highly correlated, with correlations as high as 0.75 on some tests (Hegarty & Waller, 2005). Hegarty and Waller (2005) suggest that in the future, the components of spatial visualization and spatial orientation will be differentiated using other tests of spatial ability, but currently the correlations for the existing tests are very strong and spatial visualization and spatial orientation can be considered one factor. Mental rotation can be considered a separate factor, but also can be a part of the multi-step problem-solving process in spatial visualization (Hegarty & Waller, 2005).

Spatial Problem Solving Strategies

Hegarty and Waller (2005) suggest in their review of empirical research, that spatial ability researchers administering tests of spatial ability assume that test takers use similar strategies in problem-solving on all items, which does not appear to be the case. They suggest that test takers with low spatial ability and high verbal ability often utilize an analytical or verbal strategy for problem solving and low spatial test takers with low verbal ability utilize visualization strategies for problem solving. If the tests used do not allow for differences in problem solving, testing results for spatial ability components can be unclear. Test results may not reflect the results of spatial problem solving as much as the results of analytical versus verbal strategies, or a mixture of both.

Spatial Ability and Proofreading

Spatial ability has not been studied much in the preschool through grade 12 learning environment. However, spatial ability can impact several areas of learning. For example, visualization ability can impact a student's ability to proofread on a computer screen (Woodland & Szul, 1999). Woodland and Szul (1999) conducted a study on visualization ability, proofreading, and screen color design. Subjects participated in a 2 x 4 repeated measures design. The researchers asked two questions: (1) What effect do visualization ability and color configurations have on the proofreading ability of the user? (2) Does the proofreading ability of a higher visualization user differ from that of a lower visualization user? Subjects were grouped by visualization ability, high (high visuals) or low (low visuals) as measured by VZ2, a spatial ability visualization measure developed by Ekstrom, French, and Harmon (1976), and asked to use one of four screen configurations, with color combinations of black/white and white/blue, and locate embedded errors in four documents. While the findings did not indicate a statistically significant result in spatial ability difference using the VZ2 test, researchers suggest that an increase of N (56) might demonstrate an effect of statistical significance. High visuals outperformed low visuals in error detection in each screen configuration; however, the scores were not statistically significant. The correlation of the high visuals to the four screen configurations is higher than the correlation of the low visuals to the four configurations. Both low and high visuals demonstrated the best error detection when using dark text on a light background. The authors of the study recommended increasing the N for generalizable results and using other spatial ability tests.

Spatial Ability and Learning Disabilities

No widely used assessments exist for measuring visuospatial disabilities in elementary school in the way that assessments exist for language or linguistic disabilities. Cornoldi, Venneri, Marconato, Molin, and Montinari (2003) developed a test for measuring visuospatial learning disability in students to begin to address the need for preliminary and rapid identification of visuospatial learning disability. The test, Shortened Visuospatial Questionnaire (SVS) consists of 18 items and can be used at the primary level to identify students with visuospatial deficits. The Pearson correlation for the test, controlled for interrater reliability, ranged between 0.90 and 0.95. Early identification of students with visuospatial deficits and instruction in spatial skills could impact success in science and mathematics because of the suggested relationship between spatial ability and SAT mathematics scores (Casey, Nutall, Pezaris, & Benbow, 1995) and visualization of scientific concepts (Ferk, Vrtacnik, Blejec, & Gril, 2003).

Sex Differences in Spatial Ability

Maccoby and Jacklin (1974) analyzed over 1,000 studies, and their research results suggested that statistically significant sex differences in spatial ability existed between males and females. One of their findings suggested that the sex difference in spatial ability of disembedding (finding a simple figure hidden or embedded in a more complex figure) emerged for males around early adolescence and continued through adulthood. From age 3 through age 5 no sex differences exist in research results. After age eight, inconsistent results appear, although overall reported sex differences in research results strongly suggest a male advantage on disembedding tasks. While subsequent researchers criticized Maccoby and Jacklin's research methodology as

being too simplistic because they only examined the number of studies that obtained statistically significant research findings rather than examining the quality of the studies used in their analysis, their research results proved to be foundational (Halpern, 2000). Much of the sex difference research that followed extended and supported the Maccoby and Jacklin research (Halpern, 2000).

In a review of the empirical evidence for sex differences, Halpern (2000) summarized current research and identified critical studies. Her review includes a section on sex differences in visual-spatial abilities. Halpern notes that:

> . . . [S]ex differences favoring males are consistently found with two of the three factors that entail static displays--spatial perception and mental rotation tasks (Linn & Petersen, 1986)--and with spatiotemporal tasks (Schiff & Oldak, 1990: Smith & McPhee, 1987). Tasks involving the generation and maintenance of a visual-spatial image also seem to show male superiority in speed of processing with no differences in accuracy. McGee's (1979) summary of the literature is apparently still valid--male superiority on tasks requiring spatial abilities is among the most persistent of individual differences in all the abilities literature (p. 101).

According to Halpern's review, not every spatial ability performance advantage belongs to males. Researchers have found that females consistently show an advantage in object memory (memory related to object location). Females tested with familiar and with unfamiliar objects can identify which objects have been moved at a higher rate than males.

Linn and Petersen (1985) analyzed research findings in spatial ability to create a meta-analysis of sex differences to determine the characteristics and the timetable of emergence of spatial abilities. They identified studies published after Maccoby and Jacklin's (1974) review of studies on spatial ability and before June 1982. Their research focused on three areas, the magnitude of sex differences, types or aspects of

spatial ability, and the emergence of spatial abilities. Linn and Petersen (1985) examined four research perspectives: differential -- comparing the research populations; psychometric -- correlating the different spatial tasks; cognitive -- identifying the processes used to solve spatial tasks; and strategic -- identifying the strategies used to solve spatial tasks. For the differential perspective, researchers analyzed the group mean differences. Linn and Petersen (1985) used the psychometric and cognitive perspectives to determine homogeneous groups and examine variations in performance on the same task. Researchers used 172 studies for the meta-analysis.

Linn and Petersen (1985) employed a cognitive approach in comparing spatial tasks and identified three cognitive tasks. The first task identified included spatial perception -- the relationship of items in space when using one's own body as an orienting point. The second task identified involves mental rotation -- a strategy of successfully visualizing the rotation of a 2-D or 3-D image. The strategy used could involve holistic or Gestalt rotation or an analytic (piece-by-piece) rotation. Spatial visualization, the third task, requires complex multi-step processes and could involve mental rotation and/or spatial perception, but would employ multiple analytic solution strategies. Linn and Petersen suggest that successful visualization requires employing flexibility in solution strategies to optimize efficiencies in task solutions. Inefficient strategies would result in inefficient uses of time in solving spatial tasks.

Analysis of the Vandenberg and Kuse Mental Rotations Test results produced the largest effect sizes when compared to all of the spatial test research, even other tests of mental rotation. The MRT is a pen and pencil multiple choice test consisting of 20 or 24 target items that match two alternatives shown in rotated positions. The

choices also include two distracter or incorrect rotations. The Linn and Petersen analysis suggests that spatial visualization relates to verbal or linguistic ability, while the MRT may identify a spatial skill that is unrelated to linguistic ability.

Linn and Petersen noted one problem with the research results across age groups: true homogeneity was not possible. The research sample populations used for the comparisons in the meta-analysis at different ages were not equivalent. Research participants could have been drawn from dissimilar populations (career choices, educational choices) at different developmental ages. Additionally, curricula in schools could have changed to include more or less spatial components over a period of time as sex-typing of some activities became less pronounced. Sex-typing of an activity occurs when participants or observers view an activity as linked primarily to one gender, rather than an activity in which both genders participate equally. While researchers could not determine the reason for the effect size difference, a difference exists and additional research would assist in isolating the factors influencing the sex difference in performance.

Linn and Petersen found that sex differences in performance favoring males on the timed MRT appear at every age of tested populations. Linn and Peterson suggest that females may have slower response time due to slower rotation rates because of their choice of inefficient solution strategies (i.e., piece-by-piece rotation rather than a holistic rotation) or a more cautious (double-checking answers) approach. Males solve mental rotation tasks more quickly than females; however, given enough time, females can approach male accuracy. Linn and Petersen (1985) suggest that fruitful areas of study would be strategy choice for mental rotation task solutions and further research

on mental rotation tasks upon which sex differences are most apparent. Linn and Petersen also wrote that one might infer that the interaction between biological factors and sex-typed experiences and sex-role expectations may play a role in sex differences in spatial task performance. Males and females have different spatial experiences which in turn impact spatial skill performance. Spatial training often increases effectiveness in spatial skill task performance (Blade & Watson, 1955; Sorby, 2001; Terlecki & Newcombe, 2005).

Halpern and Collaer (2005) published a literature review on sex differences in visuospatial abilities found over a 25-year period. The differences depend on the task and the test used; however, results most frequently favor males. The visuospatial difference appears to impact scores in wayfinding (navigational) tasks in the virtual and the physical world as well as mapping tasks, and scores on mathematics tests. Female anxiety about mathematics or wayfinding may also be linked to visuospatial differences. Anxiety in both areas, mathematics and wayfinding, can be linked to lower performance on visuospatial tasks.

Halpern and Collaer also summarize the theoretical perspectives from biological factors of hemispheric lateralization, hormonal fluctuations, hormonal exposures, and neuroscience discoveries, to the environmental influences of experience and training as well as performance factors and stereotype threat. Halpern and Collaer suggest that these research results could be used to further examine the processes by which male and females extract information from spatial arrays, and the impact on sex differences in tests of spatial skill. The possible connection between mathematics and visuospatial skill is particularly critical because these skills are required for success in careers in

engineering and science, areas in which females are underrepresented (p. 179). While the relationship between visuospatial ability and mathematics remains complex, Halpern and Collaer's research strongly suggests that such a connection exists, but researchers need to further examine the interactions between the variables of environment, genetics, and training. Female test scores on spatial ability tests can be improved and that improvement can have far-reaching implications for areas beyond spatial ability (p. 204).

Spatial Ability and Science

Skill in spatial ability impacts several areas of academics; spatial skill is very important for academic success in science. For example, Wu and Shah (2004) reviewed over 200 studies on visualization and chemistry using the Educational Resources Information Center (ERIC) database, which indexes articles from 1996 to the present, and *PsychInfo*, the online database for the American Psychological Association, which indexes citations from 1987 to the present. In their review of the literature, they used chemistry as one of the keywords and linked it in separate individual searches to the following terms: representation, misconception, alternative conception, framework, diagrams, visualization, spatial ability, visual ability, inscription, technology, and model.

Wu and Shah (2004) chose empirical studies from the 200 articles retrieved, and utilized the reference sections of those articles until the authors felt that they had located all of the relevant studies that encompassed chemistry and the use of: visual representations, visuospatial abilities, students' alternative conceptions, and visualization tools. Ultimately, they found 135 studies relevant to their three research questions about (1) individual differences in visuospatial ability and learning chemistry,

(2) conceptual errors in internal and external visual representations, and (3) how visuospatial tools help support visuospatial thinking in chemistry.

Of the three questions, this researcher finds the first particularly relevant to this research study because it examines individual differences in spatial ability, particularly mental rotation. The authors found that the studies seem to suggest a possible correlation between visuospatial ability and classroom performance in chemistry. According to Wu and Shah (p. 476), students with lower visuospatial ability demonstrate lower classroom performance than their peers with higher visuospatial ability. Also, students with lower visuospatial ability struggle to create visual representations of chemistry questions. Wu and Shah conclude after reviewing all of the studies that students needed visuospatial abilities to learn chemistry. Students need to use visuospatial skills to create visual representations of chemical complexities so that they can more effectively utilize visuospatial thinking in problem-solving. The authors also suggest that students be taught to transform images from 2-D to 3-D.

Ferk, Vrtacnik, Blejec, and Gril (2003) studied student visualizations of molecular structures. Three of the research questions investigated included:

> 1) do students' educational level, gender, spatial visualization, and spatial relations skills play an important role when perceiving the information about 3-D molecular structures from different kinds of molecular structure representations?; 2) is the ability to correctly perceive 3-D molecular structures crucial for solving the tasks that require mental manipulation, which also include the other mental operations (perception and rotation, perception and reflection, perception, rotation, and reflection, and perception and transfer of information about molecular structure from 2-D representations to constructing 3-D molecular models)?; (3) What proportion of students from specific educational levels are capable of correctly solving tasks that require a correct perception of 3-D molecular structures combined with processes rotation or/and reflection? (Ferk et al., p. 1231)

The study involved subjects at the eighth grade level (age 13-14 years) in six primary schools, students at five secondary schools (age 17-18 years), and fourth-year prospective chemistry teachers (age 21-25 years). The authors created a Chemistry Visualization Test (CVT) to measure perception of molecular structures in varied representations as well as students' ability to manipulate the structures mentally in three dimensions. Five types of tasks were created: perception, perception and rotation, perception and reflection, rotation, and reflection, and perception and mental transfer of information. The authors found different results for different age levels. Elementary students solved CVT tasks correctly most often using 3-D molecular models, while high school students solved the most CVT problems using computer-generated molecular models or photographs, not 3-D molecular models. The authors also found that the range of differences of achievement was greatest among the elementary students.

Based on their research results, the authors made several recommendations for the study of science at the pre-undergraduate and undergraduate levels in terms of visualization recommendations so that students comprehend 3-D molecular composition. Concrete 3-D models work best at the elementary level, while the visualizations at the secondary school and undergraduate levels work best for students when presented through the use of photographs of 3-D models or computer-generated models.

Practice at the secondary and undergraduate level could include the use of mirrors to facilitate comprehension of the processes involved such as rotation and reflection. Observations in three dimensions could be translated and replicated in two dimensional drawings. All students need more experience with 3-D manipulation with

various molecular structures. To assist in comprehension, first studying the rudimentary elements of 3-D manipulation (perception, rotation and reflection) would be most helpful, and then students could study combinations of the elements once they understood the individual elements.

Ferk et al. found no statistically significant gender differences in performance. However, one of the figures, Figure 5 (p.1238) clearly shows a female advantage on the overall scores on CVT. Students with high spatial visualization scores also scored highest on the CVT. Students with low spatial visualization scores were in the lowest scoring group on the CVT. The difference was statistically significant.

Spatial Ability and Mathematics

In 1990, Hyde, Fennema, and Lamon conducted a meta-analysis on over 100 studies of mathematics performance and found that while the gender differences in mathematics problem solving at the high school level were not large, they existed, and as a consequence, needed to be addressed. The male advantage was 0.29 in high school and showed a larger effect size in college (0.41) and an even larger effect size (0.59) in as older adults. The researchers, using Hedges and Becker (1986) formulas, calculated the effect size (d) as "the mean for males minus the mean for females, divided by the mean within-sexes standard deviation" (p.141).

