THE EFFECT OF GENDER ON SPATIAL ABILITY AND SPATIAL REASONING AMONG STUDENTS IN GRADES 2-8

by

Sharon Whitley Morris

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Education

Liberty University

2018

THE EFFECT OF GENDER ON SPATIAL ABILITY AND SPATIAL REASONING AMONG STUDENTS IN GRADES 2-8

by Sharon Whitley Morris

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

Doctor of Education

Liberty University, Lynchburg, VA

2018

APPROVED BY:

D. J. Mattson, Ed.D., Committee Chair

Crystal P. Ange, Ed.D., Committee Member

JoAnna P. Oster, Ed.D., Committee Member

ABSTRACT

The purpose of this study was to examine gender differences across three types of spatial ability; namely, spatial perception, spatial visualization, and mental rotation in conjunction with working memory. The study utilized a causal-comparative research design involving group comparisons. In this design researchers collect data about variables that they have conceptualized to be in a causal relationship to each other, but there is no intervention as in experimental research. Participants in this study included approximately 200 students in second through eighth grades at one public school and one public charter school, all located in the same school district/county. Spatial ability was measured by four categories of spatial relations tests based upon spatial cognition research proposing that spatial cognition is comprised of "three separable dimensions:" the Mental Folding Test for Children (spatial visualization), an adaptation of the Differential Aptitude Test: Space Relations (DAT: SR), Mental Rotation for Children, an adaptation of the Mental Rotations Test (MRT), Manikin Test (spatial orientation and transformation), and Mr. Peanut Task (visuo-spatial working memory). The resultant scores were used as measures of mathematical achievement and cognitive ability. Data were analyzed using MANOVA and ANOVA statistical analysis. Results suggested that mostly non-significant differences exist for spatial visualization abilities between males and females. The sole example of a significant difference between male and females was noted on the Mr. Peanut test in the fourth and fifth grades, accompanied with a partial Eta Squared (η^2) of .10.

Keywords: Spatial ability, spatial visualization ability, spatial orientation ability, gender differences, elementary students, middle school students

Dedication

To: Almighty God and His Son, Jesus Christ: ***Sola Gratia*****,** by grace alone. You created me to love learning and thirst for knowledge. It is by your power and infinite source of strength which provided stamina that fueled my efforts to complete this dissertation journey. No struggle has come my way apart from Your purpose, Your presence, and Your permission.

To the past: My grandmother, Madeline W. Keech, whose "voice" was not always heard, but one who gave of herself in a multitude of ways. More importantly, she transmitted the example of courage, fortitude, and perseverance for this young girl's heart to glean and absorb by witnessing myriad acts of unselfishness which, in turn, provided these necessary traits to draw upon at anxious times.

To the present: My children, Justin Chacy & Courtney Brett for providing such distinct meaning and direction for my life

To the future: My granddaughters, Madeline Brett & Gemma Lucy, with the hope that as young girls and women their "voice" will be heard.

Acknowledgments

I would like to acknowledge my husband, Dennis, for his understanding and patience throughout this dissertation journey; for my children, Justin and Courtney, and their spouses, Maria and Jackson, in supporting my efforts, especially during the last several years; and my parents, Luke and Betty Whitley, for instilling Christian values and morals that created a firm foundation for my life.

I would like to extend thanks to my committee chair, Dr. D. J. Mattson, for his continual support, wise counsel, and valuable critiques and suggestions for improvement during this dissertation process. I have appreciated his reflection and thought-provoking comments in seeking to understand the nuts-and-bolts of the research. I would like to thank my committee members, Dr. Crystal P. Ange and Dr. Joanna P. Oster for their willingness to serve on the committee, and their support shown to me along this pathway. Special thanks to Dr. Scott Watson, Research Consultant, for his timely feedback and recommendations to facilitate this research study. Finally, many thanks to Dr. Dawn Blasko, professor at Penn State Erie, and one of the developers of *Visualization Assessment and Training*.

I would like to express my appreciation to Mrs. Pamela Hodges for her support in providing professional opportunities to advance my continued quest for learning.

A personal acknowledgement goes to friends, Daphne R., Pam C., Nelson G. and Dr. Jim Buck for their continued assistance and interest in providing encouragement, reassurance, and inspiration. A debt of gratitude for my pastor, Rev. David Pierce, for his timely, thought-provoking sermons and discussions for practical application in my life.

I would like to acknowledge and thank the specific school districts where the data was collected, and for allowing me to conduct my research and your readiness to provide support when applicable. Special thanks go to the superintendent, curriculum director, and technology personnel for their willingness and cooperation in conducting the research. I would like to thank the principals, teachers, media technology personnel at each specific research site that supported me in this journey. Their willingness to participate, and motivation to provide feedback made the completion of this research an enjoyable experience. Finally, without the students who tested, there would be no study. Hopefully, your efforts will impact future students in positive and productive ways.

Table of Contents

List of Tables

List of Figures

*All graphics of assessments used by permission-Millisecond/Inquisit

List of Abbreviations

Analysis of Variance (ANOVA)

Augmented Reality (AR)

Cerebrospinal Fluid (CSF)

Committee on Science, Technology, Engineering, Mathematics (CoSTEM)

Common Core State Standards (CCSS)

Conceptualization of Visual Models (CVM)

Differential Aptitude Test: Space Relations (DAT: SR)

Dorso-Lateral, Pre-Frontal Cortex (DLPFC)

Early Childhood Longitudinal Study, Kindergarten Class of 1998-1999 (ECLS-K)

Economics and Statistics Administration (ESA)

Evaluation of Educational Achievement (EEA)

Externalization of Visual Models (EVM)

Functional Magnetic Resonance Imaging Scan (fMRI)

Geography, Earth, and Environmental Sciences (GEES)

Geometry Content Knowledge (GCK)

Institutional Review Board (IRB)

Intelligence Quotient (IQ)

Internalization of Visual Models (IVM)

Kaufman Test of Education Achievement-Third Edition (KTEA-3)

Magnetic Resonance Imaging (MRI)

Multivariate Analysis of Variance (MANOVA)

Mental Rotation (MR)

Mental Rotations Test (MRT-A)

Mental Rotations Test (MRT)

National Council of Teachers of Mathematics (NCTM)

No Child Left Behind (NCLB)

North Carolina Standard Course of Study (NCSCOS)

Opinions Relative to Integration (ORI)

Pluralism and Diversity Attitude Assessment (PADAA)

Positron Emission Tomography (PET)

Purdue Spatial Visualization Test: Rotations (PSVT:R)

Science, Technology, Engineering, and Mathematics (STEM)

Spatial Numerical Association of Response Codes (SNARC)

Spatial Orientation (SO)

Spatial Orientation Test (SPOT)

Spatial Perception (SP)

Spatial Relations (SR)

Spatial Visualization (SV)

Spatial Visualization Test (SVT)

Socioeconomic Status (SES)

Statistical Package for the Social Sciences (SPSS)

Trends in International Mathematics and Science Study (TIMSS)

Virtual Reality (VR)

White Matter (WM)

CHAPTER ONE: INTRODUCTION

Overview

Chapter One provides a brief description of the background, problem, purpose, and significance of this quantitative study which explored the effect of gender on spatial ability and spatial reasoning among students in grades two through eight. Additionally, the chapter provides the research questions, null hypotheses, and identification of the variables for the study. Finally, a list of relevant terms and definitions is included.

Background

Recent developments in reorganizing curricular objectives across the United States relate to the new Common Core State Standards (CCSS). Teachers, researchers, and leading experts collaborated in various states to design and develop the standards. Options were given to each state to independently choose to adopt the CCSS beginning in 2010. According to the National Governors Association (2010), the federal government has not been involved in the development and creation of the standards; teachers, principals, and superintendents led the execution of the CCSS. The Common Core State Standards provide a:

> Consistent, clear understanding of what students are expected to learn, so teachers and parents know what they need to do to help them . . . designed to be robust and relevant to the real world. Reflecting the knowledge and skills that our young people need for success in college and careers is imperative in order to compete successfully in the global economy. (National Governors Association, 2010).

To date, 45 states, four territories, the District of Columbia, and the Department of Defense Education Activity have adopted the CCSS. Students were assessed using the new CCSS in the school year 2014-2015. Previously, North Carolina's curricular guide for all state educators was the North Carolina Standard Course of Study (NCSCOS). With the implementation of new, more rigorous standards and assessments, the demands are such that teacher evaluations are increasing accountability.

While the focus on spatial skills as a segment of geometric instruction is not new, the need for continued improvements in students' spatial visualization abilities is imperative for America's global competitiveness. Many researchers consider the cognitive skills of visualizing in three dimensions, and other spatial skills are interconnected and linked to success in the academic disciplines of science, technology, engineering, and mathematics (STEM) fields (Metz, Donohue, & Moore, 2012; Sorby, 2009; Sutton & Williams, 2008; Towle et al., 2005; Webb, Lubinski, & Benbow, 2007). The STEM initiative is an education coalition whose central mission is to "inform federal and state policymakers on the critical role that science, technology, engineering, and mathematics education plays in U. S. competitiveness and future economic prosperity" (National Center for Education Statistics, 2014, p. 3). According to an Executive Summary published by the Department of Commerce, Economics and Statistics Administration (2011), the STEM workforce is "critical to America's innovative capacity and global competitiveness," (p. 1) yet women and minorities are underrepresented in these leading-edge jobs of which there may be many extenuating factors. The Administration of President Barack Obama proposed that reform in this area is "stymied by the federal government's fragmented approach to STEM education" (Department of Commerce, 2011, p. 1) and recommended a comprehensive restructuring of the STEM programs in order to facilitate a more unified national approach. Therefore, the Committee on Science, Technology, Engineering, Mathematics (CoSTEM) was created to "coordinate the Federal programs and activities in support of *STEM* education pursuant to the requirements of the act" (United States General Accounting Office.

(2011, p. 15). The importance of providing access for all students, but especially females and individuals from lower socioeconomic groups, is necessary to train citizens for the 21st Century. If a person's perception of his or her spatial skills is meager or poor, these observations may influence the nature of activities or vocation that the individual may choose.

North Carolina teachers are required to implement the Common Core mathematics standards in their classrooms. These national standards have been under extreme scrutiny since their inception. However, North Carolina schools have been aligning their standards with the National Council of Teachers of Mathematics (NCTM) recommendations for many years. Whatever standards are in place, spatial ability and reasoning have been areas of low performance in state classrooms.

According to the curriculum standards of the National Council of Teachers of Mathematics, (National Council of Teachers of Mathematics [NCTM], 1989, p. 49). Spatial literacy is embedded in nearly every discipline in the school curriculum.

Linn and Petersen (1985) defined spatial ability as a general skill in "representing, transforming, generating and recalling symbolic, nonlinguistic information" (p. 1484). King, professor at the University of Bath, England, Department of Geography, Earth, and Environmental Sciences (GEES), viewed spatial literacy from an Earth science point of view, considering it a fundamental concept in GEES, "and one that is often troublesome to students in these disciplines" (King, 2006, p. 25). The difficulties experienced by students in the GEES department included (a) locating, visualizing, mentally moving or translating between 2D, 3D and 4D in relation to maps and (b) a sense of location on a map with respect to the real world (e.g. finding their location on a map when out in the field (p. 26). Bednarz (2005) suggested that spatial literacy is a critical skill, asserting that:

> Spatial thinking is the lever to enable students to achieve a deeper, more insightful understanding of subjects across the curriculum. It is a pervasive way of thinking that crosses disciplinary boundaries. It is not an ADD-ON but a missing link. (Slide 5).

Research from several studies indicates a correlation between spatial ability and problem-solving performance (Bayrak, 2008; Boakes, 2009; Rafi, Samsudin, & Said, 2008). A publication by NCTM, *Principles and Standards for School Mathematics* (2000), continued to address student performance outlined in its K-12 curricular content with geometry as one of the five essential strands. Nestled within the geometry strand are spatial skills, an important standard that should support "students' visualization, spatial reasoning, and geometric modeling to solve problems" (p. 43). Wetzel (2009) stated that mathematics is a complex process requiring visual and cognitive perception abilities, comprehension ability, and adequate prior knowledge.

Another aspect of the spatial visualization issue is gender differences (Linn & Peterson, 1985; Sorby, 2009). In a study by Robinson and Lubienski (2011), the achievement trends of math and reading for males and females from kindergarten to eighth grades were tracked in a longitudinal, causal-comparative design study. The study also examined if there were gender gaps and if so, where on the continuum were the gaps dispersed and the observation of teacher effects on those gaps. The sample included a high of 20,578 kindergarten students to a low of 9,725 in the spring of their eighth grade year. Achievement scores and gaps were explored using the Early Childhood Longitudinal Study, Kindergarten Class of 1998-1999 (ECLS-K). This data set was collected by the U. S. Department of Education. The researchers examined the achievement scores of the students at the 10^{th}, 50^{th}, and 90^{th} percentiles of males and females at each data collection point. Exploring the scores over time by gender provided an additional context for the subsequent gap analyses in order to identify when one group is "gaining new skills while another group is stagnating" (Robinson & Lubienski, 2011, p. 279).

Researchers found no indication that extraneous variables such as socio-economic level, race, or grade level contributed to the differences in growth of males and females. The study confirmed that while there were no math achievement gender gaps in kindergarten, by first grade a math gender gap favoring males appears in the standardized and scale scores, continuing to third through fifth grades. Overall, males scored significantly ahead of females on the direct math assessment by the end of middle school. Interestingly, teacher ratings throughout the study favored higher ratings for the females' math achievement than that of the males (Robinson & Lubienski, 2011, p. 294). This study is significant in that it suggests that females lose ground in math during their elementary years as opposed to the middle school years. They concluded that "future math-focused interventions with females may be better targeted toward elementary grades than previously thought" (p. 296). In addition, they emphasized that "disparities within genders are much larger than disparities between genders" (p. 298).

Hoffler (2010) provided a meta-analysis review of 27 different research situations from 19 studies accompanied by a discerning theoretical review regarding spatial ability in an overall sense. The review encompassed the existing state of research that relates to the connections between visualization learning and spatial awareness. The studies chosen for the meta-analysis spanned 15 years (1994 to 2009), and most of the research focused on secondary or college students. Arising from the assessment of literature were several ways to assist learners who demonstrate low spatial ability, whether with specific aspects of visualization or with certain features of a learning assignment. This review proceeded from the perspective that spatial visualization is defined as "any kind of non-verbal illustration" (p. 246) with the central focus on pictorial visualizations.

Recently, an executive report was published by the U. S. Department of Commerce (2011) detailing an extensive summary of the situation concerning women in STEM careers. The Economics and Statistics Administration (ESA) describes science, technology, engineering, and mathematics jobs (STEM) as "professional and support occupations in the fields of computer science and mathematics, engineering, and life and physical sciences" (p. 2). An alarming trend has occurred throughout the past decade that while college-educated women have increased their part in the workforce and fill close to half of all jobs in the American economy, they hold "less than 25 percent of STEM positions ". . . they hold a "disproportionately low share of STEM undergraduate degrees, particularly in engineering" (Department of Commerce, 2011, p. 1). The summary confirmed that "only one in seven engineers is female" (p. 3). The 11 page report found that while there are moderately few women attaining STEM degrees, they are concentrated in the physical and life sciences, which contrasted with men who are primarily in the engineering realm. The report aimed to provide data and awareness and evidence for encouraging women in STEM that will "enable more informed policymaking" (p. 8).

There is a connect between gender discrepencies in STEM fields and elementary students. The majority of the STEM careers focused in the technology and engineering fields find their foundation creating and manipulating 2-D and 3-D shapes, or pre-engineering concepts, in beginning geometric learning environments and experiences at the elementary level (Towle et al., 2005; Voyer, Voyer, & Bryden, 1995). Therefore, perhaps the focus should be remediating the lack of emphasis and attention on spatial ability and performance in order to enhance proficiency for young learners.

Problem Statement

The research conducted on spatial visualization abilities appears to show gender differences in performance functions (Sorby, 2009; Sorby & Veurink, 2012). The ability to mentally rotate 3-D objects is especially important in engineering, and this skill has the greatest gender disparity in spatial-skills performance, favoring males. For the past 20 years, in an effort to improve spatial skills among engineering students at Michigan Technological University, Sorby and Veurink (2012) have been involved in the development and implementation of a course and curriculum that would address this problem. Students enroll in university courses that never had the opportunity to "develop their spatial skills" (Sorby & Veurink, 2012, p. 1) and are at a "disadvantage in spatially demanding fields such as engineering" (Sorby & Veurink, 2012, p. 1). All incoming students who enter the engineering program take the Purdue Spatial Visualization Test: Rotations, a test assessing mental rotation ability. Those who scored 60% or less were targeted for spatial skills training. While not all outcomes were statistically significant, "trends towards improved grades through spatial skills training were evident" (Sorby & Veurink, 2012, p. 2).

In an effort to shed light on the importance of developing spatial visualization skills at the elementary level and confront the problem of gender disparities, the need to address the gap in the current literature with regards to gender discrepancies at the elementary level as well as identify the precise level that the gender differences occur arises.

Purpose Statement

The purpose of this causal-comparative group design study was to examine gender differences across three types of spatial ability; namely, spatial perception, spatial visualization, and mental rotation involving group comparisons among three particular grade spans. The grade spans included grades two to three, four to five, and six to eight. In this design, researchers collect data about variables that they have conceptualized to be in a causal relationship to each other, but there is no intervention as in experimental research (Gall, Gall, & Borg, 2007). A second purpose of the study was to determine at what level, if any, that the spatial visualization discrepancy occurs between girls and boys.

Significance of the Study

A significant outcome of the study would suggest that leaders and instructors will better understand how to assist females in raising their cognitive skills and/or confidence levels for future advancement in career fields, particularly the STEM areas. For whatever reason, curriculum objectives and/or instructional facilitators may not offer inclusive opportunities for girls, thereby creating a continued lack of growth in achievement data. Knowing the specific grade level of the gap existing between male and females' spatial visualization scores will provide a focus for educators to target instruction with intensive support. Removing barriers that hinder females from future success will be a vital step in realizing a societal goal of gender parity.

Research Questions

The following research questions guided the researcher in the investigation.

RQ1: Is there a difference in the mean scores of spatial visualization tests between male and female students in second to third grades in the area of geometric spatial visualization?

RQ2: Is there a difference in the mean scores of spatial visualization tests between male and female students in fourth to fifth grades in the area of geometric spatial visualization?

RQ3: Is there a difference in the mean scores of spatial visualization tests between male and female students in sixth to eighth grades in the area of geometric spatial visualization?

RQ4: How do gender and age of students in the second through eighth grades impact geometric spatial visualization?

The alpha value of .05 will be modified to .025 as the cutoff for significance in all null hypothesis testing.

Identification of Variables

The independent variable in this study was the two biological sex categories of the students, male and female. The participants in this study included 203 students in second through eighth grades at one public school and one public charter school, all located in the same school district. All students were from a rural, homogeneous group who use English as their first language. The schools were located in a rural county with a population of 23,699 individuals, showing a median household income of $35,585 and including the number of persons below the poverty level at 24.9% (U.S. Census Bureau, 2013). One of the schools was designated as a Title I school, while the second school was not categorized with Title I distinction.

The status of Title I indicates whether a school qualifies as part of the federal program that provides funding for learning institutions with a high poverty rate in order to assist students. The federal program No Child Left Behind (NCLB) was enacted by the United States Congress on January 3, 2001 and signed into law in 2002 by President George W. Bush to which its purpose was to "close the achievement gap with accountability, flexibility, and choice, so that no child is left behind" (President's Commission on Excellence in Special Education [PCESE], 2002, p. 1). Title I is an arm of the NCLB law. This status is determined by the number of students who qualify for free and reduced lunches. The school's poverty level must be at least

40% in order to be designated as School-wide distinction whereby the entire school can participate in a specified program to create a method of delivering Title I services in schools that are eligible. This process allows schools to "address the educational needs of children living in impoverished communities with comprehensive strategies for improving the entire school so every student achieves high levels of academic proficiency" (PCESE, 2002, p. 2).

As of July 2013, *The Student Success Act* (H.R. 3989), a reauthorization of the Elementary and Secondary Education Act, was passed by the United States House of Representatives. According to the Education & Workforce website, the *Student Success Act* will "restore local control, support effective teachers, reduce the federal footprint, and empower parents" (USDOE, 2014). The *Student Success Act* dramatically lessens the federal role in education by returning authority to states and local officials in the task of measuring student performance and turning around low-performing schools (USDOE, 2014).

The dependent variable was the resulting scores, or level of achievement, of the four spatial visualization tests from each participant. Spatial ability was measured by four categories of spatial relations tests based upon spatial cognition research proposing that spatial cognition is comprised of "three separable dimensions" (Voyer, Voyer, & Bryden, 1995): the Mental Folding Test for Children (spatial visualization), an adaptation of the Differential Aptitude Test: Space Relations (DAT: SR) (Bennett, et al, 1973), Mental Rotation for Children, an adaptation of the The Mental Rotations Test (MRT) (Vandenberg & Kuse, 1978), Manikin Test (spatial orientation and transformation) (Englund, et al, 1987), and Mr. Peanut Task (visuo-spatial working memory) (Morra, 1994; De Ribaupierre & Bailleux, 1995). The scores from the geometric spatial visualization tests were compared for gender differences with a focus on observable age or grade level(s) differences that become apparent.

Definitions

1. *Common Core State Standards (CCSS)*- Common Core state standards are an educational, state-led initiative implemented by 45 of the 50 states of America in 2010. The Common Core refers to English/Language Arts and mathematics, and Essential Standards refer to science and social studies. The standards were released by the National Governors Association Center for Best Practices and the Council of Chief State School Officers (National Governors Association for Best Practices, 2010).
2. *Differential Aptitude Test-Space Relations (DAT:SR)* - This test consists of 50 items and evaluates the spatial ability of visualization where the participant must choose the correct three-dimensional object from four alternatives that would result from folding the given two-dimensional pattern (Bennett, Seashore, & Wesman, 1973).
3. *Gender* - Gender is the term that may be used to refer to "assumptions about sex differences-those characteristics and traits socioculturally considered appropriate to males and females" (Unger, 1979, p. 1085). Many authors indicate that the term *sex* implies biological origins and anatomical categories (Denmark, Rabinowitz, & Sechzer, 2005; Etaugh & Bridges, 2010; Goldberg, 2010; Lips, 2008; Wood, 1999) while *gender* refers to "the state of being male or female" (Hyde, 2014, p. 5) or the social categories of male and female (Helgeson, 2005). The APA publication manual offers guidelines for the distinction between the terms *sex* and *gender* that are appropriate to mention at this time stating that "sex is biological" and should be used when the "biological distinction is predominant" (American Psychological Association [APA], 2010, p. 71). *Gender* is "cultural and is the term to use when referring to women and men as social groups" (APA, 2010, p. 71). Muehlenhard & Peterson (2011) distinguished between the

ambiguous terms of *sex* and *gender* in their paper, highlighting the historical distinctions of inconsistency of their usages.

4. *Mental Rotation* - Mental rotation is the rotation of an object or an array of objects which involves imagining or visualizing movement relative to an object-based frame of reference, specifying the location of one object (or its parts) with respect to other objects (Kozhevnikov & Hegarty, 2001).
5. *Mental Rotations Test (MRT-A)* - A test which assesses a person's skill in visualizing rotated solids (Vandenberg & Kuse, 1978).
6. *No Child Left Behind (NCLB)* - NCLB is a federal law enacted by Congress in 2001 under the presidency of George W. Bush.
7. *North Carolina Standard Course of Study (NCSCOS)* - NCSCOS is the content standards for each grade level and high school course which provides a uniform set of learning standards for every N. C. public school (North Carolina Department of Public Instruction [NCDPI], 2003).
8. *Purdue Spatial Visualization Test-Rotations (PSVT-R)* - A test where participants are shown a criterion object and a view of the same object after undergoing a rotation in space. Next, they are shown a second object, and must indicate what their view of that object would be if the second object were rotated by the same amount in space (Guay, 1976).
9. *Spatial Ability* - Spatial ability is the ability comprised of three components: spatial visualization, spatial perception, and mental rotation (Scali, Brownlow, & Hicks, 2000).

10. *Spatial Orientation* - Spatial orientation is the ability to “perceive spatial patterns or to maintain orientation with respect to objects in space” (Ekstrom, French, Harman, & Derman, 1979, p.149).
11. *Spatial Orientation Test (SPOT)* - The SPOT test examines the participant’s orientation skills in two dimensional and three dimensional spaces and measures one’s ability to imagine different perspectives or orientations in space (Hegarty, Kozhevnikov, & Waller, 2004).
12. *Spatial Perception* - Spatial perception is the performance which necessitates “making judgments of horizontal and vertical orientation in space despite distracting background information” (Voyer et al., 1995, p. 252).
13. *Spatial Visualization* - Spatial visualization is the ability to manipulate or transform the image of spatial patterns into other arrangements (Ekstrom et al., 1979).
14. *STEM* - STEM is an acronym that represents the initiative science, technology, engineering, and mathematics.
15. *Title I School* - Title I status indicates whether a school is part of the federal program that provides funding for schools with high poverty rates to help students who are behind academically or at risk of falling behind.

CHAPTER TWO: LITERATURE REVIEW

Overview

The foundation for children's mathematical development is established in the early years according to the Principles and Standards for School Mathematics (Seefeldt & Waski, 2006, p. 249). It is important for children to have a variety of materials to manipulate and the opportunity to sort, classify, weigh, stack, and explore if they are to construct mathematical knowledge. In order to have opportunities to learn math, children need firsthand experiences related to math, interaction with other children and adults concerning these experiences and "time to reflect on the experiences" (Seefeldt & Waski, 2006, p. 250).

Many educators may think of geometry as a study of axioms, postulates, proofs of theorems, constructions, and so on. This could be motion geometry, solid geometry, plane geometry, Euclidean geometry, or another type. The important issue is not the name, but rather the type of experiences children are intended to have as part of the elementary school geometry curriculum. Wetzel (2009) stated that mathematics is a complex process requiring visual and cognitive perception abilities, comprehension ability, and adequate prior knowledge.

Experiences in geometry should allow for the intuitive investigation of concepts and relationships. The study of geometry is important for many reasons. One of the most important reasons is to develop adequate spatial skills. Early geometry experiences are valuable in developing spatial abilities. Children's early experiences in geometric spatial activities provide involvement with shape explorations and classifications. Participation in such activities helps build the visualization necessary in working with formulas for solids in middle school mathematics. Research from several studies indicates a strong correlation between spatial ability and problem-solving performance (Hatfield, Edwards, & Bitter, 1997).

According to the curriculum standards of the National Council of Teachers of Mathematics, spatial sense is "an intuitive feel for one's surroundings and objects in them" (NCTM, 1989). These abilities must be nurtured through geometric activities. Spatial skills include interpreting and making drawings, forming mental images, visualizing changes, and generalizing about perceptions in the environment. Spatial literacy is embedded in nearly every discipline in the school curriculum. Research from several studies indicates a strong correlation between spatial ability and problem-solving performance (Bayrak, 2008; Boakes, 2009; Rafi et al., 2008).

Spatial skills encompass several aspects such as spatial ability, spatial visualization, and spatial orientation. Kellogg (1995) asserted that spatial intelligence is a component of general intelligence and categorized by several elements. There is much debate in the literature concerning the precise description of spatial ability (Akasah & Alias, 2006). There are five main components of spatial ability according to Maier (1998), which are displayed in Table 1.

Table 1

The Five Factors of Spatial Ability

Factor	Spatial Ability Component
1	Spatial Relations (SR)
2	Spatial Perception (SP)
3	Spatial Visualization (SV)
4	Mental Rotation (MR)
5	Spatial Orientation (SO)

Adapted from "Spatial geometry and spatial ability: How to make solid geometry solid," by P.H. Maier, in F. Cohor-Fesenborg, K. Reiss, G. Toener, & H.G. Weigand (Eds.), *Selected papers from the Annual Conference of Didactics of Mathematics*, 1998.

Olkun (2003) defined *spatial ability* as "the mental manipulation of objects and their parts in two-dimensional and three-dimensional space" (p. 8). *Spatial relations* is generally described as mental integration (Olkun, 2003), the "relationship among the parts of a single object" (Nagy-Kondor, 2007, p. 114. *Spatial perception* is defined as the performance which necessitates "making judgments of horizontal and vertical orientation in space despite distracting background information" (Voyer et al., 1995, p. 252).

Spatial visualization, as defined by several researchers, is the "ability to manipulate or transform the image of spatial patterns into other arrangements or the mental rotation of a spatial configuration in short term memory" (Ekstrom et al., 1976, as cited in McGee, 1979, p. 891). Maier (1998) stated that the "spatial relations between the movement of the objects is changed" (p. 70). Williams, Sutton, & Allen (2008) emphasized that spatial visualization typically "relates to the movement of an object in a particular spatial context or the repositioning of internal parts" (p. 2).