The researchers report that female performance in computation appears to be higher than male performance, but male performance in the area of mathematical problem-solving appears to be higher than female performance and the difference emerges in the high school years. The meta-analysis revealed some sex differences, although the authors acknowledge that without access to the content of the

mathematical tests used in the meta-analysis, gender gaps for certain types of mathematical questions could not be ascertained.

Casey, Nutall, Pezaris, and Benbow (1995) reported on the relationship between high spatial ability and scores on the mathematics portion of the Scholastic Aptitude Test (SAT-M). They discovered that when they removed questions that involved mental rotation in the math portion of the exam, the sex differences in mathematics scores on the SAT-M vanished. Their study of college-bound high spatial ability and low spatial ability high school students found that scores on a test of mental rotation correlated with mathematics ability for female study participants in all four samples. The researchers reported correlations between 0.35 and 0.38. When mental rotation scores were covaried out, female and male performance differences on the SAT-M showed no significant statistical difference. However, when researchers analyzed math SAT scores without regard for mental rotation scores, the male advantage existed for three out of the four samples. Only the sample of gifted and talented students demonstrated no statistically significant gender advantage.

Environmental Influences on Math and Science Achievement and Spatial Ability

Bleeker and Jacobs (2005) studied the association between mothers' beliefs about their daughters' ability in math and science with the achievement levels and career choices of the daughters. The socialization influence of parental beliefs for females had a statistically significant effect on self-efficacy, course selection, and college major. The researchers tested a middle school population of students and their parents. Their results suggest that the mother's prediction for their child's success in a mathematics related career during the seventh grade year related strongly to their

child's choice of a physical science or computer related career in high school. Mothers who expected their daughters to succeed in mathematics courses in middle school found that when their daughters reached sophomore year, the daughters felt more confident about their success in a math or science career.

That math/science confidence continued for the daughters two years after high school as they pursued career choices. In contrast, mothers who rated their middle school daughters low in their ability to succeed in a math career had daughters who were 66% less likely to pursue a career path that included physical science or computing, and four times more likely to pursue careers in life sciences or business. Mothers' perceptions of sons' ability in middle school appeared to have no statistically significant effect on career choice later. The study involved primarily white, middle-class parents. Different populations may have stronger or weaker gender stereotyping. The researchers did not evaluate the impact of gender-differentiated societal influences on career choice, including teachers, peers, or media.

Steele (1997) studied the impact of societal influences on mathematics achievement on women and African Americans. His research on stereotype threat suggests that achievement results follow domain identification. Domain identification can be defined as a social category with which an individual affiliates. Dominant domain identification would be the strongest social category, for example, female, African American, Asian American. The societal stereotypes associated with the domain influence the individual's self-perception of abilities. If the dominant domain members underperform in a tested area, the individual generally underperforms in a tested area. Steele's research found that female test-takers and African Americans need not be

reminded of the societal stereotypes. Those stereotypes pervade the culture and negatively impact female and African American performance on quantitative tests due to increased test anxiety and internal pressure to disprove the stereotype.

Brosnan (1998) administered the Group Embedded Figures test, a spatial ability test to students and used two different descriptions when administering the test. For one group of students, he described the test as a test of empathy. For a second group of students, he described the test as a test of spatial ability. When the test was described as a test of empathy, female scores showed no statistical difference with the two male groups, males in either the spatial or empathy group. However, the scores for females whose instructions included the description of the test as a spatial test showed a statistically significant difference from the scores of males in either the empathy or spatial description group and females in the empathy description group.

McGlone and Aronson (2006) suggest that spatial ability test results for females are influenced by dominant domain identification and stereotype threat. Females feel pressure to disprove the stereotype of low female performance on spatial tests. This pressure actually serves to depress scores by raising anxiety levels when test-taking. Given the same tests without a spatial ability or mathematics label, females tend to receive higher scores on spatial ability. Their study examined the effect of priming the identification with the dominant domain for female undergraduates. Females reminded of their enrollment as a student in a competitive college prior to spatial ability testing received higher average scores on the MRT than females reminded of their gender prior to taking the MRT. Dominant domain identification can influence test results, even when no direct reminder of the stereotype is present. Their research results suggest that

reminding students of a positive dominant domain stereotype prior to testing serves to improve performance of individuals who may consider themselves to be a part of a negative domain stereotype. The researchers tested female undergraduates at a selective private college. The research results may differ when testing another population.

One might suggest that the culture in a single-sex all female environment minimizes stereotype threat. Inconclusive research results exist on the effect of single-sex education. Salomone (2002) addressed the subject of the legality of single-sex education and the paucity of research available on the effect of single-sex education in the public sphere by presenting an argument for funding additional research in the area of single-sex education,

> Perhaps what distinguishes single-sex programs from other pedagogical proposals is not that the research findings are inconclusive, but that we have difficulty uncoupling gender segregation from its tainted history of male privilege and women's subordination and, more importantly, from the shameful legacy of racial segregation. Nevertheless, to argue as many opponents do, that single-sex programs are impermissible because they lack adequate supportive data, which in turn cannot be gathered unless such programs are permitted to exist for a sustained period, obviously represents the most irrational and disingenuous form of circular reasoning. More fundamentally, the argument implies that single-sex programs are inherently harmful, a mere conjecture without grounding in research evidence (p. 70).

This research project did not have female single-sex education as its focus, as that variable was outside of its scope. This research project took place in a single-sex setting. However, stereotype threat to date has not been researched in a single-sex setting and compared to a coeducational educational setting.

Performance Factors and the Mental Rotations Test

Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) examined the question of sex differences on spatial tasks, specifically, what are the spatial tasks in which males do better than females and why. Peters et al. found that the Paper Folding Test and the Card Rotation Test, two tests of spatial ability, did not produce reliable sex differences for the university students involved in their study, but the Mental Rotations Test did produce sex differences.

The Mental Rotations Test tests skill in three-dimensional object rotation. The MRT consists of multiple choice items which contain a target figure and four choices of rotated drawings. Two of the figures match the target figure but appear in rotated positions and two drawings known as distractors are incorrect. A correct answer consists of choosing the two correct alternatives and ignoring the distractors. In the Peters et al. research, one of the questions researched was whether practice effect, the improvement of performance due solely to repeated testing and familiarity with the test, applied only to a particular set of items on the MRT, or was applicable to all of the items on the test. The researcher predicted (based upon previous research on the MRT) that the population tested would differ in between-subject designs. Comparing math-science majors to non-math-science majors may not yield accurate results.

In the study, undergraduate students with science (engineering, biological, and physical sciences) and arts (social studies, arts, and humanities) majors were voluntary participants. Researchers asked the students to complete a battery of tests and questionnaires including the MRT, the card rotation test, the paper-folding test, a handedness questionnaire, and problem-solving strategies on the MRT. The

researchers tested each student for handedness using a 14-item questionnaire and found a statistically significant effect for handedness and academic program (science or arts) with no statistically significant interaction for gender and handedness.

Consequently, the researchers recommended that handedness need not be controlled for unless the number of “nonright-handers” in the sample represents the population disproportionately. The survey included questions on the frequency of playing computer games that required spatial manipulation and questions for female students on their menstrual cycle. In addition, students took the MRT in two three-minute subsections. Participants needed to correctly identify both matching figures to score a correct answer for that question.

Researchers also administered two other spatial tests: the card rotation test and the paper-folding test. A subset of participants completed a questionnaire in which they analyzed their problem-solving strategy on the MRT. Research results showed that males who rotated the entire figure mentally while solving the MRT problem performed at a statistically significant level better than those who solved the problems by rotating parts of the figure. Females and males who used a nonverbal strategy performed better than males and females who used a verbal strategy to solve the problems on the MRT.

In further analysis, Peters et al. compared the "ratio of questions solved correctly/total number of questions attempted" (p.47). Females solved 56.3% of the attempted questions correctly, while males solved 71.5% correctly. Peters, et al. (1995) found strategy differences between males and females in solving problems on the MRT, but the effect sizes lacked statistical significance.

Researchers found no correlation for computer game playing and MRT scores for male or female participants, and found no correlation for MRT performance and to what extent either gender liked or disliked the test. However, the researchers discovered a slight but statistically significant correlation for females in MRT performance and the amount of time spent playing with Lego® blocks (The LEGO Group, Billund, Denmark, www.lego.com). However, the study's results indicate no relationship with block play and MRT performance for males. Researchers noted some practice effects when comparing a control group of female students in the arts and sciences program whose initial scores were within one standard deviation of the treatment group. Researchers administered the MRT seven times and each time the mean score increased for the control group. In a similar study, students took the MRT once weekly for four weeks and gender differences remained stable, but the test scores for each group increased each week.

Goldstein, Haldane, and Mitchell (1990) found that males tend to solve problems on the MRT more quickly than females, who tend to work through problems more carefully and slowly. Their study participants were given 6 minutes to complete the MRT and asked to draw a line after the last attempted item. After the 6-minute time limit had elapsed, participants could complete the rest of the test without time limits. Researchers found that testing females without time limits led to female performance that did not differ statistically from male performance.

Voyer, Voyer, and Bryden (1995) conducted a meta-analysis on sex differences in spatial ability. They studied 286 effect sizes (mean standardized difference between the scores of males and females on a specific test). They grouped the tests into three

categories: spatial perception, mental rotation, and spatial visualization. Mental rotation showed the largest effect size of the three categories, with males consistently outscoring females by a standard deviation of 0.6. They noted that a large gender difference occurs when the scoring of the MRT awards points only for correctly matching two figures on each of the 24 questions as opposed to awarding points for matching each correct figure. This method reduces the chance of arriving at a correct answer by guessing and was also the scoring method used by Peters (2005). Voyer, Voyer, and Bryden (1995) conclude their study by suggesting additional empirical work to "disentangle the influence of social, environmental, and biological factors on the magnitude of sex differences in spatial performance in general and on the Mental Rotations Test in particular" (p. 264).

Voyer and Saunders (2004) performed a factor analysis on MRT test-taking strategy and by measuring types of responses on the MRT. In their analysis, they counted as correct those responses with both rotation choices correct for each target item. They hypothesize that one correct choice and one incorrect choice or two incorrect choices reflects a guessing strategy on the part of the test-taker, while one correct or incorrect with one blank represents a reluctance to guess. Voyer and Saunders (2004) suggest that females may use a guessing strategy less frequently than males.

Peters (2005) found, the magnitude of sex differences statistically significant in a two part MRT test. Participants attempted more problems in the second part. Peters (2005) hypothesized that the increase in the number of problems attempted could be the result of practice effect. Less than 20% of the female participants attempted the last three problems of the first set, compared to almost 40% of the males. In the second set

of MRT problems, less than 30% of the females attempted the last three problems compared to just over 50% of the males.

The second study involved males and females from the same undergraduate pool with the timing conditions changed slightly. Approximately half of the group had three minutes to complete the first set of MRT questions while the second group had six minutes to complete the first portion. In the three-minute version of the test, just over 10% of the males and just under 7% of females attempted to solve the last problem, problem number 12 in the first part of the MRT. In the 6-minute version, almost 80% of the males and just fewer than 60% of the females attempted to solve the last problem. When the 6-minute time limit was used, males and females did not differ statistically in the number of problems attempted but they differed in the number of problems solved. During the 6-minute time limit, males solved problems with an average score of 18.0 out of a possible 24 and females solved 14.4 problems. These results indicate that the gender gap between male and female scores on the MRT can be reduced by altering testing conditions such as time limits.

Bent Twig Hypothesis and Spatial Experience

Sherman (1978) began examining the results of research studies on mathematical ability and its connection to spatial ability. Sherman suggested that boys receive additional training in verbal skills because they lag behind girls in verbal skills. However, girls do not receive any additional training in spatial skills and problem-solving skills, despite the fact that these are areas of deficit for girls. Sherman suggests that focused training in spatial skills and problem solving for girls could improve performance in these areas.

Sherman developed the Bent Twig Hypothesis in which she suggests that females often prefer verbal strategies for problem solving more frequently than males do, and this preference could be at the expense of developing more visual spatial problem-solving strategies. The dominant male culture includes more visual spatial activities than the dominant culture for females. As a consequence, males receive more opportunities to develop visual spatial skills in sex-typed (or stereotypic) masculine activities than females do. These spatial skills enhancing activities include games that require aiming, such as many sports activities. Other sex-typed masculine activities include chess, blocks, construction or transportation toys, and models or kits.

Males often travel farther from home than females, and practice navigational and spatial skills while walking, riding bicycles, or driving automobiles. In school, males often enroll in more advanced math, science, and technical courses, such as mechanical drawing, in which visualization skills will be further developed. Males and females may or may not differ in spatial skills from early childhood, but the opportunity to practice and develop spatial skills seems to occur more frequently due to socialization differences with males than with females. As the twig is bent, so grows the tree. More frequent opportunities for using spatial skills enhance initial spatial skills, whereas lack of opportunity inhibits spatial skill growth (Sherman, 1978).

Baenninger and Newcombe (1995) examined the published research literature on two issues: the impact of environment on spatial and mathematics skills, and the kind of environmental support needed to enhance mathematic and spatial skills. They examined the research on schooling effects, training effects, formal experience, self-expectation and feelings of competence, informal experience through mathematical

activity, spatial activity, and coursework. They also examined the correlations of spatial experience and ability, and historical change as well as the interaction of biological and social factors. Their research results provide evidence that environmental and social experiences influence the development of spatial skills and mathematic skills for males and females. The type of environment needed to enhance spatial skills and mathematic skills typically occurs more frequently for males than females.

As a result of their review of the empirical evidence, Baenninger and Newcombe for call for additional research on incorporating spatial curriculums that would assist both male and female students in developing mathematical and spatial skills to an asymptotic level to allow for the highest possible level of performance. Spatial ability impacts academic success in mathematics and science. To maximize individual potential in these areas, Baenninger and Newcombe suggest that researchers need to investigate successful environmental interventions at every level to foster spatial skill growth.

Quaiser-Pohl and Lehmann (2002) designed a study to compare spatial experience of males and females and performance on a redrawn version of the Vandenberg and Kuse Mental Rotations Test (MRT). The study survey consisted of questions about computer experience and spatial activities as well questions that asked participants to rank themselves on spatial ability and their attitude toward physics and mathematics. Quaiser-Pohl and Lehmann found that females with more spatial experience in technical areas and less experience in traditional female sex-typed spatial activities such as arts and needlework activities obtained statistically different higher mean MRT scores. Additionally, they found that females active in several sports

activities also had higher mean MRT scores than females without sports activities experiences.