Kozhevnikov & Hegarty (2001) explained *mental rotation* as the rotation of an object or an array of objects which involves imagining or visualizing movement relative to an object-based frame of reference, specifying the location of one object (or its parts) with respect to other objects. The ability to mentally rotate an object, whether 2-D or 3-D, is commonly defined in terms of accuracy and speed (Adanez & Velasco, 2002). Much of the research has revealed gender differences in spatial ability with the most significant discrepancies found in the category of mental rotation (De Lisi & Wolford, 2002; Geary, Gilger & Elliot-Miller, 1992)

Finally, *spatial orientation* is defined as the "ability to perceive spatial patterns or to maintain orientation with respect to objects in space" (Ekstrom et al., 1976 as cited in McGee, 1979, p. 891). In addition, spatial orientation comprises mental rotation tasks.

Olkun (2003) used the classifications from the Table 1 above to sort the idea of spatial ability into two main components: Spatial visualization (SV) and spatial relations (SR). The phases of spatial development involve three stages according to Sorby (1998). The first stage relates to topological skill development which includes the capacity to perceive an object's closeness in relation to another object, the object's order compared to the group, and its inclusion or exclusion of a larger environment. Stage 2 focuses on the development of projective skills, visualizing and recognizing three-dimensional objects from various perspectives of angle rotation. Stage 3 encompasses the union of projective and measurement skills involving the motion geometry features of translation, reflection, and rotation, and the measurement concepts of volume, area, and distance (Sorby, 1998).

This literature review addressed the importance of developing spatial visualization in elementary students for their future success. The topic was explored by examining early spatial development, gender differences, contrasting studies, developmental differences, the improvement of spatial ability, the effects of spatial visualization on mathematics achievement, and the practical importance of spatial visualization in real life.

The purpose of this literature review was to examine the research associated with gender differences in spatial skills across three types of spatial ability; namely spatial perception, mental rotation, and spatial visualization among elementary students. The literature provided a strong basis for understanding that spatial ability is a combination of biological factors such as gender and socio-cultural factors that influence the development of spatial ability in both males and females.

Theoretical Framework

This research study was grounded in several theories. The first was Kolb's experiential learning theory. The second was the cognitive learning theory, originating most likely with Piaget and including theorists such as Vygotsky, Gestaltists (Wertheimer, Kohler, and Koffka), Bloom, and Bruner. The third was stereotype threat theory based on the research of Steele and Aronson (Aronson & Steele, 1995).

Experiential Learning Theory

Kolb (1984)**,** educational theorist and pioneer of the experiential learning theory, proposed that learning is the "process whereby knowledge is created through the transformation of experience" (p. 49). Kolb's recurrent model consists of four stages that include concrete experience, active experimentation, abstract conceptualization, and reflective observation. Kolb viewed learning as an "integrated process with each stage being mutually supportive of and feeding into the next." Kolb, 1975, p. 33). Kolb's theory proposed that one can enter the cycle at any stage, and follow through its logical sequence.

Cognitive Learning Theory

Blanton (1998) stated the importance of cognitive science in relation to cognitive learning theory for understanding better the practical connections to enhance the curricular design and implementation of actual learning for students. Cognitive learning deals with the manner in which learners use their particular modes of processing in order to "acquire, retain, and retrieve information" (Blanton, 1998, p. 171). This theory seeks to recognize the two types of knowledge: declarative and procedural. Declarative knowledge is focused on the properties of the environment around oneself. Procedural knowledge is concerned with practical application or a method of doing something. Another aspect of knowledge, metacognition, deals with thinking about one's ability, skills, and understanding (p. 171). Blanton organized the commonalities of the cognitive learning theories. Blanton asserted that the dilemma "arises whether to design instruction to capitalize upon cognitive processing strengths or to design instruction to strengthen cognitive processing weaknesses" (p. 172). Blanton (1998) stated that features of the cognitive learning theories should always stress *relevance* and *economy of effort* (p. 173). Blanton shared these ideas to assist the reader in considering the impact of cognitive learning on appropriate and successful instructional design for all types of learners, regardless of their cognitive perspective.

With each successive theorist, new constructs keep emerging that build layer by layer the rich information of the cognitive theory of learning. The primary theorists were Piaget, Vygotsky, Gestaltists (Wertheimer, Kohler, and Koffka), Bloom, and Bruner. This theory originated most likely with Piaget and his ideas on schema, which asserted that students must make connections with prior learning and background knowledge in order to assimilate the new information to provide meaning. Bruner expounded on this theory using the phrase "mental map" whereby learners follow a pathway en route to the new information (Bruner, 1960, p. 173).

Stereotype Threat Theory

This theory refers to the psychological factor of being "at risk of conforming, as a self-characteristic, a negative stereotype about one's social group" (Aronson & Steele, 1995). Aronson and Steele's experiments revealed that the performance of Black college freshmen and sophomores on standardized tests resulted in poor scores compared to White students when the awareness of race was accentuated. Conversely, the Black students performed "better and equivalently" (p. 797) with White students when race was "not emphasized" (p. 797). This research raised awareness of the manner in which students' test performance outcomes may be affected by a "heightened awareness of racial stereotypes" (p. 799).

Stereotype threat can cause apprehension, anxiety, low expectations for success, low self-esteem, and result in lower test performance (Lucas & Alwens, 2000). Other studies have shown that stereotype threat is thought to increase achievement gaps not only in race but also in regard to gender (Brown & Josephs, 1999; Cadinu, Maas, Frigerio, Impagliazzo, & Latinotti, 2003; Lucas & Alwens, 2000; Nguyen & Ryan, 2008).

In their study, Ryan and Ryan (2005) asserted that stereotype threat can be experienced by even moderately well-achieving females. When the threat of stereotype was present, the females' displayed behaviors that demonstrated that they were more depressed and underperformed anytime the stereotype threat was activated.

Several studies have reported higher anxiety levels for females than males when completing math tasks, and the deficient, suboptimal performance in mathematics has been associated with this anxiety or apprehension (Ashcroft & Moore, 2009; Frenzel, Goetz, Pekrun, & Wyatt, 2010). The research revealed that the negative stereotype awareness may threaten females and heighten their underperformance in comparison to males (Huguet & Regner, 2007; Schmader & Johns, 2003).

Twamley (2009) explored the effects of stereotype threat theory by examining girls' math performance in single-sex, middle-grades classrooms composed of fifth and sixth grade girls. The two-fold purpose of the study addressed the "important contribution of stereotype threat to the understanding of the gender achievement gap in mathematics," (p. 9) and the "effects of the gender (dis)identification based on induced stereotype threat" (p. 9).

In their Executive Summary "Why So Few?" sponsored by the National Science Foundation, The American Association of University Women conducted a study on the underrepresentation of women in science, technology, engineering, and mathematics by accessing research from the previous twenty-five years (American Association of University Women [AAUW], 2013). The inclusive report addresses the many components of the disparity of females in optimal career paths.

Marcus (2014) addressed the dilemma in her article:

> Women make up about half of the workforce in America, but they only represent 24% of the workforce in STEM fields. Why should we care? First and foremost, this statistic calls attention to an untapped potential; talent that we need in science, technology, engineering and mathematics in order to remain competitive from a global perspective. But for women, this is important on another level because careers in STEM industries offer better compensation and more career advancement opportunities. In fact, women who hold STEM positions earn 92 cents to the dollar versus 77 cents for women who are not in these fields. (Marcus, 2014, p. 1).

Women from underrepresented racial-ethnic backgrounds experience more severe situations. AAUW (2013) reported that of the

> more than 7,000 computer-science doctoral faculty in 2006, only 60 were African American women; numbers for Hispanic and Native American women were too low to report. African American women also made up less than 1 percent of the 17,150 postsecondary teachers in engineering. (pp. 15-16)

In the science, technology, engineering, and mathematics (STEM) fields, the most underrepresented area for women is computer science, with the current statistic of 18% of females holding bachelor's degrees (National Science Foundation [NSF], 2013). The National Science Foundation (2013) reported that this percentage has not increased over the past decade. The question is why is there a lack of diversification in the computer science field and the disproportionate exclusion of females from some of the most lucrative careers (Hill, Corbett, & St. Rose, 2010). Master, Cheryan, and Meltzoff (2016) delved into the factor(s) that may deter females from computer science courses and the stereotypes that may "undermine girls' interest and sense of belonging" (p. 424). They manipulated the environments of the computer science classroom by decorating it using objects acknowledged as stereotypical or non-stereotypical. The study revealed that the stereotype threat reduced the feelings of the women and their sense of belonging and interest in the computer science classroom (p. 426). The individual's performance in the stereotype-threatening situations reflects not only the competence of the individual, but the social group in which the individual belongs (p. 428). Stereotype threat theory provides evidence that the level of mathematical learning for women can be reduced through negative stereotypes, and diminished learning can lead to poorer performance.

Relationship of Theories to Study Context

As society becomes more diverse, classrooms should follow that pattern, too as teachers attempt to meet the needs of children that have various readiness levels, varying interests, and a variety of learning modes. It seems sensible that since individuals are all fashioned with unique and varying DNA arrangements, everyone would have different methods in which information is received that makes sense and provides meaning. Literature shows that in order for diverse students (especially in low socioeconomic situations) to show significant academic improvement, instruction must be meaningful and relevant (Payne, 2005).

To explore this concept of meeting the needs of diverse learners, specifically students with disabilities, Lucas (2011) targeted pre-service teachers' attitudes. One hundred ten pre-service teachers were surveyed at a private, liberal arts university in North Carolina. The survey instruments Pluralism and Diversity Attitude Assessment (PADAA), and Opinions Relative to

Integration (ORI) measured the attitudes of teachers in regards to including students with disabilities in the regular education classroom environment. The study found that the inclusion of an introductory course impacted the improvement of pre-practicum teachers' attitudes toward diverse learners.

One aspect in reaching all types of learners is to acknowledge their particular learning styles. In 1983 Harvard University professor, Gardner developed a theory of multiple intelligences. Gardner (1983) suggested that educators limited students with forms of tests based on traditional intelligence quotient (IQ). testing. Gardner proposed eight different intelligences to account for a wider range of potential for children and also adults to demonstrate intellectual ability. They included linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal, intrapersonal, and naturalist (Gardner, 1983). Understanding that children are unique persons with various abilities enables teachers to reflect and question their approach of teaching in order to look beyond the narrow confines of the dominant methods of skilling, curriculum, and testing.

Related Literature

Historical Summary

Early spatial development. Mohler (2008) comprised an extensive research of spatial ability beginning with Sir Francis Galton's (1880) early investigation into mental imagery. Mohler showed a chronological format of the historical aspects of spatial research into four major categories as seen below in Table 2. The chart displays the research contributions beginning from the initial stages of the 1880s to modern day (Mohler, 2008, p. 20).

Table 2

Chronology of Research with Themes and Approaches

Date Range	Themes and Approaches
1880-1940	Acknowledgment of a spatial factor separate from general intelligence through psychometric studies
1940-1960	Acknowledgment of multiple space factors through psychometric studies; emergence of myriad spatial assessments
1960-1980	Psychometric studies into cognitive issues; emergence of developmental and differential research
1980-	Effect of technology on measurement, examination, and improvement; emergence of information-processing research

Adapted from "A review of spatial ability research," by J. Mohler, *Engineering Design Graphics Journal*, pp. 9-30. 2008.

Thorndike (1921) pioneered the idea of distinguishing between different types of "intellectual functioning" (p. 22). Showing differences of opinion with Spearman (1927) whose perspective was a "singular view" of intelligence (p. 22), Thorndike contended that in addition to abstract intelligence (measured by standardized tests), there existed "mechanical" and "social" intelligence correspondingly significant to the idea of intellect.

Piaget, in his research involving children's mathematical thinking, was concerned with imagery, concepts of space, spatial relationships and the changes that these concepts undergo (Piaget & Inhelder, 1948). Even in the early years of a child, the progression of crawling to the walking stage is important in developing spatial skills. Clearfield (2004) demonstrated in his study of eight and 11 month-old crawlers and 14 month-old novice walkers that the different patterns of behavior demonstrated suggested that "spatial memory may be linked to movement" (p. 230). The study indicated that infants as young as 11 months of age could use relations between landmarks to find a hidden goal (their mother). The data suggested that whatever infants learn about using cues in the environment is at least partly tied to how they move through it. Other studies have documented a relationship between the onset of crawling and increased spatial skills (Bai & Bertenthal, 1992; Bertenthal, Campos, & Barrett, 1984; Horobin & Acredolo, 1986).

In order to be able to use a map, one has to establish the correspondence between symbols on the map and objects in the real world. Researchers believed that the ability to deal with differences in scale came much later developmentally, and consequently, children's difficulties with map tasks have been connected with a lack of understanding of scale relations (Liben & Downs, 1989). Valyeva and Huttenlocher (2003) examined children's understanding of scale relations in their study involving four- and five-year-old children locating an object in a two-referent space. Their study showed that both four- and five-year old children could reproduce location in a two-dimensional space using distance information.

Many researchers believe that more time should be spent on instructing students in geometry and spatial reasoning because these skills form the foundation for learning mathematics and other subjects (Brinkman, 1966, McGee, 1979). Clements (1998) examined how young children learn about space and geometry, referring to Piaget's belief that children have constructed "perceptual space" by infancy but develop ideas about space through action.

The developmental research shows that spatial ability is affected by age (Halpern, 2000). As children develop, spatial ability improves with the age progression during childhood (Orde, 1996). However, studies have shown that spatial ability declines as senior adults' progress into later adulthood (Pak, 2001). Factors affecting age-related discrepancies often include processing speed differences, experience, and knowledge (Salthouse, 1987).

In the 1950s, two Dutch middle school mathematics instructors, a husband and wife team, Dina van Hiele-Geldof and Pierre van Hiele, developed the theory of geometric thought based on the gaining of understanding that geometry is a mathematical system in their research in the Netherlands (van Hiele, 1986, p. 79). In their model of five levels of understanding (see Table 3), students progress through the tiers of understanding geometric ideas beginning with the most basic level, visualization & recognition, to analysis, to informal deduction, deduction, and continue to the most advanced level, rigor" (Crowley, 1987, p. 1-3). Rather than progress along developmental continuums according to Piagetian models, the van Hieles' model demonstrated that "students progress based on their experiences rather than age, and it is imperative that teachers provide experiences and tasks so that students can develop along this continuum" (Breyfogle & Lynch, 2010, p. 234).

Table 3

The van Hiele Theory of Geometric Thought

Level	Geometric Ideas
0	Visualization and Recognition
1	Analysis
2	Informal Deduction
3	Deduction
4	Rigor

Gender Differences

Another aspect of the spatial visualization issue is gender differences. The term *gender* may be used to refer to "assumptions about sex differences-those characteristics and traits socioculturally considered appropriate to males and females" (Unger, 1979, p. 1085). There has been much controversy in the appropriate use of the two terms for contextual meanings in the literature of psychology and related fields. Muehlenhard & Peterson (2011) distinguished between the ambiguous terms of *sex* and *gender* in their paper, highlighting the historical distinctions of inconsistency of their usages. Many authors indicate that the term *sex* implies biological origins and anatomical categories (Denmark et al., 2005; Etaugh & Bridges, 2010; Goldberg, 2010; Lips, 2008; Wood, 1999) while *gender* refers to "the state of being male or female" (Hyde, 2014, p. 5) or the social categories of male and female (Hegeleson, 2005). The APA publication manual offers guidelines for the distinction between the terms *sex* and *gender* that are appropriate to mention at this time stating that "sex is biological" and should be used when the "biological distinction is predominant" (APA, 2010, p. 71). *Gender* is "cultural and is the term to use when referring to women and men as social groups" (APA, 2010, p. 71).

The meta-analysis of Linn & Petersen (1985) found that sex differences in visual-spatial ability were "large only for mental rotation, medium for spatial perception, and small for spatial visualization" (p. 17). Voyer, Voyer & Bryden (1995) showed sex differences to be strongest for tests in the mental rotation category, large for the spatial perception category, and variable and non-significant for spatial visualization tests (p. 17).

Hilmar and Amponasah (1998) investigated gender differences in the spatial ability categories from groups of white, Norwegian-born college students. The participants included one group of technology students and one group of social science students. The results showed that gender differences in favor of men were found in all the spatial ability categories within both student groups. A larger gender difference was seen among technology students than among social science students. The male technology students scored highest, and the female social science students scored lowest on all the spatial ability tests (p. 4). Among the spatial activity questionnaires, females scored significantly higher than males. Hilmar and Amponasah (1998) concluded that effect sizes for the three categories of spatial abilities were similar to previous results, "that the differences were as large as previously found in other countries" (p. 6). At the outset of their study, they expected the differences in comparable gender groups to be small because of the strong gender-egalitarian ideology and policy in Norway in the last decades. The data failed to support the hypothesis that gender differences are decreasing.

Manger and Eikeland (1996) based their research on the frequent argument that boys' advantage in mathematics is rooted in a corresponding advantage in visual-spatial skills (Benbow, 1988; Maccoby & Jacklin, 1974; McGuiness, 1993). Due to a lack of studies testing the role of spatial visualization between boys and girls, Manger & Eikeland's purpose was to examine sex differences in spatial visualization and mathematical achievement at the end of elementary school. Participants were randomly selected from 49 of the 117 third-grade classes in Bergen, Norway. Forty-four of these classes were followed up in the spring term three years later. While numerous studies on sex differences in mathematical achievement suggest that the gender gap is negligible during the elementary school years, Manger & Eikeland's study supported the results of other studies that there are differences favoring boys, but the effect size is small. With respect to spatial visualization as assessed by a form board test, their research found no significant sex difference, and they cautioned readers not to generalize to other areas of spatial ability, such as spatial perception and mental rotation. Manger & Eikeland felt that further research should investigate the strategies used by girls and boys on different tasks, and mental rotation tests should be included in the assessment of the connection between visual-spatial ability and mathematical achievement (p. 24).

Representations of number have been linked to spatial locations/spatial attention through decades of experimental research (McCrink & Shaki,, & Berkowitz, 2014). The Spatial Numerical Association of Response Codes (SNARC) is a widely supported example of this number relationship.

Western-educated individuals show preferences to "map smaller numbers to the left side of space, and larger to the right, in an ordered sequence" (Dehaene, Bossini, & Giraux, 1993). Because of an internal *mental number line*, this effect is attributed to a "cognitive mapping of symbolic number to a spatial continuum" (Moyer & Landauer, 1967). The concept of mapping of number to space is initiated when individuals process symbolic numerals, in addition to sets of objects, represented by non-symbolic number systems (Bulf, Macchi, & de Hevia, 2014; Shaki, Fischer, & Petrusic, 2009). Findings from studies comparing young pre-readers from different cultures and the directionality of gaining cognitive academic skills revealed that the "directionality of SNARC and SNARC-like effects are inculcated even before the advent of self-directed and automatized reading" (McCrink & Galamba, 2015, p. 3).

McCrink & Galamba (2014) determined the impact of symbolic and non-symbolic quantity on spatial learning using undergraduate students at a university. Either symbolic or non-symbolic numerical arrays were "embedded in the spatial locations via the software computer program, and subjects achieved more success when the information was presented right-to-left, versus left-to-right, or random flow" (p. 7). However, female participants working with non-symbolic number arrays "paired with the spatial locations exhibited better recall for left-to-right directional flow of information" (p. 11).

Contrasting studies. Conversely, several researchers have concluded from their work that the gender differences in visual-spatial skills are negligible. Tartre (1990) showed no sex differences in spatial visualization in both his middle school and high school studies. Armstrong (1985) found that 13-year-old girls even "performed significantly better than boys in spatial visualization" (p. 18).

Capraro (2001) examined the difference between student performances on two separate spatial measures. The participants were 287 sixth-grade students from three public schools in a southern state in the United States. All participants were administered the Geometry Content Knowledge (GCK) Test (Carroll, 1998). Next, all participants were administered the Spatial Visualization (SVT) subtest of the Differential Aptitude Test (Bennett et al., 1972). The qualitative portion of Capraro's study explored how gender or ethnic differences influenced GCK or SVT abilities. Results indicated a statistically significant difference between the ethnic groups for the criterion variable of geometry content knowledge (p. 14). No significant differences between males and females in geometry content knowledge were found from the regression analysis. No difference was seen in the mean geometric spatial visualization scores between ethnic groups. Race did not appear to be important when considering GSV scores. Surprisingly, no statistically significant differences were found between males' and females' geometric spatial visualization.

Developmental Differences

Developmental researchers have studied the area of hemispheric specialization in order to understand the physiology of the brain and its correlation with spatial ability (Rilea, Rosicos-Ewoiden, & Boles, 2004). Several theories seek to explain spatial ability gender differences from biological (brain lateralization and maturation rate) perspectives.

Explanations supporting a biologically based theory of spatial gender differences have some evidence in the research. Gur et al. (2000) found that males display an increase in right hemispheric activation during the processing of spatial information. In contrast, females neglect to show an increase in the activation of the right hemisphere. However, they exhibit more bilateral activation in processing spatial skills. The higher the activation of the right hemisphere, the greater the spatial performance. The researchers asserted that the *bilaterality* of females may underlie differences in spatial performance because the greater spatial results of the males are due to the *unilateral* activation of the brain (Gur et al., 2000). Conversely, there may be issues with this type of circular thinking due to the fact of the interpretation of the lateralization differences. One cannot presume that a certain way of processing spatial information is superior or more valid than the other (Turos & Ervin, 2000).

Neuroscience research revealed that there are two distinct pathways of the brain's visual areas (Motes, Malach, & Kozhevnikov, 2008). They include the "*dorsal*, or spatial, and *ventral*, or object pathways" (p. 1727). Motes et al.'s study was the first to explore neural foundations of individual differences in the processing aspects of object versus spatial visualizers. Participants were undergraduate psychology students who were administered tasks that were back-projected on a screen via the computer through which they heard the "auditory stimuli through an MRI compatible headset" (p. 1729). They completed the object-processing tasks during the functional magnetic resonance imaging scan (fMRI). Results showed greater activity for the spatial visualizers than object visualizers. Object visualizers showed "lower bilateral neural activity in lateral occipital complex, and lower right-lateralized neural activity in dorsol prefrontal cortex" (p. 1727). The activity in the dorso-lateral, pre-frontal cortex (DLPFC) was significantly higher for spatial visualizers. However, the groups did not significantly differ in parietal or left occipital-parietal activity (p. 1729).

Blazhenkova & Kozhevnikov's (2010) study aimed to examine the validity of visual-object ability to determine if object ability relates to visual art specialization as compared to the manner that spatial ability links with mathematics, physics, and other natural sciences (p. 3). Their results were consistent with earlier studies that "all visual-object measures comprise a unique factor, different from visual-spatial factor" (p. 8). The visual-object ability predicts specialization in visual art but not science, and visual-spatial ability predicts specialization in science but not visual art (p. 9). Additionally, results revealed that females were inclined to outperform males on tasks that require visual-object processing (p. 9), while the opposite held true for males and their performance on visual-spatial processing exceeding the females (p. 9).

Neuroimaging studies have provided more insight determining if specificity of brain development in regard to gender could possibly make a difference in brain connectivity. Reiss, Abrams, Singer, Ross, and Denclka (1996) applied Magnetic Resonance Imaging (MRI) techniques coupled with advanced image analysis to describe the cerebral development in children and adolescents (*n* = 85), ages five to 17 years. While the results demonstrated that boys' total cerebral volume is 10% larger compared with the females, both showed little change in total volume after five years of age. Cerebrospinal fluid (CSF) volumes and age-related changes in white matter and grey matter appear to reflect continuing maturation of the central nervous system. Their work indicated that both male and female subjects show a "similar pattern of cerebral asymmetry: a rightward prominence of cortical and subcortical grey matter and a leftward prominence of CSF" (p. 119).

Other neuroimaging techniques such as anatomical connectivity, structural MRI, diffusion MRI, functional MRI (fMRI) and Positron Emission Tomography (PET) have been applied in the summation of recent research studies of gender differences by Gong, He, and Evans (2011). In their review, they summarized research progress focused on the study of "gender differences in the human brain connectivity" (p. 576). Initially, they familiarized the reader with the scientific characterizations of the different scales of the human brain connectivity which comprises the "microscale (between neurons), mesoscale (between cortical columns), and macroscale (between brain voxels/regions)" (p. 576). For the purposes of the review, their focus was concentrated on the *macroscale* brain connectivity findings in health directed first on the basic concepts and methods used for "determining and quantifying the brain connectivity/network using multimodal neuroimaging techniques" (p. 576).

These neuroimaging techniques are non-invasive as compared to previous traditional methods of invasive techniques such as dissection, histological staining, and axonal tracing which limited prior studies to postmortem and animal brains (p. 576). Many of the studies included in their research showed gender differences in the "morphology of the corpus callosum. . . but these results of a gender effect are controversial" (Gong et al., 2011, p. 580). The corpus callosum is the major "white matter tract connecting the two hemispheres," (Gong et al, 2011, p. 580) and it has been suggested that "larger callosal size indicates greater interhemispheric anatomical connectivity" (Gong et al., 2011, p. 580).

Subsequently, the results were reviewed regarding the gender differences of the White Matter (WM)-based anatomical connectivity/network (Gong et al., 2011). From the collective studies, Gong et al. found that male and female human brains "display differences in the network topology that represents the organizational patterns of brain connectivity across the entire brain "(p. 575). They asserted that future research should consider gender when "designing and conducting experiments and/or interpreting the results of the brain connectivity and its network" (p. 588). Much of the research involving neuroscientific methods correlates to gender-specific connectivity and networks related to health and disease issues.

The maturation rate theory is another controversial hypothesis. Girls' faster rate of physical maturation may lead to the left hemisphere of the brain specializing earlier, which augments early verbal skills. Conversely, the slower maturation rate of boys is believed to stimulate stronger “right-hemispheric specialization” during the adolescence period which creates a pattern for enhancement of later-emerging spatial skills and abilities (Waber, 1976). Waber proposed that a “slower maturation rate may allow for the stronger inter-hemispheric differentiation that is necessary for good spatial skills” (Waber, 1976). Investigators have attempted to replicate the findings of Waber but have shown limited success (Rovet, 1983). There is a general consensus that those individuals with right-brain dominance accomplish spatial tasks better and display more highly-developed spatial skills (McGlone, 1980). Waber (1976) found that males display more right-brain dominance and they mature at a faster rate in this area.

Can Spatial Ability Be Improved?

Mathematics is a complex process requiring visual and cognitive perception abilities, comprehension ability, and adequate prior knowledge (Wetzel, 2009). Many researchers have questioned whether spatial visualization and the ability to mentally rotate objects can be improved upon. For many years, a belief existed that the potential for spatial thinking was an inborn characteristic and this innate ability was fixed (Baillargeon, 2008).

In fact, the malleability of spatial skills has been met with skepticism by many researchers for several years, with many arguing that spatial skills training only leads to short improvements. The plasticity of the spatial skills results only in cases where the training and measurement tasks are very similar (Sims & Mayer, 2002). However, research has been conducted to test this theory. Most recently, the comprehensive meta-analysis to date on spatial skills training found that spatial skills were “moderately malleable and that training, on average, improved performance by almost half a standard deviation” (Uttal et al., 2013, p. 27).

Seng and Chan (2000) investigated the nature of spatial ability and its relationship to the mathematical performance of elementary school pupils, which included 72 boys and 55 girls, ages 10-11 years in their study. They used four measurement instruments based on spatial orientation and visualization. The boys were found not to be significantly better than the girls in the four spatial tasks, but a significant positive relationship was found to exist between spatial ability and mathematical performance.

Interestingly, a study conducted by University of Toronto researchers discovered that differences between men and women on some tasks that require spatial skills are largely eliminated after both groups play a video game for only a few hours (Feng, Spence, & Pratt, 2007). The research suggested that a new approach involving action video games can be used to improve spatial skills that are essential for everyday activities such as reading a map, driving a car, or learning advanced math. Feng, a psychology doctoral student and lead author of the study, stated that after finding the gender difference, “our second experiment showed that both men and women can improve their spatial skills by playing a video game and that the women catch up to the men . . . and the improved performance of both sexes was maintained when assessed after five months” (Feng, Spence, & Pratt, 2007, p. 1).

Likewise, Sorby (2009) supported the case for spatial skills instruction in computer technology. In analyzing longitudinal data collection throughout the years, Sorby (2009) asserted there is “strong evidence to suggest that training in spatial skills has had a significant positive impact on student success, particularly for women engineering students (p. 4).