Researchers also found a positive correlation with computer experience and MRT scores for females. They suggested several intervention strategies in line with Sherman's Bent Twig Hypothesis, among them, increasing female participation in technical activities from an early age, including participation in mathematics, science, and computer courses, as well as sports activities that improve spatial skills. They concluded by recommending further research in the areas of educational interventions and training programs that improve female spatial ability.

Spatial Training and Mental Rotation

Terlecki and Newcombe (2005) studied the relationship between videogame/computer usage and sex differences in mental rotation ability. They found that gender differences in spatial ability may be related to computer experience. They cite a concern for the digital divide along gender lines if spatial experience and training for low spatial ability students are not addressed in the school curriculum. Their research study divided participants into high spatial experience and low spatial experience groups. The high spatial experience group was 59% male and 41% female, and the low spatial experience group was 13% male and 87% female. The population sample consisted of 29% male and 71% female undergraduate students. Experience with computers correlated at a statistically significant level to MRT scores, regardless of gender. Additionally, Terlecki and Newcombe found that participants with high computer experience received a mean Scholastic Aptitude Test score of 1094, whereas participants with low computer experience obtained a mean SAT score of 976, a

difference of 118 points. Terlecki and Newcombe suggest that facilitating computer experience could improve spatial ability test scores for both sexes. While they acknowledge that some computer experience could be the result of self-selection, computer experience remains an important variable and requires further investigation.

Terlecki, Newcombe, and Little (2007) examined spatial training for males and females with high and low spatial experience. The factors included in their analysis were trajectories for improvement of spatial skills, transfer of spatial skills to other activities, maintenance of improvements of spatial skill over time by participants, the effect of test/retest on improvement of spatial skill testing, and the extent to which videogame practice transfers to spatial skill tasks and whether those effects are durable. Their research pointed to several conclusions. The growth of mental rotation skills during repeated testing and training over a semester was a continuous upward trajectory and the skill improvement continued for the participants when tested two to four months later. Videogame training improved transfer of spatial skills more than solely repeating spatial testing.

Differences were found in growth trajectories, especially for the women who initially tested low for spatial experience. Women with low spatial experience improved their spatial ability at a less rapid rate than women with high spatial experience. Women with low spatial experience also improved at a less rapid rate than men. The men showed an initial rapid improvement that leveled off and women participants showed initial slow growth, but demonstrated a steady increase in skills over the course of the semester. The pattern of slow, but steady growth was particularly evident for the women who began the research project with low spatial experience.

Despite the improvement of skills for both men and women, the researchers suggested that the participants performed at less than their maximum potential. One finding of particular interest indicated that women with low spatial experience who participated in videogame training, scored nearly as well on the MRT as high spatial experience men and low spatial experience men with repeated testing and no training of any kind.

These results suggest that while it may be discouraging for low spatial experience women to participate in spatial skill training because the improvement can be slow, videogame training or similar spatial skill training could possibly bring low spatial women to a spatial skill level nearly equivalent to untrained men. What is not clear is how much training or how long training would need to last for women to perform as well as untrained men in spatial ability testing after the women concluded their videogame training. The effect of training transferred to other spatial tests and lasted over several months. Overall, the researchers saw a 20% improvement at the end of the project over initial MRT test results, with transfer effects still visible after two to four months. The researchers state the need for more research on effective educational interventions in improving spatial skills. Their research results suggest that spatial skills training instituted and sustained over long periods of time can create durable improvements in spatial skill for both men and women, although the growth trajectories might be different for men and women. Initial high ability in spatial skill is not necessary for improvement.

Impact of Spatial Training on Spatial Visualization in Engineering

Blade and Watson (1955) researched an aspect of spatial ability -- spatial visualization -- in the 1940s and 1950s. Their findings indicated that enhanced spatial visualization skills resulted from the successful completion of freshman engineering courses at the undergraduate level, despite what students' spatial visualization scores may have been upon admission to the program. A high level of spatial visualization skills as measured by admissions testing, or scores improved through participation in a freshman engineering curriculum, correlated strongly with increased graduation rates for engineering students, especially in mechanical and electrical engineering in three schools participating in the research study. At the time of the research study, most of the engineering students participating in the study were male.

The tests used for the research study were the spatial tests developed and administered by the College Entrance Examination Board (CEEB, 1939) included the Spatial Relations Test Form VAC-1. The test had two parts, given over a period of 60 minutes with a total of 90 problems. The Spatial Relations Test Form VAC-1 was administered three times, the first time as part of the admissions process, the second time after the completion of freshman year engineering curriculum courses, and the third time just prior to graduation. Postfreshman year engineering students increased their scores on the test over 30% at each of the three schools. The students maintained or increased those gains through graduation.

Researchers found additional correlations between high preadmissions scores on the Spatial Relations Test and experience with mechanical drawing in high school, as well as experience with hobbies that required some form of technical expertise, for

example, using hand tools, repairing simple mechanical or electrical tools, or work experience of a mechanical nature. Mechanical experience of some sort prior to taking the Spatial Relations Test appeared to give some students a competitive edge in initial testing. After the completion of freshman year engineering courses, some of that difference was reduced, although almost all of students benefited from the engineering curriculum regardless of their initial test scores. Some of the engineering students with low initial scores on spatial ability tests tested in the high spatial ability range after their freshman year and maintained those gains until testing just prior to graduation.

The researchers found that scores on a spatial visualization test after the completion of common engineering courses strongly predicted academic success in engineering, and at a higher rate than the preadmissions Spatial Relations Test. They recommended that all programs basing their admissions or program criteria on high initial scores on the Spatial Relations Test may choose to consider delaying testing until students had additional spatial experience.

Sorby (2000) studied the relationship of spatial ability to learning 3-D modeling software. She compared two groups of students. The first group comprised of students enrolled in the fall of 1998 in an introduction to computer aided drafting class was compared to a group of students enrolled in the same course in the following spring. The class met for one hour of lab/lecture and one two-hour computer lab session. Fifty percent of the coursework involved 3-D modeling software. The 2-D coursework included drafting techniques. Researchers administered three spatial ability pre-tests: the Purdue Spatial Visualization Test (PSVT:R) (Guay, 1977), the Mental Cutting Test (MCT) (CEEB, 1939), and the Mental Rotations Test (MRT) (Vandenberg & Kuse,

1978). For both groups, the scores on the spatial tests failed to predict the ability to work with 2-D drafting software. However, spatial skills measured by the DAT correlated with a student's ability to work successfully with 3-D modeling software.

Medina, Gerson, and Sorby (1998) examined which spatial experiences impact gender differences in spatial visualization skills in engineering students in Brazil and the United States. Brazilian students took a four part spatial visualization test that, while not a standard visualization test, has been used to assess different aspects of spatial visualization. The Brazilian students filled out an additional questionnaire about spatial activities and experiences thought to enhance spatial skills. The authors listed the following factors as possible influences on the determination of spatial ability: age, handedness, geometry instruction, work experience, sports involvement, play with construction blocks and construction toys, video/computer game play, technical coursework, art courses, experience with drafting and graphics, and project-based work experience.

The researchers found that the most statistically significant predictor of U.S. students' success in the introductory engineering graphics course was students' scores on the PSVT:R. The U.S. participants took the PSVT:R during freshman orientation, and filled out a similar spatial activities and experience questionnaire. At both universities, researchers found statistically significant sex differences on spatial ability test scores. Although the testing instruments were different, the results were similar and some conclusions can be drawn from the data collected despite the difference in the testing instruments. The factors found to be of statistical significance were gender, drafting coursework, and play with construction toys (in Brazil the statistical significance was for

the male participants only). Overall, women were less likely to have participated in activities that support spatial visualization skill development.

Because spatial visualization skills are crucial to engineers, improving spatial visualization skills in engineering students continues to be of interest to researchers. Gerson, Sorby, Wysocki, and Baartmans (2001) designed a research project to determine the effectiveness of multimedia software for improving spatial visualization skills in first-year engineering students. Participants in the research project were students who had failed the PSVT:R during freshman orientation. The multimedia software developed by the researchers consisted of a textbook and a computer software program containing lab exercises. In the original course employing the software program, first-year engineering students increased spatial visualization skills to statistically significant levels.

The researchers also found improved retention rates among female engineering students at the university. The computer software exercises permitted students to manipulate 3-D objects on the screen similarly to the way in which they would manipulate actual objects during the class lecture portion of instruction. For the research project, researchers tested four modules: Making Isometric Sketches, Orthographic Projection, Flat Patterns, and Rotation of Objects about One Axis. In the following year, researchers added five more modules: Rotation of Objects about Two or More Axes, Object Reflections and Symmetry, Cross Sections of Solids, Surfaces and Solids of Revolution, and Combining Solids.

The students who failed the PSVT:R had two choices for subsequent coursework. They could take the original course or a new course. The new course

consisted of a two-hour supervised lab each week in which enrolled students worked through multimedia software modules and related exercises in a workbook developed to coordinate with the multimedia software modules. Students in the new course had no other formal instruction beyond the supervised lab time and the information presented on the multimedia software. Students in the original course utilized the multimedia modules and participated in two hours of lecture each week, but did not complete workbook exercises. Gender was not examined as a factor in the research. Students in both groups completed pre- and post- standardized tests to determine gains for each group. Four other pre- and post- spatial ability tests were administered: the Differential Aptitude Test: Space Relations (DAT:SR), (Bennett, Seashore, & Wesman, 1973), the Purdue Spatial Visualization Test: Rotations (PSVT:R), (Guay, 1977), the Mental Cutting Test or MCT (CEEB, 1939), and the 3-D Cube test or 3-DC (Gittler & Glueck, 1998).

Students in the new course made the largest performance gains in the spatial tests. The new course consisted of a two hour supervised lab, workbook exercises, and multimedia software. In both groups the gains were statistically significant for all of the tests. However, students enrolled in the original course showed the larger post-test gain in MRT performance results when compared to the results of students in the new course. For all other spatial ability tests, the larger gain in performance came from the students in the new course. Because the test results were not reported by gender, it is not known in which course female students would have made the largest gains.

Sorby, Drummer, Hungwe, and Charlesworth (2005) conducted a study attempting to develop spatial visualization skills of nonengineering students. The

researchers tested first- and second-year nonengineering students for spatial skills using the Purdue Spatial Visualization Test: Rotations (Guay, 1977) and split the students into four groups. The fourth group was a control group.

The three experimental groups used materials developed to enhance the spatial visualization skills of engineering students. One group used only the workbook developed for the course. The second group used only the computer software developed for the course. The third group used both the software and the workbook. Weekly instruction in spatial visualization skills occurred over a ten week period for each experimental group. Researchers tested all four groups at the end of the 10-week period. Students completed a survey about their preference for material presentation and they preferred the software only presentation. However, that method proved to be the least effective in improving spatial visualization test scores.

The largest gains on the PSVT:R, 11.6 points, came from the workbook only group. The second largest gain, 11.2 points, was for the workbook and software group. The gain by the software-only group was comparable to the gain by the control group, 8.4 for the software-only group and 5.3 by the comparison group. The gains were not subdivided by gender and group, so it was not possible to examine the effect of the type of presentation by gender. The only gender information reported was that females in the study spent more time on the spatial material than did the males.

The group that spent the least time on the material was the software-only group. Seventy-two percent of the software-only group spent less than one half hour a week, while 13% of the software and workbook group and 16% of the workbook-only group spent less than one half hour per week. Students in all three treatment groups could use

manipulative cubes to assist them when working through the spatial curriculum. Forty-one percent did not use the manipulative cubes at all, 37% used them infrequently, 14% used them much of the time, and 8% used them whenever they were available.

Seventeen percent of the females never used the manipulative cubes compared to 51% of the males. Fourteen percent of the females used the manipulative cubes whenever the cubes were present compared with 6% of the males. These figures were not reported by treatment group type. All participants were surveyed about confidence levels and women participants reported statistically significantly higher gains than the male participants in confidence levels.

Spatial Ability and Information Seeking

When computers first appeared, programmers and system designers paid little attention to user interfaces. System demands took precedence. System designers expected users to adapt to the interface design. Despite the wide ability range of users, system designers expected productivity levels to be the same. Once users learned the system, their efficiency levels, or the time required for task completion would fall within the similar time ranges. Concerned with the impact individual differences make on computer use, Egan (1988) began to investigate the role of individual differences in the time required to complete different types of computer tasks. Egan reviewed research studies that examined three common computer tasks: text editing, information searching, and programming. He discovered that the ratio of differences in completion times of certain computer tasks could be as high as 22:1. Egan measured task completion time by measuring the time spent correcting for errors as well as, the time required for identifying the errors.

Other researchers have reported lower ratios when task completion time measured only the identification of errors, and not the time needed for the correction of errors. In examining performance variables, performance differences among users had a larger range than differences in training methods or system design. Egan suggests that accommodating individual differences, including differences in spatial ability, could result in higher efficiencies for users and a broader pool of users or employees available to use the system or program. Additionally, technology is often used in settings meant to be accessible to a large part of the public, for example the computers in a public library. Designing systems that accommodate individual differences would remove barriers that hinder use in public settings or in places of employment. From a business standpoint, accommodating individual differences would result in a larger market for products and systems and a more efficient workforce.

Egan sought to document the range of individual differences in users and isolate some of the performance variables so that more effective user interfaces could be designed. In examining the research studies on text editing, information searching, and programming to create a meta-analysis, task completion time appeared to be reported more consistently than other performance factors such as; errors, number of attempts, or proportion correct on first attempt. Descriptions of the errors made in task completion informed the researchers in the surveyed studies about the difficulties with task, but the reporting methods varied from study to study. To accurately compare studies, Egan used several items for comparison purposes: maximum and minimum completion times, and ratio of scores between maximum and minimum completion times, first and third

quartile scores, and the ratio between those quartile scores, standard deviation, and the coefficient of variation.

In interpreting a performance ratio of maximum to minimum completion times, a 10:1 ratio means that a person at the top of the range is 10 times faster at task completion than a person at the bottom of the range. Translated into daily activities such as waiting in a grocery line, one cashier could be ten times faster than the cashier in another line. Since sample sizes varied greatly, Egan (1988) decided to use interquartile ranges for comparison purposes. In this study, he compared the differences between users performing in the 25th percentile and to the users in the 75th percentile. Many of the studies Egan reviewed reported small sample sizes and using the 5th and 95th percentiles would have resulted in less stable comparisons. Egan found three studies on information searching with enough data for analysis given on individual subjects to compare results across studies in a small meta-analysis. He compared Vincente, Hayes, and Williges (1987), Dumais and Wright (1986), and Greene, Gomez, and Devlin (1986).

The Vincente, et al. (1987) study examined the use of a hierarchical file for text by users trained to use a screen browser. The hierarchical file system consisted of three levels of hierarchy in a total of 15 files. The top level of the hierarchy contained one subject, army operations. The second level consisted of four topics under army operations; armoured personnel carriers, army operations, combat support, and tanks. The bottom or third level contained subtopics under the topics of tanks and armoured personnel carriers. The task required users to find one line of text in a 2,780-line file structure. The correct answer was listed in only one place in the hierarchy. The interface

consisted of a window in which seven lines of text could be viewed at one time. The 12 commands available to the users could be divided into two categories. The first category consisted of commands that went across, or up and down the hierarchy. The second category contained commands that searched inside the file itself.

In the analysis of individual differences, Vicente et al. discovered that vocabulary and spatial visualization predicted performance on this task to a large degree. In fact, 45% of the variance in the research results could be predicted by those two measures. Of the two predictors, spatial ability was the strongest predictor of performance. On average, users with high spatial ability, as determined by several measures of spatial ability from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harmon, 1976), performed twice as fast as subjects with low spatial ability.

While computer experience was important, it did not predict performance when analyzed in isolation. If spatial ability was disregarded, no correlation existed between performance and computer experience. Vincente suggests that perhaps users with low spatial ability avoid computers or that computer users have high spatial ability. Users with the most computer experience also tested in the high range for spatial ability. Users with low spatial ability used the commands zoom and scroll more often than users with high spatial ability. Vincente suggested that the results seem to indicate that low spatial ability users lost their way in the file. Users with high spatial ability maintained awareness of their location within the file without employing scroll commands.

Looking at a file as a continuous file appeared to be critical to users with low spatial ability. In comparison, users with low spatial ability struggled to determine their location within the file after employing a command that executed a discrete cut (search,

index, section) instead of a continuous scroll up or down. Utilizing scroll commands to provide a continuous transition between display views reduces overall efficiency. Scrolling up and down a file moves the user through several files (topics and subtopics) to a new file in the hierarchy. Using the zoom command keeps the user within the same file in the hierarchy of files. Frequent use of the zoom command indicates that the user does not have a clear mental map of the system. In contrast, using the scroll commands indicate that users know their location in the hierarchy.

In their conclusion Vincente et al. suggest spatial visualization best predicts efficient performance in information seeking in a hierarchical file system. The difference in performance between high spatial and low spatial ability users was significant enough statistically to warrant further investigation and eventual redesign of user interfaces. The authors suggested that additional research is needed to further isolate the variables and identify the interventions that will increase spatial ability in low spatial ability users, and the accommodations that will be effective for low spatial users without inconveniencing high spatial users. Vincente et al. referenced the Blade and Watson (1955) study in his research to suggest that improving user spatial ability is possible.

In the Dumais and Wright (1986) study, participants retrieved news articles (objects) they filed after assigning either a two letter names or a screen location as a retrieval cue for the object. The researchers set up a practice session and three sessions of retrieval tasks in two conditions. In one condition, researchers asked the participants to assign the objects a two letter object name. In the other condition, the researchers asked the participants to arrange the icons representing the electronic files

on their computer desktop in a way that made sense to them, and then place the objects in the electronic file.

The first block of file retrieval tasks used required users to retrieve the news articles that they filed in one of ten files to answer a series of questions. The second block of tasks required participants to locate the answers in one of twenty files, and the third block of tasks required participants to find the information in one of thirty files. The researchers found that as the number of files increased, the time required to complete the task increased. Comparing the results of location retrieval vs. name retrieval, retrieving by location was less efficient. Researchers recorded a high statistically significant effect ($p < .001$). The average number of folders opened ranged from 1.6 in the name condition to 3.2 in the location condition. Using Egan's (1988) conversions, the maximum to minimum retrieval times varied from a range of 7:1 to 10:1 (p. 548).

In the Greene, Gomez, and Devlin (1986) study, users learned to query a database using a programming language or a tabular interface developed for the research project. The results differed from the Dumais and Wright (1986) study and Vicente et al. (1987) because the maximum/minimum completion time ratios were much smaller, 3:1, and the coefficient of variation was in the range of .30 as analyzed by Egan (1988).

While Egan (1988) was unable to conclude which spatial ability was responsible for the efficiencies in information seeking, programming, or text editing, it appeared that spatial ability was a factor in determining efficiency in human-computer interaction. Users with low spatial ability made more errors than users with high spatial ability on the tasks he examined in his meta-analyses. Focusing on reducing user errors by producing

user interfaces that improve performance of users who struggle with task efficiency would be a worthy goal for system designers, especially for those tasks where a wide range of users would benefit. Egan recommended that any system design should not be an obstacle for users to overcome, rather an extension of their own capabilities. Egan suggested that Interface training and redesign of interfaces could reduce errors and create task efficiencies

Curl, Olfman, and Satzinger (1998) examined the impact of spatial visualization on database user interfaces. One of their research hypotheses suggested that high visualization ability participants would outperform lower visualization ability participants, with spatial ability measured by the VZ-2 test (Ekstrom, French, & Harmon, 1976) on a database exercise. The participants were undergraduate students who completed one course in computer skills that included instruction on SQL commands. The database task presented to the participants involved knowledge within their expertise. The researchers found that participants with high spatial visualization scores outperformed participants with low spatial visualization scores and the effect was statistically significant, $p = .001$. Researchers found a related research result when examining the interaction of spatial ability and spatial and nonspatial database views. High spatial ability participants outperformed low spatial ability participants in both views. The gap in performance was largest for the nonspatial database view. While the results were not statistically significant, they were clearly observable. Mean scores for the low spatial group in the nonspatial database views were 55.3 and 70.9 for the high spatial view. In the spatial view, the difference was 69.7 and 78.3, again with the high spatial participants outperforming the low spatial participants. Researchers conclude "spatial

visualization ability, in particular, was shown to be an important predictor of the correctness of end-user performance" (p. 63).

Thomas (1998) examined the factors that influence performance on two databases, the JSTOR® database (JSTOR, Ann Arbor, MI, www.jstor.org) (JSTOR is a scholarly journal database which contains full-text titles in the areas of education, business, science, history, mathematics, among others), and on a geospatial library under development at a California university. Thomas tested for spatial ability using the Kit of Factor-Referenced Cognitive Tests licensed by the Educational Testing Service (ETS) of Princeton, New Jersey. Thomas divided her participants, students in an instructional technology course required in a teacher credentialing program, into high spatial ability and low spatial ability groups. High spatial ability participants outperformed low spatial ability participants in both the JSTOR and the geospatial interfaces. In analyzing the research results, computer experience was not statistically significant in successful completion of JSTOR tasks. However, high spatial ability participants also reported greater satisfaction with both user interfaces than lower spatial ability users.

Spatial ability affects information retrieval times as reflected in research studies; however, spatial ability is modifiable to some extent. Little research has been located by the researcher on the impact of improving spatial ability to reduce time required on information seeking tasks.

Summary of the Literature Review

Spatial ability researchers work in many disciplines. For many years, engineering and psychology researchers utilized successful interventions to improve spatial skill, but

much of that research was little publicized outside of their respective fields.

Communication about spatial research occurring across the disciplines has not been uniform or well-reported in cross-discipline literature. However, little is known about improving spatial ability and the role of spatial experience on improving spatial ability outside of the areas of engineering and psychology. Interventions to improve spatial skills for low spatial ability individuals could improve their quality of life in many ways by giving them additional career choices, helping them become more effective users of technology, as well to become more efficient in information seeking tasks by improving personal information infrastructure. Effective spatial skill improvement interventions need to be further researched, particularly at the pre-kindergarten through twelfth grade level, where interventions could make a lifelong impact. For spatial skill interventions to produce maximum success, many variables need examining, including problem-solving strategies, performance factors, stereotype threat, and the interaction between biology and environment. This research project proposed to examine the variables of spatial visualization training on mental rotation scores and the impact of mental rotation scores on an information retrieval task in a single-sex environment.

CHAPTER 3

METHODOLOGY

Introduction

This exploratory study examined two factors: the impact of a spatial curriculum in a single-sex school, and the impact of spatial ability on an information retrieval task. The extent to which a spatial visualization curriculum could improve Mental Rotations Test (MRT) scores from a pretest to a posttest for girls was the first factor examined, using the spatial visualization curriculum developed by Sorby and Wysocki (2002). The curriculum was originally developed to enhance the spatial visualization skills of engineering students at Michigan Technological University, but is being tested on larger groups of students including high school and non-engineering undergraduate students (Sorby, personal communication, November 29, 2005, June 13, 2008; Sorby, Hungwe, & Drummer, 2008).

Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) used questions about MRT test-taking strategies in a study and Gurney (2003) used the same questions, slightly modified, in her study. This research study used the questions in the format created by Peters et al. to determine test-taking strategies. The information retrieval task used four tasks developed for a doctoral study by Thomas (1998) and utilized the scholarly journal database JSTOR® (JSTOR, Ann Arbor, MI, www.jstor.org). Thomas, the author of the JSTOR study, was unable to be located by this author and the alumni office of the University of Southern California so permission could not be documented.

Research Questions

1. To what extent can spatial ability, specifically mental rotation, in 10th-grade girls be increased by providing increased spatial experience in a biology classroom?
2. Does spatial ability as measured by the Mental Rotations Test impact search efficacy while using JSTOR for database search tasks?

Research Design

The research method involved three parts. This study compared mental rotation ability, a subset of spatial ability, as measured by the Vandenberg Test of Mental Rotation, prior academic performance, test-taking strategies, and confidence levels using *t*-tests. The result of interest was the score on the Vandenberg Mental Rotation Test. The cause investigated was spatial visualization training to enhance spatial ability, specifically the ability to perform mental rotation. The second part of the study measured the results of the use of a spatial visualization curriculum designed to enhance mental rotation. The results from the second part compared control and treatment group pretest scores on the MRT to posttest scores on the Mental Rotations Test after the treatment group completed the spatial curriculum. The researcher analyzed changes in test-taking strategies or confidence levels of the students in the treatment group. The third part analyzed the efficiency as measured in time on information seeking task performance by high and low spatial participants.

Hypotheses

1. Mental rotation skill in 10th-grade girls attending a single-sex school will be enhanced by providing increased spatial experience through a spatial curriculum in a 10th-grade

biology classroom when compared to girls in the control group as demonstrated by higher scores on the MRT posttest.

2. Girls with higher spatial ability, as determined by the Mental Rotation Test administered as a pretest, will have higher Preliminary Scholastic Aptitude Test (PSAT/NMSQT® practice test [College Board, New York, NY, www.collegebaord.com]) math scores when compared to the girls with lower spatial ability in both the control and treatment groups in both the pretest.

3. Girls who report on the personal test-taking strategy and confidence survey that they rotate whole images in their minds rather than section by section will score higher in the pretest and posttest.

4. The number of girls in the treatment group who report rotating images in their minds as a whole instead of section by section will increase after completing spatial training.

5. Girls in the treatment group will attempt more problems during the 3-minute time on the MRT than the girls in the control group after completing spatial training.

6. Students in the high spatial ability group as determined by MRT score will perform JSTOR search tasks in less time than students in the low spatial ability group.

Setting

The researcher conducted the study using sophomore biology students at an all-girl, day, independent (private) school located in a metropolitan area with more than one million residents, and within a community that is largely Caucasian of European descent. A regional accrediting agency accredits the school every seven years. The school maintains socioeconomic diversity through a financial aid program that provides financial aid assistance to 17% of the students. For the years 2003-2008, the student-

of-color population exceeded 20% of the total student body. The school allocates more than a million dollars each year for financial aid for students. Annual tuition provides the primary source of revenue and financial support for the school, while endowment fund interest and annual giving funds the gap between tuition payment receipts and the cost of maintaining the school's facilities and programs. Each student and her parents or guardians apply for admission through a process which includes student testing, transcripts, an onsite visit by the student, recommendations from current teachers, and personal interviews with a division director and an admissions director.

Students attend school from 30 different zip codes through several transportation options including, private transportation, public school transportation, and through transportation resource sharing with another local private school.

The nonsectarian college preparatory school, established in the 1800s, located in the Midwest, educates approximately 670 girls from infancy through 12th grade on one central campus. Approximately 100 faculty members are employed by the school. Sixty percent of the members of the faculty possess advanced degrees. Administrators choose faculty on the basis of teaching skill, recommendations, and knowledge of content area. Thirteen percent of the teachers are people-of-color.

The oversight of the school rests on the head of school and the associate head of school. The board of trustees is comprised of 30 members, 18% of whom are people-of-color. The head of school reports to the board of trustees and the associate head of school reports to the head of school. The school consists of four divisions: early childhood (infants through kindergarten); lower school (grades one through five); middle school (grades six through eight); and upper school (grades nine through twelve).

Administratively, each division has a principal, called a division director who is responsible for the oversight of that division. Each division has an administrative assistant, and other support staff which includes learning support specialists.

One hundred percent of the graduates are accepted into four-year undergraduate programs. The mean Scholastic Aptitude Test® subject test (College Board, New York, NY, www.collegeboard.com) (SAT) mathematics score for the graduating class of 2007 was 641 and the average SAT critical-reading score was 640. The students at the school average more than 100 points above the state and national means for SAT scores for females with a mean score of 142 points above the SAT mathematics mean nationally for females and 139 points nationally for the SAT critical reading mean score for females. Research site students also averaged 115 points above coeducational independent school means for mathematics and 109 points for critical reading. (See Table 1 for comparisons of SAT scores by school type and gender. Reports by gender were unavailable for state and national independent school means).

Table 1

Comparisons of Mean SAT Mathematics and Critical Reading Scores

	Females Class of 2007	Males Class of 2007	Coed Class of 2007
Research site mathematics mean SAT score	641	Does not apply	Does not apply
State mean mathematics SAT (all schools)	525	563	542
State mean mathematics SAT (independent schools)	Not available	Not available	543
National mean mathematics SAT (all schools)	499	533	515
National mean mathematics SAT (independent schools)	Not available	Not available	526

(table continues)

Table 2 *(continued.)*

	Females Class of 2007	Males Class of 2007	Coed Class of 2007
Research site mean critical reading SAT scores	640	Does not apply	Does not apply
State critical reading mean SAT scores (all schools)	533	539	536
State critical reading mean SAT scores (independent schools)	Not available	Not available	544
National critical reading mean SAT scores (all schools)	502	504	502
National critical reading mean SAT scores (independent schools)	Not available	Not available	531

Source: College Board (2008).