Interestingly, many researchers suggested that spatial abilities can be improved using the technologies of virtual reality (VR) and augmented reality (AR). Gupta (2012) described virtual reality as a created artificial environment using computer hardware and software in a presentation for the user to interact in a simulated situation that mimics the appearance and feelings of a real environment. The user must utilize special earphones, goggles, and gloves, which all receive input from the computer system in a superficially physical way. Lee (2012) defined augmented reality as a "technology that allows computer generated virtual imagery information to be overlaid onto a live direct or indirect real-world environment in real-time" (p. 31). Augmented reality differs from virtual reality in that VR users "experience a computer-generated environment" (Lee, 2012, p. 31) whereas AR users experience the "real environment but extended with information and imagery from the system" (Lee, 2012, p. 31).

Many of the popular computer/video games implement virtual and augmented reality technology in the realm of entertainment. While many suggest that students' motivation and learning can be enhanced and strengthened using virtual and augmented reality technologies (Chang, Morreale, & Medicherla, 2010), the cost of adopting the technologies in education and training remains quite challenging because of the issues of its "integration with traditional learning methods, costs for the development and maintenance of the AR system, and general resistance to new technologies" (Lee, 2012, p. 14).

Austrian researchers Kaufmann and Schmalstieg (2003) have worked toward a systematic development of AR applications in the device Construct 3-D that may offer practical efforts for educational purposes in the field of geometry in order to improve spatial visualization skills. The 3-D geometric construction tool setup uses a "stereoscopic head mounted display (HMD) and the Personal Interaction Panel (PIP) which is a two-handed 3-D interaction tool that simplifies 3-D model interaction" (Kaufman, Schmalstieg, & Wagner, 2000, p. 263) and is based on the collaborative augmented reality system 'Studierstube' (Kaufmann et al., 2000, p. 263). Kaufman et al. (2000) asserted that students can view the three-dimensional objects via the Construct 3-D device that before they had to “calculate and construct with traditional methods” (p. 264) and by working “directly in 3-D space complex spatial problems and relationships can be comprehended better and faster than with traditional methods,” (p. 264) which has been the main advantages of implementing the tool. However, the majority of Kaufmann et al.’s (2000) research has focused exclusively with college age and older high school students. With the increase of technological wireless mobile devices such as PC tablets, smart phones, and other electronic innovations, these applications offer a greater measure of promise for training in the educational venues.

In an effort to demonstrate a connection between mathematics and spatial ability, Cheng and Mix (2014) focused on six- to eight-year-old children, one of the few studies conducted on younger subjects. Their participants included 58 children who were randomly assigned to a spatial training group or the no-training control group (p. 5). Assessments included the mental rotation test, spatial relations subtest, and a mathematics performance test. They concluded that their study was the first to “show a direct effect of spatial training per se on math performance in early elementary-aged children” (p. 7) and even a “single session of spatial training led to significant improvement on certain problems” (p. 7).

Mansfield (1985) urged the teaching of projective geometry to improve spatial abilities. As stated previously, projective geometry involves the third stage of spatial development (Sorby, 1998). These projective and measurement skills consist of the ability to envision the concepts of distance, translation, reflection, rotation, volume, and area. These aptitudes, in turn, will promote the ability to reason, predict, and represent knowledge in appropriate ways. Many aspects of our world can be viewed from a geometric perspective. How individuals develop the ability to visualize and conceptualize spatial properties and what factors affect the development of these cognitive structures are still unanswered questions (Rosser, 1980).

Despite findings that propose males are superior to females in spatial ability (Anastasi, 1958; Fruchter, 1954), it has been found that spatial visualization is more related to mathematics performance for girls than for boys (Sherman, 1978). Moses (1980) found that genetic factors are not the cause of these differences, but with proper instruction, females can perform as well as males at creative visual thinking and problems requiring spatial ability.

The Effects of Spatial Visualization on Mathematics Achievement

Research indicates that if students are able to visualize, they have a much greater chance for success in mathematics (Fruchter, 1954; Meserve, 1973). Spatial visualization has been shown to be related to mathematics performance (Fennema & Sherman, 1977, 1978). Neglecting instruction in spatial competence could discriminate against the less spatially-minded student, erecting a barrier that may later hinder success in future math proficiency (Rosser, 1980). Battista, Wheatley, and Talsma (1982) investigated spatial ability and cognitive development and how the two are such important factors in learning mathematics. They used pre-service elementary teachers as participants. The course was a mathematical study of spatial relations combined with a requirement of logical-deductive thinking, where they hypothesized that formal thought would be needed for success. The study found that the main effect due to cognitive development was significant, but the main effect due to spatial visualization and the interaction was not significant. Spatial visualization scores of students enrolled in the geometry course were significantly higher at the end of the semester than at the beginning. The researchers concluded that cognitive development was a better predictor of geometry course grades than spatial visualization ability.

Researchers in other countries are interested in the effects of spatial skills. Seng and Yeo (2000) explored the role of a cognitive style, spatial visualization, and its high correlation with student achievement. Their work focused on three aspects: whether students with high, average, and low spatial visualization ability differed in their preferred learning modes; whether the three groups showed a difference in their preferred learning styles; and the relationship between learning styles and brain hemisphericity. Results showed that students with high spatial ability did not differ significantly in their scores in any of the four learning modes compared to students with average or low spatial ability. Another finding from the study showed that there were more left-brain dominant subjects among the low-spatial ability group, and more high- spatial ability students among the right brain group. These results correlate to Salthouse's (1987) study which showed that spatial ability is primarily a right brain activity. Seng and Yeo (2000) suggested more visual information be used in classroom instruction including more hands-on or experiential approaches where teaching style should be matched to students' learning styles in order to enhance academic success.

Van Garderen (2002) compared visual imaging and problem solving by students of varying abilities. Van Garderen investigated sixth-grade students' use of visual imagery while solving mathematical word problems. Students included those with learning disabilities, average-achieving students, and gifted students. The results indicated that gifted students used significantly more visual images compared to the average-achieving students and students with learning disabilities. Students with LD used more pictorial representations than the other students. The average-achieving students and students with LD performed more poorly on measures of spatial visualization ability than the gifted students. These results indicated the important instructional implications for all educators.

Higbee and Thomas' (1999) study also addressed the factors related to achievement in mathematics. Their research explored the relationship between affective variables (academic self-concepts, attitudes toward success in mathematics, motivation, math and test anxiety, perceptions of the usefulness of mathematics, self-esteem, and locus of control) and mathematics achievement among high-risk students enrolled in a sequence of developmental mathematics courses that implemented a variety of instructional methods. Higbee & Thomas related that many students enrolled in developmental education programs have ability but lack the motivation or confidence to achieve. Most of the participants responded positively to activities involving tangrams and Legos that required visualization as well as manipulative skills. Significant findings in the research were that mathematics test anxiety decreased and students' confidence in their ability to be successful in mathematics increased.

Current Research

In a study by Robinson and Lubienski (2011), the achievement trends of math and reading for males and females from kindergarten to eighth grades were tracked in a longitudinal, causal-comparative design. The study also examined if there were gender gaps, where on the continuum the gaps were dispersed, and the observation of teacher effects on those gaps. The sample included a high of 20,578 kindergarten students to a low of 9,725 in the spring for eighth graders. In this study, only 7,075 students were involved due to reasons such as dropping out for invalid scores, lack of assessment for LEP students in early grades, and missing test data (Robinson & Lubienski, 2011, p. 276). Achievement scores and gaps were explored using the Early Childhood Longitudinal Study, Kindergarten Class of 1998-1999 (ECLS-K). This data set was collected by the U. S. Department of Education. Math teacher survey data were collected for half of the fifth and eighth graders with the other half assigned to science. The estimates were unbiased since the sample was split randomly (p. 277). The assessment items were field-tested, and reliabilities were high, ranging from .89 to .96 (p. 277).

Whether looking at the *t* scores or scale scores, the study showed no significant gaps between male and female mean scores at the beginning of kindergarten (Robinson & Lubienski, 2011). At the third and fifth grades, the mathematics gender gap widened in favor of males (p. 283). In reading, the results were ambiguous. Using the scale scores, the growth of the females' scores increased during kindergarten to third grade. However, using the standardized scores, females were "losing relative ground" to males (p. 283). The distribution of scale scores widened until eighth grade. In the spring scores, of the bottom 5% of readers, 67% were male (p. 288).

Robinson and Lubienski (2011) found no indication that confounders such as socio-economic level, race, or grade level contributed to the differences in growth of males and females. They asserted that distributions are more similar than different and that conclusions should not be made that females cannot excel in math as well as males. This study is significant in that it suggested that females lose ground in math during their elementary years as opposed to the middle school years and the focus should place more attention on the lowest-achieving males. Finally, the teachers' views of girls' competence should be addressed to reduce bias and stereotypical perspectives in order to offer advantages for later career choices.

Sorby & Veurink (2012) compiled and analyzed data collected from 1996-2011 on all first-year engineering students entering Michigan Technological University, specifically using the results from the Purdue Spatial Visualization Test: Rotations (PSVT:R). The disaggregated data from more than 11,000 students included domestic, international, minority, race, ethnicity, and gender differences of students enrolled in the engineering orientation classes. Scores from females and African Americans were found to show significant discrepancies as compared to Caucasian males who attended Michigan Tech.

Hoffler (2010) provided a meta-analysis review of 27 different research situations from 19 studies accompanied by a discerning theoretical review regarding spatial ability in an overall sense while including the existent state of research that relates to the connections between visualization learning and spatial awareness (p. 246). The studies chosen for the meta-analysis spanned 15 years (1994 and 2009) with most of the research focusing on secondary or college students. Arising from the assessment of literature were several ways to assist learners who demonstrate low spatial ability, whether with specific aspects of visualization or with certain features of a learning assignment. This review proceeded from the perspective that spatial visualization is defined as “any kind of non-verbal illustration” (Hoffler, 2010, p. 246) where the central focus is on pictorial visualizations.

A study focusing on 563 academically gifted 13-year olds tracked over the course of 30 years was evaluated by Kell, Lubinski, Benbow, and Steiger (2013). Their findings indicated a link between spatial skills, creativity and technical innovation while examining the hypothesis that “spatial ability plays a unique role in the development of creative products” (p. 1831).

However, it has been construed that gender stereotypes take root early in children’s lives. Cvencek, Meltzoff, and Greenwald (2011) conducted a study of 247 children in the Seattle-area elementary schools. Their findings concluded that girls’ and boys’ attitudes about math begin to diverge as early as second grade. Boys linked math with their own gender while girls connected math with boys. In the self-concept test, boys identified and acknowledged themselves with math much more than girls did.

Contributing to this line of thought is Ivinson’s (2014) perspective on tracking the “gendered effects of sex-group categorization onto pedagogy, policy and practice” (p. 155). Ivinson’s informative paper plotted the educational standards and policies from 1988 to 2009 in

England and Wales that spurred the "rhetoric of gender gap as a key political and social concern" (p. 155). Ivinson based the evidence on three major governmental reports published between 1932 and 2007. The article was the result of participation with various international contributors in a conference sponsored by Luxembourg University. The discussions focused on various methodologies to better understand gender variations in successful educational settings. Ivinson asserted that if

> teachers are constantly presented with the message that boys and girls learn differently due to innate genetic make-up, they are likely to be disempowered and believe that their pedagogic strategies cannot work against boys' and girls' innate genetic features. In effect, they are being told that biology controls learning and that culture or social contexts and, thus, their own classroom environments cannot counter the forces of nature. (p. 166)

Ivinson argued that these "patterns of inequality" must be addressed through the political and educational policies by participating in "multiple scales of analysis" (p. 16).

Strategies That Are In Place

In order to compare statistical data of international educational systems, the National Center for Education Statistics conducts studies among other various activities (U. S. Department of Education, 2012). One particular endeavor, the Trends in International Mathematics and Science Study (TIMSS), under the auspices of the International Association for the Evaluation of Educational Achievement (IEA), is piloted every four years for the assessment of fourth and eighth graders in mathematics and science. The TIMSS 2007 mathematics assessment results showed United States fourth graders' average score was higher than the "average scores of 4th graders in 23 of the 35 other participating education systems, lower than the scores in eight education systems, and not a measurable difference from the scores in the remaining four education systems" (U. S. Department of Education, 2012). All of the systems that outperformed the United States were located in Europe or Asia.

Recent developments in reorganizing curricular objectives across the United States relate to the new Common Core State Standards. Teachers, researchers, and leading experts collaborated in various states to design and develop the standards. Options were given to each state to independently choose to adopt the CCSS beginning in 2010. According to the National Governors Association (2010), the federal government has not been involved in the development and creation of the standards; teachers, principals, and superintendents led the execution of the CCSS. The Common Core State Standards provide a

> consistent, clear understanding of what students are expected to learn, so teachers and parents know what they need to do to help them . . . designed to be robust and relevant to the real world. Reflecting the knowledge and skills that our young people need for success in college and careers is imperative in order to compete successfully in the global economy. (National Governors Association, 2010, What Parents Should Know section).

To date, 45 states, four territories, the District of Columbia, and the Department of Defense Education Activity have adopted the CCSS. Students were assessed using the new CCSS in the school year 2014-2015.

Another approach that is currently being implemented at the college level at 20 engineering schools in the United States is ENGAGE, Engaging Students in Engineering. The goal of the project, funded by the National Science Foundation, is to increase the capacity of engineering schools to "retain undergraduate students by facilitating the implementation of three research-based strategies, one of which is to improve students' spatial skills" (Metz et al., 2012).

The program enhances the environment for the engineering students who possess weaker spatial skills to gain additional training (Metz et al., 2012).

Finally, the initiative STEM career-fields of education is an acronym for the disciplines of teaching and learning in science, technology, engineering, and mathematics. At a recent Women's History Month Observance, Dr. Rebecca Blank, Secretary of Commerce, spoke in reference to engaging more females toward the STEM careers. She stated that "closing the gender gap in STEM degrees will boost the number of Americans in STEM jobs, and that will enhance U. S. innovation while sharpening our global competitiveness" (Blank, 2013, p. 1).

Summary

The practical importance of spatial visualization is reflected in real life. Words are only one way of symbolizing ideas. Numbers, pictures, graphs, maps, diagrams, photographs, and other means are also used to convey information. Spatial literacy is embedded in nearly every discipline in the school curriculum, including mathematics, social studies, geography, science, and the arts. Competence in spatial skills with spatial symbols is essential for careers in engineering, mathematics, science, graphic design and other arts and many trades and professions, from carpentry to biomedical engineering, and of course, STEM careers. Many practical experiences involve problem-solving situations that require knowledge of geometric concepts such as determining the amount of wallpaper, paint, grass, or fertilizer to buy and other work situations.