Biology classes were chosen for the setting because a student's level of spatial ability can impact visualization of scientific models. Low spatial ability students have more difficulty visualizing scientific concepts.

This study did not examine sex differences because did not compare male and female performance. However, the absence of males in the classroom may have impacted performance.

Participants

Participants came from a range of ethnic and socioeconomic backgrounds, although the majority were middle- to upper-class Caucasians. Twenty percent of the females in the sample were students of color. Each student had access to a Tablet PC in her classroom housed in a cart in the classroom. The first lab of the school year was used to introduce the Tablet PCs to the students. Two biology teachers worked together loosely to coordinate class materials, class presentations, biology notebook checks, and assessments, although their styles of presentations differ. Four sections of biology participated in the research project. All of the students were females between the ages of 14 and 16. Convenience sampling was used for this study. The researcher was

employed as an administrator at the school at the time of the research project, but had no classroom responsibility that impacted the academic grades and records of the participants. All students participated on a voluntary basis.

Method

Spatial Visualization Curriculum Research Project

Of the four sections of 10th grade biology sections participating, two classes were control groups and two were treatment groups. The biology sections designated “control” and “treatment” were chosen randomly. The researcher sent consent forms home with each student and a letter to the parents and guardians explaining the study. The treatment classes met for 20 sessions of 30 minutes each over a six-month period. The control classes met for four 30-minute sessions. The first session introduced the projects.

The second 30-minute session was spent administering the Vandenberg Mental Rotations Test. Students were given 3 minutes to complete Part 1 and 3 minutes to complete Part 2. There was a 1-minute break between Parts 1 and 2. After the 3-minute time limit was called on Part 1, students drew a line under the last set of images completed to show how far they progressed on the test within the allotted time. They repeated the procedure for Part 2.

The test can be scored two ways. Each test item has two correct answers out of four possible answers. There are 20 test items, 10 in each section. In one method, students can receive credit for each correct answer for a possible total of 40 points. A second method is to give one point for each correct line. To receive credit, each line

must have two correctly identified drawings . If one item is incorrect, the whole line is counted as incorrect. The highest possible number of points is 20.

This study used the scoring by line method where both answers on a line must be correct to get one point. The maximum number of points possible is 20. This reduced the chance that the students would get a correct answer through guessing rather than problem-solving. The researcher scored all of the tests. The results were recorded as follows. The first score was the total number of correct answers from the MRT pretest. The second score was the total number of correct answers within the 3-minute time limits for Parts 1 and 2. The third score was the total number of problems attempted during the 3-minute time limits for Part 1 and Part 2.

After the completion of the MRT pretest, students answered test-taking strategy and confidence questions. These questions measured the students' recollections of their problem-solving strategies and their confidence levels while taking the MRT.

The treatment group began sessions on the spatial visualization curriculum during one 30-minute period out of every six-day rotation. Participants were tested for mental rotation as the school year began. The spatial visualization curriculum was introduced at the beginning of the school year in October and students in the treatment group participated in a total of 15 30-minute sessions administered once every six-day rotation. Each 30-minute class session was followed by approximately 30 minutes of workbook practice outside of class to reinforce the skills taught during the 30-minute class session. At the end of the course, treatment and control group students retook the Mental Rotation Test (MRT). The dependent variables were the scores on the pre- and post-Mental Rotation Tests. Each girl had a total score of correct answers untimed for

the pretest. Each girl had scores for the number of questions attempted during 3-minute test-taking section of Part 1 and the 3-minute test taking section of Part 2 for pre- and posttests.

At the completion of the spatial curriculum, the control group and the treatment group took the MRT posttest and answered the strategies and confidence questions.

JSTOR Database Searching Project

Students who participated in the spatial curriculum portion of the research project were asked to participate in the JSTOR portion of the project. The number of students participating in this portion of the project was smaller. The researcher tested students in small groups over a two-week period because of the lack of a common time for large group testing due to activities at the end of the school year. Each set of instructions remained the same. The researcher asked students not to discuss about the research questions on the JSTOR exercise until after the researcher had collected all of the data. Each student received a stopwatch to measure time spent on each question. Students recorded the time on the stopwatch as they completed each question while the stopwatch continued to run. Each group practiced starting and recording the time on the stopwatch. Each group then opened the window for JSTOR. Students turned over the JSTOR task sheet and the researcher showed the students where to enter the beginning and the ending times for each question, as well as the answer for each question. Each group received thirty minutes to work on the four JSTOR tasks. At the end of 30 minutes the researcher collected the JSTOR task papers and the students left, but the researcher reminded not to discuss the JSTOR task questions with anyone else.

Tests and Instruments

Mental Rotations Test

The Mental Rotations Test was originally based on work by Shepard and Metzler (Shepard & Metzler, 1971) and further developed by Vandenberg and Kuse (1978). The MRT is a pencil and paper test that has been shown to have the largest gender gap of various tests of spatial ability (Masters & Sanders, 1993). The instructor spent five minutes on the instruction for the Mental Rotations Test and working through the examples. The test consisted of two parts; each part consisted of 10 items. Each item on the test had a figure to be used for comparison. Students chose two out of four figures that matched the target figure. The other two figures were distractors. The correct two figures were the same as the target figure used for comparison, but the figures had been rotated around an axis in space. Students competed part 1in 3 minutes and drew a line showing where they stopped at the 3-minute mark. They completed part 2 in 3 minutes drawing a line to mark where they finished working on their last question. After students completed both timed parts, they were permitted to work on the unfinished sections in an untimed condition on the pretest.

Personal Strategies and Performance Questionnaire

Used in the research of Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) and slightly modified by Gurney (2003), these questions examine MRT test-taking strategies (see Appendix A). Students were asked to remember how they solved the spatial problem, if they rotated the image as a whole in their minds, or section by section. In some studies, rotating figures section by section meant that the

test-taker was less efficient with the time on task. Mentally rotating the figure as a whole is frequently more efficient.

This research project examined whether a difference existed in test-taking strategy and the pretest results of the MRT for speed and accuracy by analyzing the results of the timed portion. The results of the posttest were analyzed to see if more efficient strategies (whole image) were chosen by the treatment group after they completed the spatial curriculum. This researcher examined the number of questions answered correctly, pretest and posttest, to see if any change emerged in the problem-solving strategy. Questions on strategy also asked students if they used a verbal strategy or a kinesthetic strategy to solve the problem. The last two questions included confidence questions about the task. Students answered the questions on strategy and confidence after each administration of the MRT. In a personal communication, Peters wrote that the questions were open domain (May 27, 2007).

Preliminary SAT/National Merit Qualifying Scholarship Test (PSAT/NMSQT)

The PSAT tests for critical reading skills, writing skills, and math problem-solving skills. All ninth graders take a PSAT test as part of their coursework at school. The PSAT test scores for the ninth grade year are considered practice scores only. The critical reading skills scores and the math-problem solving scores were analyzed for possible relationships to the MRT timed test scores. The PSAT test is administered in the fall. Students took the test prior the introduction of the spatial curriculum.

Spatial Visualization Curriculum

The curriculum, *Introduction to 3-D Spatial Visualization*, consists of nine modules developed by Dr. Sheryl Sorby of Michigan Technical University for use with

engineering students who need to enhance spatial ability to be successful in their engineering coursework (Sorby, 2000). It has also been tested on non-engineering students and was found to enhance spatial visualization skills (Sorby, Drummer, Hungwe, & Charlesworth, 2005). The course consists of a workbook and a CD-ROM. Students completed eight modules and one week after their completion of the course took a retest on the Vandenberg Test of Mental Rotation.

The researcher used the spatial curriculum by employing the CD-ROM software from *the Introduction to 3-D Spatial Visualization: An Active Approach* (Sorby & Wysocki, 2003). The software consists of nine modules but only the first eight modules were part of the research project. The modules were as follows:

Module 1: Isometric Drawings and Coded Plans

Module 2: Orthographic Drawings

Module 3: Flat Patterns

Module 4: Rotation of Objects about a Single Axis

Module 5: Rotation of Objects about Two or More Axes

Module 6: Object Reflections and Symmetry

Module 7: Cutting Planes and Cross Sections

Module 8: Surfaces and Solids of Revolution

Students used two 30-minute class periods to work on each module. Some modules did not require two full 30-minute sessions. When the students finished early, they began working on the workbook pages as homework and as reinforcement to the lesson. Workbook pages were due within five school days of completing each module. This researcher offered no additional spatial skill instruction. Students assisted other

students when needed, but no formal instruction occurred. Sorby found that the CD-ROM alone or the workbook pages alone were not as effective as combining the workbook pages and the CD-ROM exercises (Sorby, 2005). If completing the module required only one 30-minute class period, the class moved on to the next module.

JSTOR Tasks

Students attempted to solve four JSTOR tasks on the worksheet. Each student received 30 minutes to complete the four tasks (See Appendix B). The tasks varied in difficulty. The first task could be solved in a fairly straightforward manner. The next two tasks required several steps to solve, and the fourth task was designed to be extremely difficult. Task four was solvable, but required some sophisticated problem-solving skills. This researcher expected that few, if any, students could solve it.

Materials/Apparatus

Each student used a pencil with an eraser for both the spatial curriculum portion and the JSTOR portion. The students completed the Mental Rotations Test (the sample problem section, Part I, and Part II), and answered the personal strategies and performance questions. Then the treatment group began working through the spatial curriculum exercises on the classroom Tablet PCs. After the treatment group completed the spatial curriculum, all students took the MRT a second time and answered questions a second time about strategies and confidence in performance on the MRT. The JSTOR portion took place as a separate exercise after the spatial curriculum was completed by the participants.

For the instruction in the spatial curriculum, students in the treatment group used a Tablet PC pre-loaded with the spatial visualization software for instruction during class

time and worked out-of-class on the worksheets in the workbook for reinforcement as homework.

Data Collection Procedures

Approval

The researcher received approval for the study prior to the commencement of the study. This included gaining permission from the school for use of the institution as a study site. Study participants and their parents were informed of the intent of the study, the data collection procedures, and the student's right to refuse to participate at any time without concern for the consequences. Girls and their parents completed consent forms describing the study. The Mental Rotations Test is in the public domain and did not require permission to use.

Independent variables

Students in the treatment group worked through exercises in a spatial visualization workbook. The researcher measured the time required to solve the MRT problems for students in both control and treatment groups. The researcher also measured the time required to solve the JSTOR questions.

Dependent variable: *MRT Score*

Students also answered personal strategies and performance questions after taking the pre-test MRT, and again after the post-test MRT.

Analysis of Results

For each hypothesis, the researcher analyzed groups using inferential analysis though paired sample *t*-tests and independent two sample *t*-tests for equality of measure. The researcher compared the results of the analysis of the pre- and posttest

scores of spatial ability, the number of questions attempted on the MRT and posttest, and the MRT survey results on rotating images as a whole or section by section. The researcher compared academic scores to MRT pretest results as well as personal strategies, pre- and posttest to see if high verbal scores or high math scores or grades related to MRT scores or strategies. PSAT scores provide a measure of academic skills through standardized test scores. The researcher set the level of statistical significance at 0.05 to see if true differences between the two groups existed. The researcher tested the assumption of equality of variance between groups with Levene's test. Based on these results, the researcher determined whether spatial visualization training increased the mental rotation skills of the students participating in this study. This researcher calculated the effect sizes for each hypothesis using Cohen's *d* as the measure for effect size.

CHAPTER 4

ANALYSIS OF RESULTS

Introduction

Results of the study will be reported in this chapter. Each hypothesis will be presented individually with the analysis of the research results. Thirty-six sophomore biology students participated in part one of the research project which examined to what extent spatial training impacted Mental Rotations Test (MRT) scores. Part 1 tested Hypothesis 1, Hypothesis 2, Hypothesis 3, Hypothesis 4, and Hypothesis 5. Twenty-four sophomore biology students participated in part two of the research project which examined Hypothesis 6 and the impact of MRT scores on efficiency and speed in searching the JSTOR® database (JSTOR, Ann Arbor, MI, www.jstor.org).

Research Questions

1. To what extent can spatial ability, specifically mental rotation, in 10th-grade girls be increased by providing increased spatial experience in a biology classroom?
2. Does spatial ability as measured by the Mental Rotations Test impact search efficacy while using JSTOR for database search tasks?

Hypothesis 1

Mental rotation skill in 10th-grade girls attending a single-sex school will be enhanced by providing increased spatial experience through a spatial curriculum in a 10th-grade biology classroom when compared to girls in the control group, as demonstrated by higher scores on the MRT posttest.

A *t*-test for two independent samples was conducted on the post-MRT timed (posttest) scores to evaluate if a difference existed between the treatment group girls and the control group girls. The summary of the results is presented in Table 2.

Table 2

Results of t-*Tests Comparing Treatment Girls to Control Girls*

Variable	*df*	*t*	*d*	*p*
Post-MRT timed	34	0.44	0.15	0.33

Hypothesis 1 tests the null hypothesis that girls in the treatment group obtain the same score on the timed portion of the MRT (posttest) given after the treatment girls completed the spatial curriculum as the girls in the control group. The alternative hypothesis is that the girls in the treatment group score higher.

H_0: $\mu_{treatment} = \mu_{control}$

H_A: $\mu_{treatment} > \mu_{control}$

With alpha set at 0.05, the *t*-test for two independent samples was not statistically significant, $t(34) = 0.44$, $p = 0.33$. Using Cohen's (1988) measures for determining effect sizes (small = 0.2, medium = 0.5 and large = 0.8) the effect size *d* of 0.15 indicates no effect size of note. Control group girls ($M = 11.41$, $SD = 2.60$) had scores similar to the treatment group girls ($M = 10.79$, $SD = 5.30$). The results support the conclusion that control group girls and treatment group girls have similar scores on the post-MRT timed test (posttest).

Hypothesis 2

Girls with higher spatial ability, as determined by the Mental Rotation Test administered as a pretest, will have higher Preliminary Scholastic Aptitude Test (PSAT/NMSQT® practice test [College Board, New York, NY, www.collegeboard.com]) math scores when compared to the girls with lower spatial ability in both the control and treatment groups in the pretest.

The cutoff for creating these two groups used the mean of the MRT total timed (pretest) for these subjects. A *t*-test for two independent samples was conducted on the PSAT math scores to evaluate if there was a difference between the high spatial ability girls and the low spatial ability girls. A summary of the results is presented in Table 3.

Table 3

Results of t*-Tests Comparing Low Spatial-Ability Girls to High Spatial-Ability Girls*

Variable	*df*	*t*	*d*	*p*
PSAT math	32	0.13	0.05	0.45

Hypothesis 2 tests the null hypothesis that girls with high spatial ability will have the same score on the PSAT math as the girls with low spatial ability. The alternative hypothesis is that the girls with high spatial ability score higher.

H_0: $\mu_{\text{high spatial}} = \mu_{\text{low spatial}}$

H_A: $\mu_{\text{high spatial}} > \mu_{\text{low spatial}}$

With alpha set at 0.05, the t-test for two independent samples was not statistically significant, $t(32) = 0.13$, $p = 0.45$. The effect size *d* of 0.05 indicates no effect size using Cohen's (1988) measures for determining effect sizes (small = 0.2,

medium = 0.5 and large = 0.8). Low spatial-ability girls (*M* = 54.78, *SD* = 9.26) have PSAT mathematics scores similar to high spatial-ability girls (*M* = 54.36, *SD* = 6.91). The results support the conclusion that girls with low spatial ability have similar scores on the PSAT mathematics test as girls with high spatial ability.

Hypothesis 3

Girls who report on the personal test-taking strategy and confidence survey that they rotate whole images in their minds, rather than section by section, will score higher in the pretest and posttest. (Appendix A contains the confidence and strategy questions used).

T-tests for two independent samples were conducted on the MRT Total Timed Scores (pretest) and the Post-MRT Timed (posttest) scores to evaluate if there was a difference between the girls using mental rotation and the girls who do not use mental rotation. The summary of the results of the *t*-tests is presented in Table 4.

Table 4

Results of t*-Tests Comparing Girls using Mental Rotation to Girls Using no Mental Rotation as a Problem-Solving Strategy*

Variable	*df*	*t*	*d*	*p*
MRT Total Timed	32	1.58	0.56	0.06
Post-MRT timed	31	1.24	0.44	0.11

Hypothesis 3 tests the null hypothesis that girls who use mental rotation will have the same score on the MRT Total Timed (pretest) and Post-MRT timed (posttest) as the girls with who do not use mental rotation. The alternative hypothesis is that girls who

use mental rotation score higher on MRT Total Timed (pretest) and Post-MRT timed (posttest) than girls who do not use mental rotation.

H_0: $\mu_{\text{use mental rotation}} = \mu_{\text{no mental rotation}}$
H_A: $\mu_{\text{use mental rotation}} > \mu_{\text{no mental rotation}}$

With alpha set at 0.05, the *t*-test for two independent samples on MRT Total Timed (pretest) was not statistically significant, $t(32) = 1.58$, $p = 0.062$. The effect size *d* of 0.56 indicates a moderate effect size. This moderate effect size indicates that while no statistically significant difference exists, a moderate practical effect exists. Girls who do not use mental rotation ($M = 8.26$, $SD = 4.09$) differ in their scores from the girls who use mental rotation ($M = 5.71$, $SD = 2.21$). The results support the practical conclusion that girls who use mental rotation score higher on the MRT-timed test (pretest) than the girls who do not use mental rotation.

With alpha set at 0.05, the *t*-test for two independent samples on Post-MRT Total Timed (posttest) was not statistically significant, $t(31) = 1.238$, $p = 0.11$. The effect size *d* of 0.44 indicates a nearly moderate effect size. This effect size indicates that while no statistically significant difference exists, a moderate practical effect exists. Girls who do not use mental rotation ($M = 11.58$, $SD = 4.18$) differ in their scores (in the practical sense) from the girls who use mental rotation ($M = 9.29$, $SD = 4.99$). The results support the practical conclusion that girls who use mental rotation have higher scores on the Post-MRT Total Timed test (posttest) than girls who do not use mental rotation.

Hypothesis 4

The proportion of girls in the treatment group who report rotating images in their minds as a whole instead of section by section will increase after completing spatial training.

A paired *t*-test was conducted on the proportion rotating whole images to evaluate if there was a difference in the proportions before and after training. A summary of the results of the *t*-test is presented in Table 5.

Table 5

Results of Paired t-*Test Comparing Scores Before and After Training*

Variable	*df*	*t*	*d*	*p*
Proportion rotating	17	1.38	0.33	0.19

Hypothesis 4 tests the null hypothesis that the proportion of girls who use whole image mental rotation before training will be the same as the proportion of girls who use whole image mental rotation after training. The alternative hypothesis is that there is a difference in the proportion of girls who will use whole image mental rotation after training than before.

H_0: $p_{\text{before training}} = p_{\text{after training}}$
H_A: $p_{\text{before training}} \neq p_{\text{after training}}$

With alpha set at 0.05, the paired *t*-test on proportion of girls who use whole image mental rotation before and after training was not statistically significant, $t(17) = 1.38$, $p = 0.19$. The effect size *d* of 0.33 indicates a small effect size. The proportion of girls who use whole image mental rotation before training ($M = 0.72$, $SD = 0.46$)

appears to be similar to the proportion of who use whole image mental rotation after training (*M* = 0.56, *SD* = 0.51). The results support the conclusion that the proportion of girls who use whole image mental rotation before training is similar to the proportion of girls who use whole image mental rotation after training. From the proportions presented here, the indication is that fewer girls (0.56) rotated whole images after training than before (0.72). While not statistically significant, this result indicates a trend that is opposite of the expected outcome.

Hypothesis 5

Girls in the treatment group will attempt more problems during the 3-minute time on the MRT (posttest) than the girls in the control group after completing spatial training. *T*-tests for two independent samples were conducted on the number of problems completed in Section A and the number of problems completed in Section B to evaluate the difference between the treatment group girls and the control group girls. A summary of the results of the *t*-tests is presented in Table 6.

Table 6

Results of the t-Test Comparing Treatment Group Girls to Control Group Girls

Variable	*df*	*t*	*d*	*p*
# problems Section A	34	-0.30	-0.10	0.38
# problems Section B	34	0.78	0.27	0.22

Hypothesis 5 tests the null hypothesis that the girls in the treatment group attempted the same average number of problems on the MRT posttest as the girls in the control group after training. The alternative hypothesis is that the girls in the

treatment group attempted on average more problems in Part 1 and Part 2 of the MRT posttest than the girls in the control group after training. Hypothesis 5 did not measure accuracy of the answers. The researcher investigated the effect of training on the speed of answering questions on the MRT (posttest). Did the treatment group students leave fewer questions unanswered after training? Did a difference exist between the two groups? The MRT is divided into two sections, Part 1 and Part 2. The researcher examined the results using the number of questions left unanswered in Part 1 (posttest) and the number of questions left unanswered in Part 2 (posttest) for both the treatment and the control groups.

H_0: $\mu_{treatment} = \mu_{Control}$
H_A: $\mu_{treatment} > \mu_{Control}$

With alpha set at 0.05, the *t*-test for two independent samples on the average number of problems in Part 1 solved is not a statistically significant difference, $t(34) = -0.30$, $p = 0.38$. The effect size *d* of -0.10 indicates a small effect size. The negative number indicates that the result appears to be in the opposite direction of the expected result. The average number of problems solved by girls in the control group ($M = 2.53$, $SD = 1.62$) appeared to be similar to the average number of problems solved by girls in the treatment group ($M = 2.79$, $SD = 3.19$). The results support the conclusion that the average number of problems solved in Part 1 of the MRT (posttest) for girls in the treatment group is similar to the number of problems solved by the girls in control group.

With alpha set at 0.05, the *t*-test for two independent samples on the average number of problems in Part 2 solved for girls in the treatment group versus control group is not a statistically significant difference, $t(34) = 0.783$, $p = 0.22$. The effect size *d*

of 0.27 indicates a small effect size. The average number of problems solved by girls in the control group (*M* = 2.53, *SD* = 1.84) is similar to the average number of problems solved by girls in the treatment group (*M* = 2.05, *SD* = 1.81). The results support the conclusion that the average number of problems solved in Part 2 of the MRT (posttest) for girls in the treatment group is similar to the number of problems solved by the girls in control group. At the practical level, the difference in effect sizes between Part 1 (-0.10) and Part 2 (0.27) of the test does seem to indicate a practical difference, even though this researcher found no statistical significance in the results.

Hypothesis 6

Students in the high spatial-ability group as determined by MRT Timed (posttest) score will perform JSTOR search tasks in less time than students in the low spatial-ability group. These groups were created using the mean score on MRT (posttest) to split the girls into high and low spatial-ability groups.

Several *t*-tests for two independent samples were conducted on the number of students completing Question 1, number of students completing Question 2, and the number of students completing Question 3. A summary of the results of the *t*-tests is presented in Table 7.

Table 7

Results of the t-*Test Comparing High Spatial-Ability Girls to Low Spatial-Ability Girls*

Variable	*df*	*t*	*d*	*p*
Question 1	20	-0.81	-0.36	0.21
Question 2	9	-0.37	-0.25	0.36
Question 3	15	-0.36	-0.18	0.36

Hypothesis 6 tests the null hypothesis that the girls in the high spatial-ability group will take the same amount of time to complete a question as the girls in the low spatial-ability group. The alternative hypothesis is that the girls in the high spatial-ability group will take less time to complete a question as the girls in the low spatial-ability group.

H_0: $\mu_{low} = \mu_{high}$
H_A: $\mu_{low} > \mu_{high}$

With alpha set at 0.05, the *t*-test for two independent samples on the average time to complete Question 1 is not statistically significant different, $t(20) = -0.809$, $p = 0.214$. The effect size *d* of -0.36 indicates a small effect size in the opposite of the expected direction. The average time to solve Question 1 by girls in the low spatial-ability group ($M = 48.23$, $SD = 18.81$) is similar to the average time to solve Question 1 by girls in the high spatial-ability group ($M = 41.67$, $SD = 18.55$). The results support the conclusion that the average time to complete Question 1 for girls in the high spatial-ability group is similar to the average time to complete Question 1 for girls in the low spatial-ability group, but there is a practical difference in the time needed to complete the question. It would appear that at the practical level students in the low spatial-ability group needed less time than the girls in the high spatial-ability group to complete Question 1.

With alpha set at 0.05, the *t*-test for two independent samples on the average time to complete Question 2 did not differ in a statistically significant way, $t(9) = -0.368$, $p = 0.36$. The effect size *d* of -0.25 indicates a small effect size opposite the expected direction. The average time to solve Question 2 by girls in the low spatial-ability group

(M = 466.63, SD = 195.34) is similar to the average time to solve Question 2 by girls in the high spatial-ability group (M = 425.83, SD = 172.46). The results support the conclusion that the average time to complete Question 2 for girls in the high spatial-ability group is similar to the average time to complete Question 2 for girls in the low spatial-ability group.

With alpha set at 0.05, the t-test for two independent samples on the average time to complete Question 3 is not a statistically significant difference, $t(15) = -0.355$, $p = 0.36$. The effect size d of - 0.18 indicates a small effect size opposite the expected direction. The average time to solve Question 3 by girls in the low spatial-ability group (M = 351.38, SD = 158.97) is similar to the average time to solve Question 3 by girls in the high spatial-ability group (M = 327.78, SD = 113.53). The results support the conclusion that the average time to complete Question 3 for girls in the high spatial-ability group is similar to the average time to complete Question 3 for girls in the low spatial-ability group.

These t-tests used Post-MRT Total Timed (posttest) as the variable in which the mean of 11.0833 was used as the cutoff (its own mean). The Post-MRT Total Timed (posttest) was coded as above 11.0833 as high = 1 and below 11.0833 as low = 0.

T-Test for JSTOR Question 4

Question 4 was meant to be extremely difficult. None of the participants in the research project were able to answer the question in the time allotted. It was solvable, but the answer could not be solved in one step. It required several steps. Because no participant solved Question 4, it was impossible to attain t-test results.

Summary of Analysis of Results

In summary, this research failed to reject the null hypothesis for any of the six hypotheses created to answer the two research questions. Hypotheses 1, 2, 3, 4 and 5 addressed Research Question 1, which was:

> 1. To what extent can spatial ability, specifically mental rotation, in 10th-grade girls be increased by providing increased spatial experience in a biology classroom?

These research results suggest that spatial ability cannot be increased by providing increased spatial experience in a 10th-grade biology classroom according to an analysis of statistically significant differences. However, small and moderate effect sizes indicate that differences appeared at the practical level.

Hypothesis 6 was created to address Research Question 2, which was:

> 2. Does spatial ability as measured by the Mental Rotations Test impact search efficacy while using JSTOR for database search tasks?

The research results from an analysis of statistical differences of Hypothesis 6 suggest that spatial ability as measured by the Mental Rotations test does not impact search efficacy when using the JSTOR database. However, in examining effect sizes, practical differences exist and some of the practical differences appear in the opposite of the expected direction. Chapter 5 discusses the results more fully.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Given the amount of empirical research suggesting that increasing spatial experience improves spatial skills, the project results surprise this researcher. The results are inconsistent with prior research findings. Many factors could have impacted the findings of this research project. The statistical analysis in the previous chapter shows results of no statistical significance for all six hypotheses designed to answer the two research questions. However, some of the results showed small or moderate effect sizes.

As a review, the two research questions were:

1. To what extent can spatial ability, specifically mental rotation, in 10th-grade girls be increased by providing increased spatial experience in a biology classroom?
2. Does spatial ability as measured by the Mental Rotations Test (MRT) impact search efficacy while using JSTOR® database (JSTOR, Ann Arbor, MI, www.jstor.org) for database search tasks?

One of the possible influences could be a file drawer problem, where research results of no statistical significance remain unpublished. Additionally, other possible influences could include lack of student motivation, the length and duration of the spatial curriculum, the impact of significant prior spatial experience, the impact of a single-sex environment, the small sample size, or the methodology. These factors and their possible influence on the study results will be discussed below.

A file drawer problem (of researchers not publishing studies that do not show statistically significant results) comes to mind, although Voyer, Voyer, and Bryden (1995) stated that it would take 178,205 studies of no effect of sex differences in spatial ability to counter the studies that have found statistically significant sex differences. Mental rotation test results using the MRT consistently show the largest sex differences. It may be possible that a file drawer problem exists, but it is unlikely given Voyer, Voyer, and Bryden's calculations.