By promoting spatial understanding early in life, adults give children an important foundation for the future. While the spatial visualization focus may seem trivial to some, there are serious implications for a wide range of economic factors. The tracking of high school mathematics has been identified as a "critical filter" to higher pay and prestigious occupations and should be of particular interest for all educators to take notice of individual teaching practices that may be biased or place undue stereotypical mindsets in regards to their students, thus hindering personal expectations related to the mathematics self-concept of each learner.

The literature provides a strong basis for understanding that spatial ability is a combination of biological factors such as gender and socio-cultural factors that influence the development of spatial ability in both males and females. Providing young children with geometric instruction and activity in order to enhance spatial skills seems imperative after considering the research. Although the studies have generated controversy, there seems to be a lack of focused research on the elementary student. The bulk of the research has centered on high school students, college students, or older adults. It is imperative to understand the relevance of improving spatial abilities at the elementary level, which in turn will promote the ability for young learners to reason, predict, and represent knowledge in appropriate ways. This research could provide a basis for additional studies to be conducted among elementary students in order to make equitable opportunities available for both male and female learners for continued future success.

CHAPTER THREE: METHODS

Overview

Chapter Three contains the methodology used to conduct this study. It includes an explanation of the study design, the participants and setting, the instrumentation, and data collection and data analysis procedures.

Problem and Purpose of the Study

This study began by examining early development of spatial skills and awareness, gender differences, the improvement of spatial skills, and the effects of spatial visualization on mathematics achievement. According to the curriculum standards of the National Council of Teachers of Mathematics, spatial sense is “an intuitive feel for one’s surroundings and objects in them” (NCTM, 1989, p. 49). These abilities must be nurtured through geometric activities. Wetzel (2009) stated that mathematics is a complex process requiring visual and cognitive perception abilities, comprehension ability, and adequate prior knowledge.

Spatial literacy is embedded in nearly every discipline in the school curriculum. Research from several studies indicates a strong correlation between spatial ability and problem-solving performance (Bayrak, 2008; Boakes, 2009; Rafi et al., 2008). Research also indicates that if students are able to visualize, they have a much greater chance for success in mathematics. Van Garderen (2002) compared visual imaging and problem solving by students of varying abilities. Van Garderen investigated sixth-grade students’ use of visual imagery while solving mathematical word problems. The results indicated that gifted students used significantly more visual images compared to the average-achieving students and students with learning disabilities.

Spatial visualization has been shown to be related to mathematics performance (Fennema & Sherman, 1977, 1978). Neglecting instruction in spatial competence could discriminate against the less spatially minded student, erecting a barrier that may later hinder success in future math proficiency (Rosser, 1980).

Another aspect of the spatial visualization issue is gender differences (Robinson & Lubienski, 2011). The literature provides a strong basis for understanding that spatial ability is a combination of biological factors such as gender and socio-cultural factors that influence the development of spatial ability in both males and females. The purpose of this study was to examine gender differences across three types of spatial ability; namely, spatial perception, mental rotation, and spatial visualization among students in second through eighth grades and in noticing observable discrepancies, determine when this difference occurs between girls and boys. Understanding at what level or point in time a significant difference is manifested should provide valuable feedback in assisting young learners for academic success.

Design

Rationale

This quantitative study utilized a causal-comparative research design involving group comparisons. In this design, researchers collect data about variables that they have conceptualized to be in a causal relationship to each other, but there is no intervention as in experimental research nor is there random assignment of participants (Gall et al., 2007). The design compares the mean scores of two groups on a particular measure and is useful for exploring causal relationships, even though the particular design cannot confirm results to the degree that experimental research can (Gall et al., 2007, p. 242). In group comparison and correlational research designs, the independent variable is not manipulated as opposed to experimental research designs where an intervention such as a teaching technique or an educational program is the independent variable.

Questions regarding gender differences in relation to cognitive learning are significant in the academic world so that curriculum planning can be done most effectively. The author assumes that this research will provide insight to questions concerning gender differences in learning which will impact future teacher expectations, school district personnel, and colleges of education, ultimately affecting future aspirations for females, in particular. One advantage in using this type of design for this particular setting for controlling threats to external validity is that natural environments do not undergo the same problems of artificiality or inauthenticity as compared to well-controlled laboratory settings (Shadish, Cook, & Campbell, 2002).

Design Elements

The independent variable was gender, the sex categories of male and female students. The dependent variable was the outcome of the spatial visualization test scores whereby group differences will be examined. A causal-comparative approach lacks randomization and manipulation of independent variables.

Gall et al. (2007) explained group comparison research as seeking to understand cause-and-effect relationships based on the premise that the effect has already occurred while looking to the past to determine what caused it; the focus is on the explanation of observing why it has occurred. This research compared the group differences that differed on the independent variable, namely, gender differences to determine whether they also differed on the dependent variable, the scores from the spatial visualization tests.

Research Questions and Null Hypotheses

Grade Levels Two and Three

RQ1: Is there a difference in the mean scores of spatial visualization tests between male and female students in second and third grades in the area of geometric spatial visualization?

$H_0$1: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Manikin test.

$H_0$2: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$3: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$4: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mental Rotation test.

Grade Levels Four and Five

RQ2: Is there a difference in the mean scores of spatial visualization tests between male and female students in fourth and fifth grades in the area of geometric spatial visualization?

$H_0$5: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Manikin test.

$H_0$6: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$7: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$8: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mental Rotation test.

Grade Levels Six and Eight

RQ3: Is there a difference in the mean scores of spatial visualization tests between male and female students in sixth through eighth grades in the area of geometric spatial visualization?

$H_0$9: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Manikin test.

$H_0$10: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$11: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$12: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mental Rotation test.

Grades Two Through Eight Considered at Once

RQ4: How do gender and age of students in the second through eighth grades impact geometric spatial visualization?

$H_0$13: There will be no significant difference between the mean scores of male and female students in second through eighth grades in the area of spatial visualization assessments.

Participants and Setting

The participants in this study included 325 students in second through eighth grades at one public school and one public charter school, all located in the same district. In causal-comparative research, there should be at least 15 participants in each group for comparison, according to Gall et al. (2007, p. 176). The schools were located in a rural county with a population of 23,699 individuals with a median household income of $35,585, and 24.9% of persons below the poverty level at 24.9% (U.S. Census Bureau, 2013). One of the schools was designated as Title I school, while the second school was not categorized with Title I distinction. The status of Title I indicates whether a school qualifies as part of the federal program that provides funding for learning institutions with a high poverty rate in order to assist students. The federal program No Child Left Behind (NCLB) was enacted by the United States Congress on January 3, 2001 and signed into law in 2002 by President George W. Bush to which its purpose was to "close the achievement gap with accountability, flexibility, and choice, so that no child is left behind" (PCESE, 2002, p. 1). Title I is an arm of the NCLB law. This status is determined by the number of students who qualify for free and reduced lunches. The school's poverty level must be at least 40% in order to be designated as schoolwide distinction whereby the entire school can participate in a specified program to create a method of delivering Title I services in schools that are eligible. This process allows schools to "address the educational needs of children living in impoverished communities with comprehensive strategies for improving the entire school so every student achieves high levels of academic proficiency" (PCESE, 2002, p. 2).

School One

The first school of the research sites included kindergarten through fifth grades with a total school population of 229 students. With the Title I status, 62.01% of the students receive free and reduced lunches. There were a total of 17 fully-licensed classroom teachers; 24% of teachers had advanced degrees and one had National Board Certification, and the school had a teacher turnover rate of 6%. Access to technology is positive with 100% connected to the Internet (NCDPI, 2012). The student population grouped by ethnicity included 82 White (40.2%), 34 Black (17.6%), and 7 Hispanic (14.3%) students. North Carolina End of Grade Test results for the percentage of students' scores at or above grade level for the 2012-2013 school year showed overall scores for reading at 44.8% and mathematics at 45.6% (NCDPI, 2013) (see Table 4).

School Two

The second research site was a public charter school, grades 6-12, one out of 126 initiated by the state of North Carolina, comprising a school population of 246 students, 130 performing on the North Carolina End of Grade Tests, 60 male and 70 female students. At the time of the research study, there was a sixth through eighth grade configuration. These public charter schools have open enrollment with no religious associations, no discrimination, and no tuition. Unlike the previous school, this school does not bear Title I status with only eight students (3.0%) receiving free and reduced lunch. There was a total of 31 classroom teachers with 77% fully licensed and 83% highly qualified. The percentage of teachers with emergency/provisional licenses was 3%, and the percentage of teachers who entered teaching via lateral entry was 3%. Due to the fact that this school was granted a charter by the state of North Carolina in 2011 and opened in 2012, there were no records for teacher turnover rate as of this writing. Students have access to technology with 100% Internet connection. Ethnicity of the student population for grades six through eight lacks diversity, comprised of 124 White (95.3%) and six Black (4.6%) students, with no other ethnic populations represented. North Carolina End of Grade Test results for the percentage of students' scores at or above grade level for the 2012-2013 school year showed overall scores for reading at 46.9%, and mathematics at 34.6% (NCDPI, 2013) (see Table 4).

Table 4

Research Sites: Demographic Information

	Males	Females	Caucasian	Black	Hispanic	Multi-Racial	Native American	Free & Reduced Lunch
School 1	53.7%	46.2%	64.0%	29.0%	6.0%	0.9%	0.4%	20.3%
School 2	46%	54%	95%	5%	.0%	.0%	.0%	3.0%

Instrumentation

Spatial ability was measured by four categories of spatial relations tests based upon spatial cognition research proposing that spatial cognition is comprised of "three separable dimensions" (Voyer et al., 1995). The areas included (a) spatial perception, (b) spatial visualization, and (c) mental rotation, and spatial working memory was the fourth task incorporated in the activities.

Spatial perception performance necessitates “making judgments of horizontal and vertical orientation in space despite distracting background information” (Halpern, 1986; Voyer et al., 1995). Spatial visualization is the ability to manipulate or transform the image of spatial patterns into other arrangements (Ekstrom et al., 1976). Finally, mental rotation is the rotation of an object or an array of objects which involves imagining or visualizing movement relative to an object-based frame of reference, specifying the location of one object (or its parts) with respect to other objects (Kozhevnikov & Hegarty, 2001). The fourth task of focusing on spatial working memory is integrated in the sequence of assessments for the reason that this element has been presented as a significant aspect of spatial performance (Shah & Miyake, 1996).

The following assessments were accessed through Millisecond-Inquisit Custom Scripts: Manikin Test (spatial orientation and transformation) (Englund et al., 1987), Mental Folding Test for Children (spatial visualization) (Harris et al., 2013), Mr. Peanut Test (visuo-spatial working memory) (De Ribaupierre & Bailleux, 1995; Morra, 1994), and Mental Rotation Test for Children (Wiedenbauer & Jansen-Osmann, 2008). The resultant scores were used as measures of mathematical achievement and cognitive ability. All script tasks were authored by Dr. Katja Borchert for Millisecond Software, LLC based on the publications of the previous mentioned researchers.

The assessments were discovered initially through the website of The National Science Foundation Science of Learning Center (Spatial Intelligence & Learning Center, 2017). The researcher contracted Inquisit/Millisecond company to utilize the selected four spatial visualization tests with minor variation changes in the configuration for the project’s purposes. Participants accessed the battery of tests or scripts remotely from their school computers/laptops via the website in controlled settings with the homeroom teacher acting as the facilitator. The

Inquisit/Millisecond website automatically assigned the participant a student-code for the researcher to match specific data according to grade level and gender. Each test produced summary data in ready-to-analyze format that could be easily imported into Excel and then Statistical Package for the Social Sciences (SPSS) for inferential statistics. The site maintains security firewalls at the source and input locations. Millisecond issues a session "cookie" only to record encrypted authentication information for the duration of a specific session. The session "cookie" did not include either the username or password of the user. The program's accessibility provided immediate feedback for the researcher, was dynamic in nature, and enjoyable for its participants as opposed to the traditional paper and pencil method of assessment. As an additional feature of the website, participants could access selected demonstration tests at their leisure or in the classroom to practice various spatial visualization skills.

Manikin Test

First, the Manikin Test (Englund et al., 1987) measured spatial orientation and spatial transformation. The proportions, or the "general outline and location of major features are taken from Leonardo da Vinci's *Canon of Proportions*" (p. 63). The student participants viewed the manikins superimposed on either a green circle or a red square. The manikin holds a red square in one hand or a green circle in the other. The manikin can be right side up or upside down and face towards or away from the participant (see Figure 1). Since the test was timed, students must decide as fast as possible if the manikin holds the shape that is congruent with the background in the left or right hand and press the corresponding keys on the computer keyboard (V for left and M for right). Students were given a practice block of 16 trials with performance accuracy feedback. The actual test block ran four blocks of 16 trials with no performance feedback. The manikins showed facial features, buttons, pockets, and belt buckle when forward (facing towards the participant). Similarly, back pockets, no buttons, and no belt buckles were shown when backwards (facing away from the participant). Reliability and validity is .79 “while maintaining a certain amount of face validity” (Carter & Woldstad, 1985, p. 397).

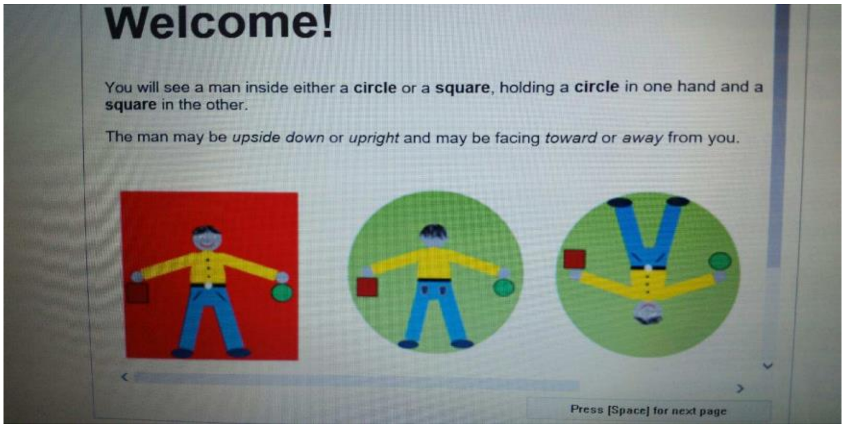

Figure 1. Manikin Test. (Draine, 2017)

Mental Paper-Folding Test

Second, spatial visualization skills of transformation were measured by the Mental Folding Test, an adaptation of the Differential Aptitude Test: Space Relations (DAT: SR) paper folding test (Bennett et al., 1973). This classic instrument has been used in research on spatial ability and is almost always mentioned in meta-analysis studies where visualization and rotation are both considered important to determine the capacity to think in spatial terms. Hyde (2014) and Newcombe (2013) noted that certain types of training and prior experience reduce or eliminate gender differences in spatial ability. Among 180 four- to eight-year-olds, Harris et al. (2013) developed and validated two age-appropriate tests of spatial ability (i.e., mental rotation and paper folding). They found that mental folding skills developed around five and a half years of age and that performance differed by ability but not by gender.