Student motivation could have been a factor In a personal conversation with Dr. Sheryl Sorby (June 14, 2008) at the Conference on Research and Training on Spatial Intelligence, Dr. Sorby indicated that she had similar nonstatistically significant results when the students were not required to complete the workbook and the CD exercises for a grade, credit, or some kind of incentive. The amount of student effort taking place outside of the scheduled class time was impossible to measure and ultimately, students participating in this research project understood that their participation was voluntary according to the rules of the Institutional Review Board (IRB).

Terlecki, Newcombe and Little (2007) studied spatial training of low and high spatial-ability individuals. Growth of mental rotation skills appeared to be a continuous upward trajectory for all participants, but for the female participants with low spatial experience, the improvement trajectory was less steep and their improvement was at a less rapid rate than women with high spatial experience or men. What was not clear from their study was the length and the amount of training needed to reach a ceiling effect. Possibly, this research study, with the small sample size and a population with a

less steep growth trajectory, was impacted by this ceiling effect. This study did not measure prior spatial experience and therefore it was not included as a factor.

In examining the issue of spatial experience, it must be noted that many opportunities exist for the students at the school to participate in classes and activities that could result in increased spatial experience. The school community and the school strategic plan support an active hands-on after school robotics program, a thriving sports program, and a school culture that emphasizes science, technology, engineering and mathematics (STEM) activities and classes. Almost all of the girls take mathematics and science courses each year including their senior year.

As noted in Table 1, the Scholastic Aptitude Test (SAT® academic success test [College Board, New York, NY, www.collegeboard.com]) scores of the students at the research sites are far above national, state, and independent school norms. The possibility exists that the mental rotation skills of the girls increased steadily all along through their school years and that their growth trajectory would be less than expected as a result. Quaiser-Pohl and Lehmann (2002) found that females with more spatial experience in technical areas and less experience in female sex-typed activities obtained higher MRT scores and the difference was statistically significant. This researcher did not compare the spatial ability of the girls participating in the research project to that of girls in another single-sex or co-educational setting. It may be that many of the girls participating in this research project would score in the high spatial (or low spatial) group when compared to a larger population sample.

Assumption Two of this research project was: “The girls attending the college preparatory private school had a normal range of intellectual abilities and brought

diverse experiences and backgrounds to the study." It may be that the girls had exceptional spatial experience before beginning the research project and that seemly small but varied spatial experiences moved them above the "normal" range of intellectual ability. The statistics for the 2006-2007 school year are as follows: out of approximately 240 girls in the high school, grades 9 through 12, 27 participated in robotics competition at the national level, 10 participated in biweekly tae kwon do classes and progressed through several belt levels during the school year. Sixty-three percent of the high school students (145 students) at the research site participated in high school athletics. These numbers are fairly typical for the research site.

It was outside the scope of this project to gather comparison data from other schools, but it would be worth pursuing baseline spatial experience information on co-educational and single-sex schools with similar demographics. The students at the research site could have exceptional experiences in comparison to a baseline norm. Spatial experience research is still in its infancy. Many studies show a correlation with spatial experience and spatial ability. More research is needed to fully understand the connection.

The research project took place in one single-sex school. These research results could be unique to this research site or may reflect the particular environmental influences of single-sex environment. The results were not compared to results at other all-girl schools or to coeducational schools with similar demographics. Stereotype threat, single-sex culture, and parental expectations as discussed in the introduction and the literature review could have impacted the results of this study.

The small size could have impacted the results. A larger sample could have resulted in a statistical analysis that would show greater change. However, research projects with large sample sizes for spatial intelligence research are difficult to find. Dr. Nora Newcombe, spatial intelligence researcher, noted in a discussion at the Conference on Research and Training on Spatial Intelligence (Newcombe, personal communication, June 14, 2008) that most spatial intelligence researchers are forced by circumstances to use small sample sizes because testing, training, and follow-up are difficult ,if not impossible, with large sample sizes.

Another methodology issue might have been the decision to use the workbook and the CD without additional classroom instruction. The spatial curriculum was designed to be a stand-alone curriculum when used on the undergraduate level; however, it might be necessary to include classroom instruction at the level of high school or at the lower levels.

An additional issue could have been the decision to used timed MRT tests. Peters (2005) found that extending the time limits improved female performance. Goldstein, Haldane, and Mitchell (1990) found that testing without time limits also improved female performance. Perhaps a more accurate measure of improvement in skill in mental improvement would use untimed tests.

This researcher used only one test to measure spatial ability, the MRT. It may be that spatial skill improvement could have been found had another test been used. Sorby uses the Purdue Spatial Visualization Test: Rotations (PSVT-R) to measure improvement in spatial visualization skill (Sorby, personal communication, May 16, 2007). Other spatial skill tests may have shown different results.

Hormone levels at the time of testing could have been an issue. Some researchers suggest that hormone levels impact spatial ability performance in females and that spatial ability fluctuates during the menstrual cycle and females generally score higher on spatial ability tests during menstruation and higher on verbal fluency midcycle. Spatial ability testing during different times during the menstrual cycle could impact results (Halpern, p. 174-175).

For this researcher, the lack of statistical significance raises more questions than provides answers. As a review, each hypothesis and the research used to support it will be examined.

Conclusions

While the analysis of each hypothesis showed no statistical significance, the supporting research will be listed with the research results from relevant projects.

Hypothesis 1

Mental rotation skill in 10th-grade girls attending a single-sex school will be enhanced by providing increased spatial experience through a spatial curriculum in a tenth grade biology classroom when compared to girls in the control group as demonstrated by higher scores on the MRT posttest.

Hypothesis 1 was derived from Sorby's research on a spatial visualization curriculum. In a particularly relevant study, Sorby, Drummer, Hungwe, and Charlesworth (2005) researched the impact of a spatial visualization curriculum on first and second year non-engineering students. Their instruction lasted for 10 weeks. The group of students using the workbook and the software showed a gain of 11.2 points on the PSVT-R, a spatial abilities test. The women participating in this study reported higher

gains than men in confidence levels. Sorby uses the PSVT-R for her research because the results on the PSVT-R predict success in engineering more reliably for the students tested. In addition, she has had less success in seeing an improvement in spatial skill when using the MRT as a test instrument (Sorby, personal communication, May 16, 2007). This study found no statistically significant effect in using a spatial visualization curriculum to improve scores on the MRT. In addition, no statistically significant effect size emerged when calculating effect sizes using Cohen's *d*. Using the PSVT-R to measure spatial skill improvement instead of the MRT could have produced different research results.

Hypothesis 2

Girls with higher spatial ability, as determined by the Mental Rotation Test administered as a pretest, will have higher PSAT math scores when compared to the girls with lower spatial ability in both the control and treatment groups in both the pretest.

Hypothesis 2 was derived from the research of Casey, Nutall, Pezaris, and Benbow (1995). When SAT mathematics test questions that required using mental rotation for the solution were removed, females and males scored equally well. If the test questions requiring mental rotation counted as part of the score for the test, males earned higher mathematics scores than females in three out of the four samples. The SAT was revised after 1995 and the mathematics portion may contain fewer or more problems requiring mental rotation. This researcher could find no information to support either change. Environmental influences have also changed since the research was

published in 1995. It may be that females have improved their ability to mentally rotate images to solve problems.

While this analysis was being prepared, Hyde, Lindberg, Linn, Ellis, and Williams (2008) published research findings of no gender differences in mathematics performance on state assessment test results from grade 2 through grade 11. However, Hyde et al. (2008) found that mathematics achievement for male and female students at the third (strategic thinking) or fourth (extended thinking) levels could not be analyzed. Questions at those levels were not included in state level assessments.

Researchers claim that “state assessments designed to meet NCLB [No Child Left Behind] requirements fail to test complex problem-solving of the kind needed for success in STEM careers, a lacuna that should be fixed”(p. 495). While Hyde et al. (2008) found no differences grades 2 through 11, they could not analyze questions requiring complex problem-solving skills which would be essential to STEM careers. Therefore it is difficult to generalize their findings to issues regarding STEM careers and spatial ability both of which are linked to advanced problem-solving.

This study found no statistically significant effects for a relationship between a student's PSAT mathematics score and the student's MRT score. This researcher also found no practical effect using Cohen’s *d* for Hypothesis 2.

Hypothesis 3

On the Mental Rotations pretest, girls who report on the personal test-taking strategy and confidence survey that they rotate whole images in their minds rather than section by section will score higher in the pretest and posttest.

Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) found that males using holistic mental rotation on the image of the target figure on the MRT scored higher than males using a section by section rotation. Peters et al. also found that females using a nonverbal strategy achieved higher scores on the MRT than females using a verbal strategy. This study found no statistically significant effect in examining strategy choice and its relationship to MRT scores. On both the MRT pretest and the MRT posttest, this researcher found small and moderate effect sizes for Hypothesis 3. The effect size was 0.56 for the pretest and slightly smaller for the posttest MRT (0.44). These effect sizes seem to suggest that girls who mentally rotate whole images score higher on both the MRT pretest and posttest.

Hypothesis 4

The number of girls in the treatment group who report rotating images in their minds as a whole instead of section by section will increase after completing spatial training.

Hypothesis 4 was largely based on the research of Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson (1995) as discussed above. It was an attempt to see if strategy choice would change as the result of spatial visualization curriculum. This study found no statistically significant change in strategy choice from pretest to posttest for the spatial visualization treatment group. A small effect size of 0.33 emerged using Cohen's *d*. However, when this researcher examined the proportions more closely, the proportion of girls who rotated images during the pretest was 0.72 and the proportion after training was 0.56. This appears to be a reduction in the number of girls using whole image mental rotation after training, which is the opposite of the expected result.

Hypothesis 5

Girls in the treatment group will attempt more problems during the 3-minute time on the MRT than the girls in the control group after completing spatial training.

Hypothesis 5 was based on the research of Peters (2005) and the work of Goldstein, Haldane, and Mitchell (1990). Peters (2005) found that males attempted to solve more MRT problems than females during a timed test. Peters used testing conditions involving both timed and extended timed tests. The timed test portion resulted in statistically significant sex differences favoring males. The extended timed tests resulted in a reduced sex differences gap; although a gap favoring males was still present.

Goldstein, Haldane, and Mitchell (1995) reported that males tended to solve MRT problems more quickly. Using a combination of timed and untimed testing conditions, the researchers found that female performance was not statistically different from male performance in the untimed conditions. Hypothesis 5 was meant to examine the relationship between a spatial visualization curriculum and the problem-solving speed. This research project found no statistical relationship between the completion of a spatial visualization curriculum and problem-solving speed on the MRT.

However, the effect size differences between Part 1 of - 0.10 and the effect size difference of 0.27 for Part 2 intrigued this researcher. The research analyzing the differences between the questions in Part 1 and the questions in Part 2 on the MRT remains sparse and split between the original version of the MRT with 20 questions and the redrawn version with 24 questions. Researchers primarily examine sex differences in test results on Part 1 and Part 2 of the MRT. None of the researchers analyzed MRT

score differences for within sex differences. Previous research suggests that the differences between test scores on Part 1 and Part 2 could be a reflection of any one of several factors, among them, the difference between questions for occluded and nonoccluded items, hormonal level differences, or angle of rotation of the test items (Quebeck, 1996; Voyer & Hou, 2006). Further research would be necessary to determine the factors that influenced the difference in number of problems attempted on Part 1 and Part 2 on this research project. The effect size for Part 1 was - 0.10, while the effect size for Part 2 was 0.27. This represents a difference in speed in problem-solving between the two parts.

Hypothesis 6

Students in the high spatial-ability group as determined by MRT score will perform JSTOR search tasks in less time than students in the low spatial-ability group.

Hypothesis 6 was based on the meta-analysis of Egan (1988), the research of Curl, Olfman, and Satzinger (1998) and the work of Thomas (1998). Egan found that users with low spatial ability resulted in more errors in executing computer-related tasks than high spatial-ability users. Egan was unable to determine which spatial abilities impacted user efficiency; however he was able to find a relationship. Egan looked a number of spatial ability studies in his meta-analysis. Few of the studies used the MRT.

Curl, Olfman, and Satzinger (1998) examined the impact of spatial visualization on the interaction of users on database interfaces. High spatial participants out-performed low spatial participants. They concluded that "spatial visualization ability, in particular, was shown to be an important predictor of the correctness of end-user

performance" (p.63). Curl, Olfman, and Sazinger did not use the MRT for their measure of spatial ability.

Thomas (1998) tested user performance in searching the JSTOR database. She found that high spatial-ability participants outperformed low spatial-ability participants in the JSTOR tasks. Thomas did not use the MRT as her measure of spatial ability.

This study found no statistically significant effect for user database searching speed and spatial ability as measured by the MRT However, if this research project had used Egan's recommendation of analyzing task completion times in an untimed condition, or used a different spatial ability measure, Hypothesis 6 might have produced different results for high spatial and low spatial participants. Effect sizes in the opposite of the expected direction surprised this researcher. This researcher calculated the effect sizes for the questions as follows: Q1 = - 0.36, Q2 = - 0.25, Q3 = - 0.18. All of the results were negative which indicates results opposite the expected direction (high spatial-ability participants would solve the tasks more quickly). Students could opt out of answering a JSTOR question if they wanted to move on to the next question. It might be that the test results would be very different if students needed to work to task completion. The sample size was small and the test was timed. Altering conditions may change the findings.

While this research project did not find results of statistical significance on any of the hypotheses, the fact remains that these results are largely inconsistent with previously published empirical research. However, this researcher found some results with small and moderate effect sizes. These inconsistencies lead to additional questions. If other spatial ability tests had been used for comparison, would the

research results still have been without statistical significance? Did the single-sex environment and the culture of an all girl school impact the test results? Were the research results specific to the unique environment of the research site chosen or would similar results have been found at another all girl school or a coeducational school with similar demographics? If compared to national norms (if such norms actually existed) would the girls participating in the research project have actually been divided in the same way into low spatial and high spatial ability groups or would they be assigned largely to the high spatial ability group when compared to a larger, more diverse population? Would using untimed MRT tests and untimed JSTOR tasks or working to task completion on JSTOR tasks have changed the research results? This researcher believes that these questions are worth further research. Recommendations for further research follow.

Recommendations

The results are intriguing enough to warrant further investigation. Some areas of research that might prove fruitful would be altering the methodology to use a larger sample size and more diverse samples for age ranges, sex, and settings. It would also be beneficial to apply different spatial ability tests and tests for indirect transfer to other types of learning. Spatial ability researcher Dr. Lynn Liben (Liben, personal communication, June 14, 2008) finds the water level test to consistently show sex differences also. Checking for a relationship using the MRT and the water level test could be an area worth pursuing.