Students were asked to mentally fold paper following specific markings and then selected from among four options the one that represented the outcome of the mental folding (see Figure 2). This multiple-choice test required children to mentally fold 2D shapes. The shapes were different colors on each side to help children distinguish front from back. The paper was a fixed object . It remained static; the student only visualized the folding of the "paper." Researchers used an *f* partial credit model for calculating reliability. Internal reliability was found to be sufficiently high for research purposes, α = 0.73 (Harris et al., 2013, p. 53). To test the consistency of the validity, a second study was conducted six months after the first study. The correlation between Test 1 (T1) and Test 2 (T2) was significant, $r = 0.66$, $p > .01$ (p. 53).

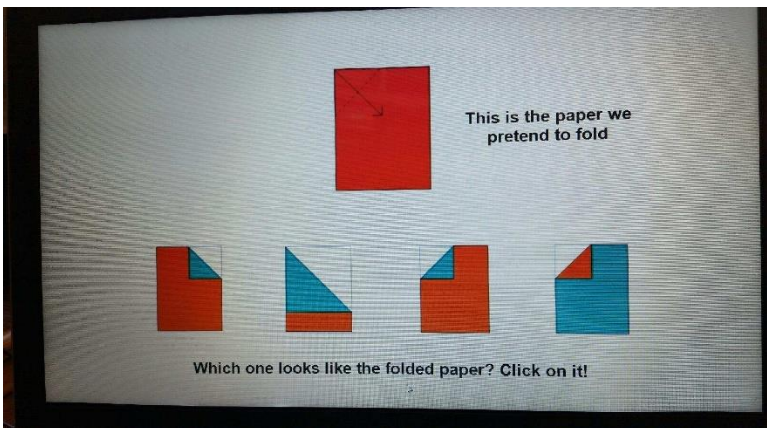

Figure 2. Mental Paper-Folding Test. (Draine, 2017)

Mr. Peanut Test

The Mr. Peanut test (De Ribaupierre & Bailleux, 1995; Morra, 1994) was integrated in the sequence of assessments since the element of spatial working memory has been presented as a significant aspect of spatial performance (Shah & Miyake, 1996). This task assessed visuo-spatial memory of colored information and location in children. The participants viewed a clown figure, Mr. Peanut, who decorated himself with colorful stickers for a specific amount of time (see Figure 3). Then he disappeared and reappeared without stickers. Students then had to select a colored sticker and click on the locations of the particular stickers based on their recall memory. A practice task was given with performance feedback. In the actual test, participants had three trials per level. Upon mastering each level with at least one correct attempt per level, students moved up a level. The test concluded if all three attempts per level fail. This task was not timed. Test-retest reliability for Mr. Peanut test is *r* =.70 (De Ribaupierre & Bailleux, 1995, p. 63).

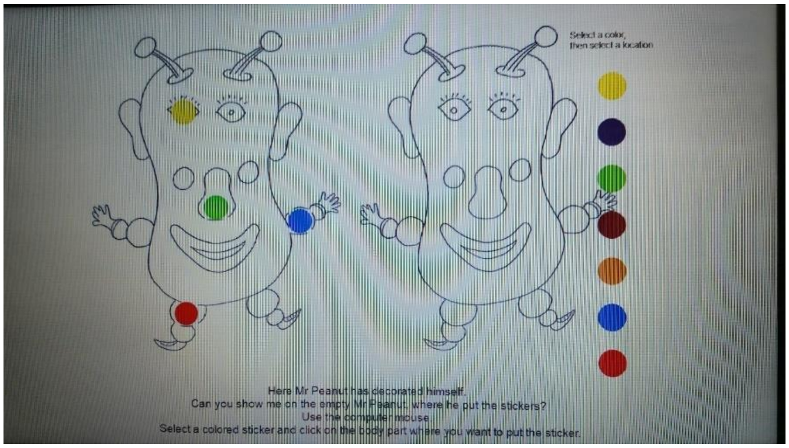

Figure 3. Mr. Peanut Test. (Draine, 2017)

Mental Rotation Test

The Mental Rotation Test was an adaptation of the Mental Rotations Test (MRT) (Vandenberg & Kuse, 1978). No working memory load was used by the student. This test also correlated with The Purdue Spatial Visualization Test-Rotations (PSVT-R) developed by Guay (1976). In a previous research study at Michigan Technological University, a student's score on the PSVT: R was determined to be the most significant predictor of success in an engineering graphics course where eleven variables were tested (Sorby, 2009).

In this set of exercises, students must choose as quickly as possible whether an object composed of 10 blocks/cubes configured in different shapes would look the same as another when rotated in five-degree steps of rotation in a three-dimensional space from 0 to 360 degrees.

Peters & Battista (2008) created applications of the mental rotations figures based on the Purdue Spatial Visualization Test (PSVT-R). However, after requesting to use the spatial rotation assessments with permission from Dr. Michael Peters, University Professor Emeritus, Neuroscience and Applied Cognitive Sciences at University of Guelph, Canada, he kindly suggested that using the specific mental rotation test was not suitable for children 10 years old and younger (M. Peters, personal communication, January 29, 2014).

In lieu of the Mental Rotating Blocks test, a more appropriate mental rotation test for children was located at the Millisecond/Inquist website based on the work of Wiedenbauer & Jansen-Osmann (2008). Participants were presented two pictures of the same animal for each trial with six different animals and two presentations: one with the same comparison animal and the other with the mirror comparison animal (see Figure 4). The activity resulted in 96 trials with eight rotation angles: 22.5 degrees, 67.5 degrees, 112.5 degrees, and 157.5 degrees. The test began with practice trials which provided positive and negative feedback given by smiley or frowny faces. Stimuli included animals such as bird, elephant, fox, alligator, cow, leopard, donkey, bear, tiger, monkey, cat, mouse, sheep, etc. The stimuli were animals from the Snodgrass and Vanderwart "Like Objects" introduced by Rossion & Pourtois (2004). Test-retest reliability was 0.71 (Wiedenbauer & Jansen-Osmann, 2008).

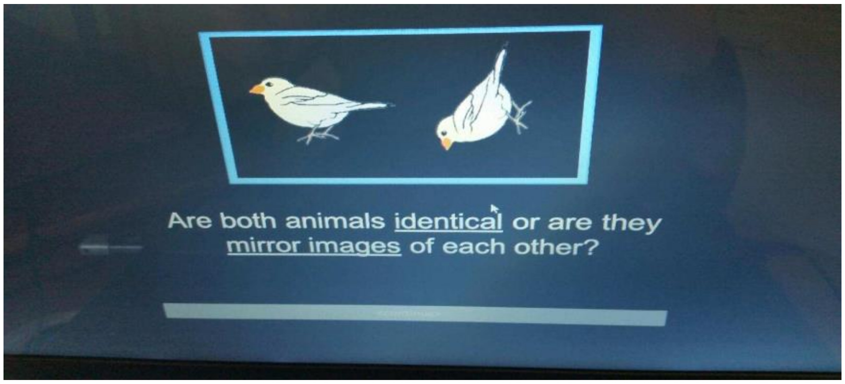

Figure 4. Mental Rotation Test for Children (Draine, 2017)

In summary, all spatial visualization test-scripts were accessed via Millisecond, Makers of Inquisit. The site “offers an extensive library of psychological testing paradigms for measuring and manipulating a broad range of psychological constructs” (Draine, 2017, Millisecond Home webpage). According to the company website, Millisecond Software, LLC was founded in 1999 by Sean Draine, Ph.D. and is located in Seattle, Washington. Inquisit Web and Lab products have been used to collect psychological data in an “extensive and diverse body of peer reviewed research,” as well as in applied research domains such as marketing, usability, and clinical trials (Draine, 2017, Millisecond Information webpage). A site license was purchased, and the tests and data were hosted on the Millisecond server until the license expires. The duration of time allotted for the complete battery of spatial activity tasks was approximately 35-40 minutes.

Procedures

After securing Institutional Review Board (IRB) approval for proceeding with the project, parental approval was secured through permission letter/packets prior to the research. To facilitate the process for the homeroom teacher, all permission letters were inserted in a manila envelope. A master copy roster sheet was attached to a manila envelope for the teacher to verify and include the date when the student was given the packet and when the packet was returned. All materials for each class were stored in a plastic container to assist the teacher in easy retrieval and storage. A two-week time period was given for the return of the permission packets upon which the researcher returned to the research sites to retrieve all of the plastic tubs containing the packets. Students were given the opportunity to choose a prize if the permission packet was returned to their teacher. Next, the researcher confirmed the number of positive responses to participate in the research and created new rosters for each homeroom teacher to facilitate the process of determining the number of students in addition to the identification of each student. At Research Site One, 189 permission packets were distributed. The packets returned included 121 positive responses to participate. At Research Site Two, 146 permission packets were distributed with 95 returned packets with consent to participate. In summary, 335 permission packets were distributed resulting in 216 returned packets giving authorization to participate in the research project. Of the total 216 participants, 106 were male and 110 were female. However, when the actual testing occurred, the number of participants fell to 188 students.

Table 5 outlines each site's demographics of male and female participants per grade level, and the total number of research participants.

Table 5

Demographics of Research Site Participants

Research Site	Males	Females	Total
School 1			
Grade 2	2	11	13
Grade 3	9	28	37
Grade Span 2-3	11	39	50
Grade 4	21	7	28
Grade 5	15	7	22
Grade Span 4-5	36	14	50
School 2			
Grades 6	12	25	37
Grades 7	12	12	24
Grades 8	15	12	27
Grade Span 6-8	39	49	88
Total Participants	86	102	188

Prior to the administration of testing, the researcher verified with each school's technology team that the weblink address for the specific *Inquisit* spatial visualization scripts/tests were installed and bookmarked for easy access on each of the computers that were utilized for the project. Once parental approval was granted, the researcher conferred with the designated teachers in a brief meeting preceding the actual administration of the assessments. A document of testing protocol and instructions, created by the researcher, was furnished for each testing administrator in order to inform his/her group of students of the assessment procedure. This process ensured the validity and fidelity of providing uniform conditions for each testing environment (Schulte, Easton, & Parker, 2009).

The Spatial Visualization Tests/Scripts were made available to participants via the classroom teacher during the designated time for computer lab. The researcher and her committee had sole access to the documents of personally identifiable material. The tests were administered in the standardized manner. Time-to-complete tasks and measures of accuracy were then assessed.

Data Analysis

Data were analyzed using the SPSS version 23.0 for Windows. To describe the sample demographics and research variables, descriptive statistics were applied. Frequencies and percentages were calculated for categorical or nominal data. For interval and/or ratio data, means and standard deviations were calculated (Howell, 2011).

First, the statistical technique of Multivariate Analysis of Variance (MANOVA) was conducted for the null hypotheses to determine whether the groups differed on more than one dependent variable (Gall et al., 2007). The MANOVA is "similar to the *t*-test and to analysis of variance (ANOVA) in that the *t* test and ANOVA can determine only whether several groups differ on one dependent variable" (Gall et al., 2007, p. 319). The MANOVA demonstrates more power than univariate ANOVA, and it has several advantages over ANOVA. First, by

> measuring several dependent variables in a single experiment, there is a better chance of discovering which factor is truly important. Second, it can protect against Type I errors that might occur if multiple ANOVA's were conducted independently. Additionally, it can reveal differences not discovered by ANOVA tests. (French, Macedo, Poulsen, Waterson, & Yu, 2017, p. 3).

The mean of the vector scores, a single mathematical expression representing the individual's scores on all the dependent variables (p. 319) in a given group, is called a centroid (Gall et al., 2007, p. 319). The purpose of the MANOVA is to "determine whether there are statistically significant differences between the centroids of different groups" (Gall et al, 2007, p. 319). A MANOVA was used to decrease the chance of a type I error. Howell (2011) stated that one of the major problems with "making comparisons among groups is that unrestricted use of these comparisons can lead to an excessively high probability of a Type I error, the error of rejecting a null hypothesis when it is true" (p. 174).

However, in choosing to analyze the data using a one-way MANOVA, several factors must be considered. The process involves checking that the data can actually be analyzed using the one-way MANOVA for outcomes of valid results to verify if the data "passes" several assumptions (Laerd Statistics, 2017). Several of the assumptions may be checked without SPSS statistics such as (1) having two or more dependent variables measured at the interval or ratio level, (2) the independent variable involves two or more categorical, independent groups, (3) there should be an independence of observations or no relationship between the observations in each group or between groups, and (4) there should be an adequate sample size (Laerd Statistics, 2017). Assumptions 1, 2, and 3 were met. Assumption 4 was also met by an adequate sample size of participants after relevant calculations. The researcher used the Stephen Olejnik chart for estimating sample size in conducting the one-way MANOVA (Gall et al., 2007). To determine sample size with three groups (grades two and three, four and five, and six through eight) with approximately 42-54 participants in each group and a total of 188 participants would yield a medium effect size of 0.70 statistical power. Additionally, there should be no univariate or multivariate outliers.

After accounting for the first assumptions previously mentioned, the first step must include testing the assumption of the equality of group dispersions (Gall et al., 2007). Next, the difference between group centroids must be tested for statistical significance. The most common test used for this purpose is Wilk's lambda (Λ), which yields an *F* value and may be compared to an *F* ratio table for determining the level of statistical significance (Gall et al., 2007, p. 321). An analysis of variance (ANOVA) may be run on each dependent variable if a significant MANOVA *F* is obtained (Gall et al., 2007, p. 321). Another assumption includes testing for a homogeneity of variance-covariance matrices using Box's M test of equality of covariance. Finally, the last assumption should test for no multicollinearity where the dependent variables should be moderately correlated with each other (Laerd Statistics, 2017).