Classroom instruction in spatial skills may change the statistical significance of the results. Most of the Sorby research was based on classroom instruction or the use

of the workbook and interactive CD-ROM. Developing a research project that includes spatial skills instruction may change the posttest MRT results at the high school level.

This study did not divide students by those who had previously taken geometry and those enrolled in a geometry course during the research project. Controlling for this variable was outside the scope of this research project. The small sample size made any further division of the groups impractical. The prior spatial experience of students was not analyzed as well to see if a relationship existed between spatial experience and MRT scores. Another area of research worth pursuing would be related to spatial experience and the growth trajectory for spatial visualization skills in a variety of single-sex and coeducational settings.

Using inventories for examining sex role and sex-typing activities, identifying spatial ability tests as tests of empathy instead of spatial ability, and examining participant and parental beliefs and expectations would be research worth pursuing to determine the effect, if any, of stereotypes and stereotype threat. Sex-typing of an activity occurs when participants or observers link an activity primarily to one gender or another, rather than to an activity in which both genders participate equally. Linn and Peterson (1985) suggested that one might infer that biological factors, sex-typed experiences, and sex role expectations may play a role in sex differences on spatial task performance. Determining to what extent each factor plays a role in spatial task performance could be a fruitful area

Handedness and spatial ability could also be a fruitful area for research. Casey (1996b) began researching the interaction between environment enhancement of spatial ability through spatial experience and innate ability by incorporating Annett's

Right-Shift Theory of brain organization (Annett, 1970, 2002) into her research. Annett's right shift theory provides a genetic component to Sherman's Bent Twig Hypothesis. A majority of people inherit a right-shift factor which causes them to be dominant in the left hemisphere (where the language centers are located), and also to be right-handed. More females than males show this dominance for language largely as a result of earlier development of the left hemisphere by females.

According to Annett (2002), the right-shift factor can negatively impact spatial ability in females because of the earlier development of the left hemisphere. Right-handed females with all right-handed relatives are most often homozygotic for the right shift-factor. They are likely to prefer verbal strategies for problem solving because of left-hemisphere dominance, and they frequently lack spatial ability. Right-handers with nonright-handed immediate relatives (mother, father, siblings) appear to be heterozygotic for the right-shift factor. A heterozygotic advantage for females seems to result in less dependence on verbal strategies for problem solving and the potential for enhanced spatial ability. Heterozygotic females could possess greater capacity for enhanced spatial ability if the right-shift theory is correct. Nonright-handed and ambidextrous individuals seem to exhibit no pattern of hemispheric dominance. For them, hemispheric dominance seems to be determined randomly.

Casey (1996b) conducted the study with male and female college student participants to test the Bent Twig Hypothesis. Subjects were grouped on the basis of their handedness subtype and college major. In examining the group of females who were majoring in math or science and had at least one nonright-handed relative, it was

found that their mental rotation ability was statistically significantly higher using the Vandenberg Test of Mental Rotation (Vandenberg & Kuse, 1978).

Casey (1996b) tested Sherman's Bent Twig Hypotheses on a sample of minority high school students attending a math/science program in a university setting. Casey found that right-handed females with at least one nonright-handed relative, who also had extensive spatial experience with activities that required mental visualizations in space of two and three dimensions, outscored the other groups of females, nonright-handed females and right-handed females with no immediate nonright-handed relatives (Casey, 1996b) on the MRT.

This researcher met Casey at a spatial skills conference while this research project was in process and asked Professor Casey why her handedness research publications seemed to end several years earlier. Casey found that the research results for handedness varied considerably and abandoned that research for a more fruitful topic (Casey, personal communication, May 16, 2007).Given that information, this researcher decided not to include handedness as one of the hypotheses. The handedness instrument used in the original data collection had not been validated and the conversation with Casey seemed to indicate that the handedness research was less important than the research in other areas. However, preliminary examination of the handedness data collected during the initial phases of the project seemed to indicate some statistical significance and will be analyzed in future publications.

More recent research on the effect of spatial activities and scores on the Vandenberg Mental Rotations Test was reported by several researchers: Ginn and Pickens (2005), Signorella, Jamison, and Krupa (1989) and Voyer, Nolan and Voyer

(2000) in which participation in spatial activities correlated with improved mental rotation scores for females. In the Ginn and Pickens (2005) study, female and male undergraduate students were tested using the MRT. One group of students participating in the study consisted of athletes at the undergraduate level who participated in at least one sport: men's and women's basketball, women's volleyball, football, and men's and women's soccer. Another group of the students were art majors and a third group of students majored in music performance. Ginn and Pickens (2005) found that the more spatial activities in which the female subjects had participated, the higher their MRT score. A statistically significant effect was found when comparing the groups of female subjects without spatial activity experience with the group of females with statistically significant spatial experience. What was not measured in this study was the amount of involvement in spatial activity or experience in factors of time or age of involvement.

Other types of spatial experience outside of school may have impacted the research results. The possibility exists that student cell phone use affected research results. Strayer and Johnson (2001) suggest that cell phone use while driving interferes with driving performance in both a hands-free or a handheld mode in a way that listening to the radio or a book on tape did not. In their study, they found that "conversing on either a handheld or hands-free cell phone led to significant decrements in simulated-driving performance" (p. 466).

Strayer, Drews, and Johnson (2003) expanded their study to investigate the cause of the impaired performance. They discovered that cell phone conversations affected visual attention. Their research suggests that "cell phone conversation, an auditory-verbal-vocal task" cannot be "successfully timeshared with driving, a visual-

spatial-manual task . . . there was a reduction in the processing of information, falling directly into the line of gaze when participants were conversing on a cell phone" (p.30). Research participants reacted to traffic signals and brake lights more slowly when conversing on a cell phone. One could suggest that the possibility exists that cell phone use influences spatial skill development since it appears that cell phone use impacts visual attention. Macgill (2007) reports that 63% of teens ages 12 to 17 use cell phones. If cell phone use impacts spatial ability and the numbers are accurate, over half of the research participants could have been affected both in the control and the research group.

This researcher did not analyze video game use by the participants. Research results by Feng, Spence, and Pratt (2007) suggest that first-person shooter action games reduce the mental rotation test performance gap for females. According to Feng et al., "functional neuroimaging has linked mental rotation tasks to selective attention and the spatial distribution of attention: the right posterior parietal cortex (PPC) is strongly activated during tasks involving attention . . . and mental rotation" (p.850). Their research data suggest that "selective attention and the ability to distribute attention spatially are critically important building blocks of spatial cognition . . . spatial attentional capacity and higher-level spatial function may be improved simultaneously by appropriate training" (p. 850). While this aspect was outside of the scope of this research project, it may be an avenue worth pursuing. Students playing first-person shooter games could have impacted the results. Future research projects should control for spatial experience.

Dance researchers find that spatial cognition for dance movements occurs in the precuneus, a parietal lobe region (Brown & Parsons, 2008). Future brain research will be able to identify which spatial skills reside in different areas of the brain. This kind of research will allow for targeted improvement of spatial skills instead of the current hit-or-miss approach.

In late 2006, after this research project began, the National Science Foundation funded a collaborative research project, The Spatial Intelligence Learning Center (SILC). All spatial intelligence researchers, regardless of academic research area, are welcome to join. SILC researchers created a Website that contains assessments, news releases, and information about research projects. Future spatial ability researchers will be able to use the information and instruments posted including spatial experience inventories and other assessments to insure standardization of research protocols.

Spatial ability researchers debate the use of the term “spatial ability.” Since many spatial researchers believe that “spatial ability” can be improved with spatial experience, they propose adopting the terms “spatial intelligence” or “spatial skill” to indicate that “spatial ability” is not fixed. For the sake of simplicity and because no definitive term emerged during this research study, this researcher decided to use the term “spatial ability” as the descriptor.

Would a different spatial visualization curriculum have yielded different results? A collaborative research project, Viz, taking place at Penn State Behrend campus, combines the resources of the engineering department with the resources of the psychology department. The result is a large scale research project devoted to

researching and improving spatial visualization skills. Using the Penn State curriculum might have produced different results.

While this project did not yield statistically significant research results, this researcher remains convinced of the importance of continuing spatial skills research and incorporating the enhancement of spatial skills in the curricula of K-12 schools and preschools. Hopefully, additional research projects will be able to identify the components of spatial ability and the strategies needed to target spatial skill improvement for students, male and female, who test low in spatial ability. Further research is necessary to understand more fully the interaction between the variables of environment, genetics, and spatial training. Additionally, this researcher believes that spatial ability influences information seeking in Marchionini's Personal Information Infrastructure and the Shannon-Weaver Model of communication.

In the age of information visualization, computer simulations and modeling, and visual databases, understanding the interactions of the variables that impact spatial ability could lead to improved design for user interfaces and more efficient information seeking behaviors. While this research project did not show statistically significant results, prior research suggests a connection worth investigating. In many studies on information seeking, spatial ability appears to be part of what Jud Copeland and others refer to as "counterframing" in information science. It is this researcher's hope that further research would include spatial ability as part of the frame and not the "counterframe" as information science researchers develop new research questions. While this researcher prepared final drafts of this chapter, *Knowledge Quest,* a journal of American Association of School Librarians, devoted its entire March/April 2008 to

maps, geospatial resources, and becoming spatially literate. Perhaps this signifies a new awareness of the importance of spatial skills and is a portent of things to come. In 1968, Borko defined information science as:

> that discipline that investigates the properties and behavior of information, the forces governing the flow of information, and the means of processing information for optimum accessibility and usability. It is concerned with that body of knowledge relating to the origination, collection, organization, storage, retrieval, interpretation, transmission, transformation, and utilization of information.
>
> It has both a pure science component, which inquires into the subject without regard to its application, and an applied science component, which develops services and products. (Borko, 1968, p.3, as quoted in Bates, 1999)

With the recent developments in information visualization, GIS, 3-D modeling and simulations, and graphics, one could suggest that the research on the impact of spatial ability on information seeking is critical for information science. Fragmented areas of research need to have well-coordinated and -communicated research agendas, and information science researchers need to collaborate with spatial skills researchers in other disciplines as a step toward viable research agendas that fit the Borko's definition.

APPENDIX A

PERSONAL STRATEGIES AND PERFORMANCE QUESTIONNAIRE

Name:
Section:

Personal Strategies and Performance Questionnaire

For each of the eight sections below, please check the best statement that describes the thought processes and strategies you used while performing test.

1. Use of Mental Rotation
   ___I rotated the whole figure in my mind when making the comparison.
   ___I rotated a section of the figure in my mind when making the comparison.
   ___I am not sure how I did it.
   ___Other (explain)_____

2. Verbal or Visual Thinking
   ___I thought through the steps verbally in my mind (i.e. "two cubes up and three down")
   ___I relied mainly on visualizing the figures and did not talk myself through the steps.

3. Use of Body Movements
   ___I used movements of my finger, hand, and/or pencil to help me with the task.
   ___I did not use movements of my finger, hand, and/or pencil to help me with the task.

4. Procedure
   ___I scanned the options for the most likely match and then made my choices.
   ___I went through the options systematically, trying the first, then the second one.
   ___I went through the options in a haphazard nonsystematic way.

5. Comparing the Target Figure
   ___I always compared all of the options to the target figure before making a match.
   ___Once I found the match, I didn't compare the rest of the options to the match.
   ___I used both methods at different times to make a match.

6. Personal approach
   ___I developed a specific approach to solve all of the problems.
   ___I tried various approaches to solve the problems.
   ___I had no specific approach

7. Personal concern
   ___I was more concerned with getting all of the answers completed.
   ___I was more concerned with getting the correct answers.
   ___I was equally concerned with getting the correct answers and completing the test.
   ___I did not care how I did.

8. Determining my confidence level and checking my work

___I was confident of my answers and did check them before I moved onto the next problem.

___I was confident of my answers and did not check them before I moved onto the next problem.

___I was vaguely confident of my answers and did check them before I moved to the next problem.

___I was vaguely confident of my answers and did not check them before I moved to the next problem.

___I was not confident of my answers and did check them before I moved onto the next problem.

___I was not confident of my answers and did not check them before I moved on the next problem.

___I guessed most of the time.

OVERALL EVALUATION

How would you rate the Mental Rotations Test on a scale from 1-6, from 1=easy to 6=impossible.

Please circle one:
1=very easy
2= moderately easy
3 = neither easy or impossible
4 = difficult
5 = very difficult
6 = impossible

APPENDIX B

JSTOR TASKS

JSTOR Tasks

PARTICIPANT NUMBER_____

You should be at the main JSTOR title page which you were shown before beginning this task. You should be at the following web site:

http://www.jstor.org/logon/

TASK 1

BEGINNING TIME: 00:00:00 COMPLETION TIME: _____

View the complete extended list of journals available. Provide the name of the fourth mathematics journal listed.

ANSWER:
_____

Did not complete _____ I got frustrated and gave up _____ at _____(time).

This task was (please rate): Easy 1 Medium 2 Difficult 3 Very Difficult 4

TASK 2

BEGINNING TIME: _____ COMPLETION TIME: _____

Browse the table of contents of Volume 57 (v.57), Issue 3, of The Journal of Modern History. Provide the authors' names for two of the first six articles listed.

_____
_____

OR

Proved the first word in the fourth entry of the table:
_____

Did not complete _____ I got frustrated and gave up _____ at _____(time).

This task was (please rate): Easy 1 Medium 2 Difficult 3 Very Difficult 4

TASK 3

BEGINNING TIME: _____ COMPLETION TIME: _____

Search in all political science journals, all education journals, and all population studies journals between June 30, 1991 and December 31, 1993 for an article with "democracy" in the title by author Olson. Include in your search all articles, reviews, opinion pieces, and other items. Please provide the following:

Full name of journal:
_____

Vol. #: _____ Issue No. _____

Full name of article:
_____

Did not complete _____ I got frustrated and gave up _____ at _____(time).

This task was (please rate): Easy 1 Medium 2 Difficult 3 Very Difficult 4

_____

TASK 4

BEGINNING TIME: _____ COMPLETION TIME: _____

Do an extensive search for either "Bill Gates" or "Microsoft" in all economics journals, all education journals, The Journal of Money, Credit, and Banking, and the World Politics journal. Search only for articles and opinion pieces published between January 1, 1986 and December 31, 1995.

Go to the first article listed, titled (fill-in):
_____

"First, _____ _____ have an _____ to _____

in _____ only if they _____ and _____ _____

Did not complete _____ I got frustrated and gave up _____ at _____(time).

This task was (please rate): Easy 1 Medium 2 Difficult 3 Very Difficult 4

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