Effect sizes were calculated by the researcher for all tests using the statistical data. This information gives the importance of the identified results of the statistical tests which in turn implies practical significance (Howell, 2011). Howell stated that effect size is the "difference between two populations divided by the standard deviation of either population which is sometimes presented in raw score units (p. 318). Cohen's (1988) grouping conventions included small effect = .2, medium effect = .5, and large effect = .8. Cohen's *d*-family effect sizes are based on “differences between means” (Howell, 2011, p. 436). For the MANOVA tests, the researcher used Eta squared (η^2), the r-family measures related to the size of an effect that resemble the correlation between the dependent and the independent variable (Howell, 2011, p. 436). These effect sizes are as follows: small = .01, medium = .06, and large = .138.

CHAPTER FOUR: RESULTS

Overview

Chapter Four contains the results of the statistical analysis of the comparison of the study data. Data were captured from two study sites and aggregated so that the mean scores of spatial visualization tests between male and female students in grades two through eight could be analyzed. Results suggested that mostly non-significant differences exist for spatial visualization abilities between males and females. The sole example of a significant difference between male and females was noted on the Mr. Peanut test in the fourth and fifth grades, accompanied with a partial Eta Squared (η^2) = .10, reflecting a medium effect size. Conversely, a significant difference was noted with MANOVA and ANOVA analysis of the impact of grade levels. Students in the seventh grade scored significantly higher on the Mr. Peanut spatial visualization test with a partial eta squared value of .103, suggesting a small to medium effect size.

The purpose of this causal-comparative study was to examine gender differences across three types of spatial ability, namely, spatial perception, spatial visualization, and mental rotation involving group comparisons among three particular grade spans: grades two and three, four and five and six through eight. In addition, another purpose of the project was determining or identifying the precise level that the gender differences may occur. A causal-comparative design was appropriate because of the necessity to make observations involving group comparisons. In this design, researchers collect data about variables that they have conceptualized to be in a causal relationship to each other, but there is no intervention as in experimental research nor is there random assignment of participants (Gall et al., 2007).

Research Questions and Null Hypotheses

RQ1: Is there a difference in the mean scores of spatial visualization tests between male and female students in second and third grades in the area of geometric spatial visualization?

$H_0$1: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Manikin test.

$H_0$2: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$3: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$4: There will be no statistically significant difference between the mean scores of male and female students in second and third grades in the area of spatial visualization as measured by the Mental Rotation test.

RQ2: Is there a difference in the mean scores of spatial visualization tests between male and female students in fourth and fifth grades in the area of geometric spatial visualization?

$H_0$5: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Manikin test.

$H_0$6: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$7: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$8: There will be no statistically significant difference between the mean scores of male and female students in fourth and fifth grades in the area of spatial visualization as measured by the Mental Rotation test.

RQ3: Is there a difference in the mean scores of spatial visualization tests between male and female students in sixth through eighth grades in the area of geometric spatial visualization?

$H_0$9: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Manikin test.

$H_0$10: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mental Paper folding test.

$H_0$11: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mr. Peanut test.

$H_0$12: There will be no statistically significant difference between the mean scores of male and female students in sixth through eighth grades in the area of spatial visualization as measured by the Mental Rotation test.

RQ4: How do gender and age of students in the second through eighth grades impact geometric spatial visualization?

$H_0$13: There will be no significant difference between the mean scores of male and female students in second through eighth grades in the area of spatial visualization assessments.

Results

A MANOVA was used to test the null hypotheses that combines $H_0$1- $H_0$12 and determine the impact gender has on spatial relation skills in grades two through eight. To assess $H_0$13, a multivariate analysis of variance (MANOVA) and three analyses of variances (ANOVA) were conducted to compare all male and female students' scores grouped by the effect of grade level on the spatial visualization tests to determine whether groups differ on more than one dependent variable (Gall et al., 2007). However, prior to conducting the MANOVA, an analysis was performed to check the dependent variables for normality. A Shapiro-Wilk's test ($p > .05$) (Shapiro & Wilk, 1965) and a visual inspection of the histograms showed that the spatial visualization test scores were approximately normally distributed for both males and females, with a skewness of .425, -.177, -.886, 1.34, and a kurtosis of .034, .542, .900, 1.21. Skewness and Kurtosis should be located in the span of -1.96 to +1.96 (see Figures 7, 8, 9, 10). These values fall within this range (Cramer, 1998).

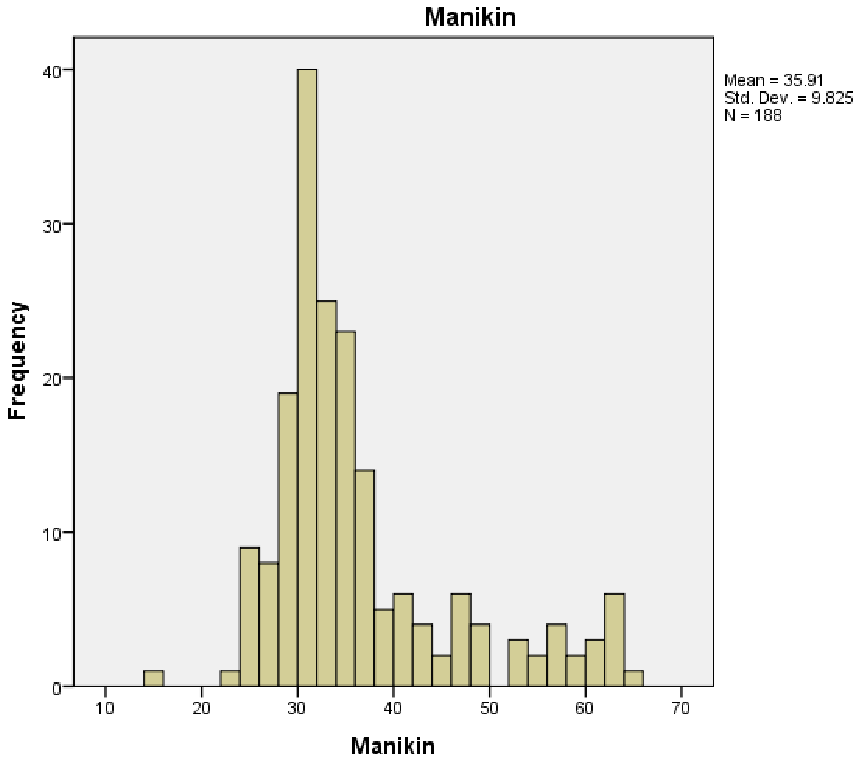

Figure 5. Manikin Spatial Visualization Test.

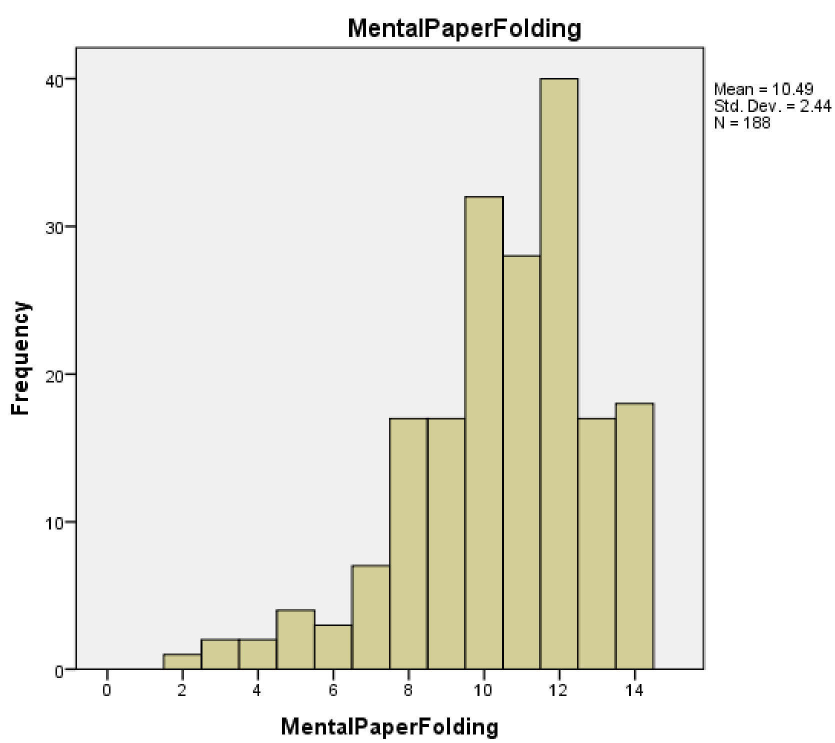

Figure 6. Mental Paper-Folding Spatial Visualization Test.

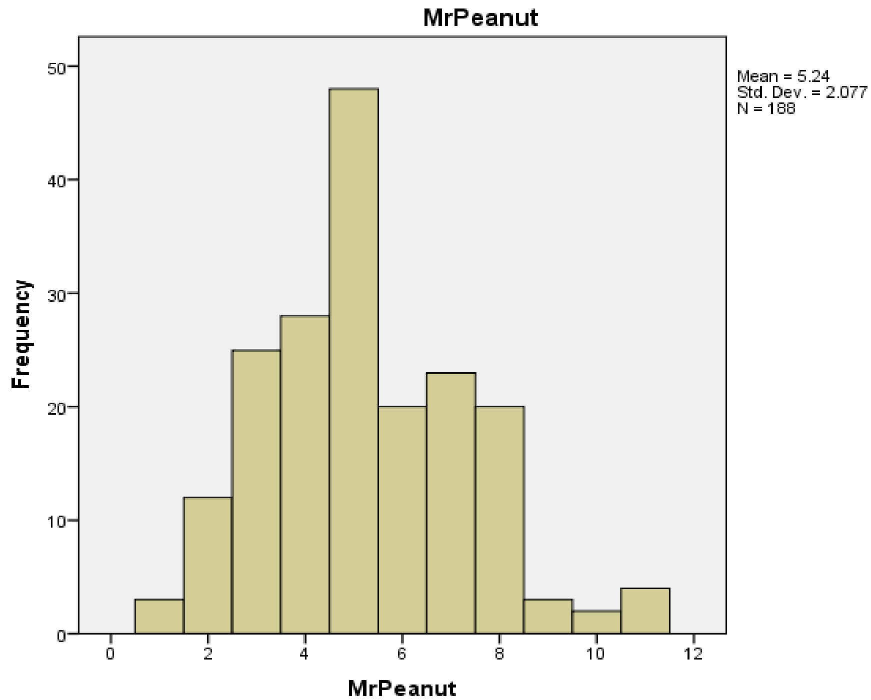

Figure 7. Mr. Peanut Spatial Visualization Test.

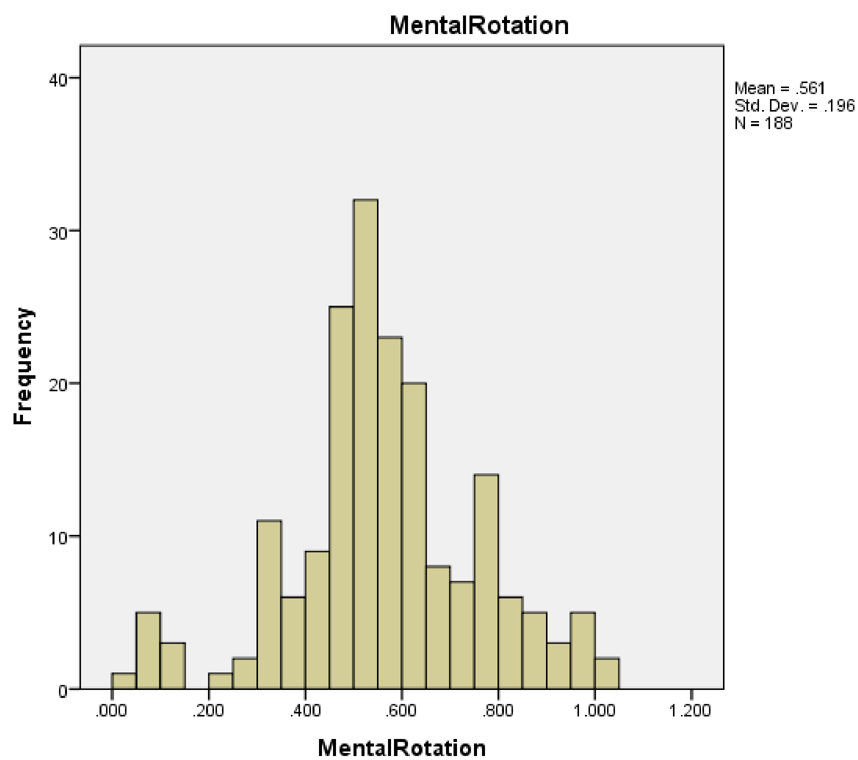

Figure 8. Mental Rotations Spatial Visualization Test.

Next, a series of Pearson correlations were conducted between all of the dependent variables in order to test the MANOVA assumption that the dependent variables were correlated with each other (Meyers, Gampst, & Guarino, 2006). An appropriate pattern can be observed between the dependent variables, suggesting the suitability of a MANOVA (see Table 6). There was a significant positive relationship between grade level and the scores of Manikin spatial visualization tests, $r(185) = .182$, $p = .01$. There was a significant positive relationship between grade level and the scores of Mental Paper Folding spatial visualization tests, $r(185) = .209$, $p =$ 004. There was a significant positive relationship between grade level and the scores of Mr. Peanut spatial visualization tests, $r(185) = .139$, $p = .06$. There was a significant positive relationship between grade level and the scores of Mental Rotation spatial visualization tests, $r(185) = .103$, $p = .16$. In addition, the Box's M test value of .145 was significant with a $p > .05$ (Szapkiw, 2011). Thus, the covariance matrices between the groups were assumed to be equal for the purposes of the MANOVA.

Table 6

Correlations Among Variables: Grade Level and Spatial Visualization Tests

	1	2	3	4	5
1. Grade Level	_	.182*	.209**	.139	.103
2. Manikin	.182*	_	.052	.182*	.122
3. Mental Paper F.	.209**	.052	_	.006	-.024**
4. Mr. Peanut	.139	.182*	.006	_	.033
5. Mental Rotation	.103	.122	-.024.	.033	_

Notes. **$p < .01$ (2-tailed), *$p < .05$ (2-tailed)

A one-way multivariate analysis of variance (MANOVA) test was conducted to compare all dependent variables, the male and female students' scores of the spatial visualization assessment tests, with grade level. There was a statistically significant difference between grade level when considered together on the variables of spatial visualization tests (Manikin, Mental Paper-Folding, Mr. Peanut, and Mental Rotation), F (24, 622) = 2.19, $p < .001$; Wilk's $\Lambda = .754$, partial Eta Squared (η^2) = .068. The observed power was .99. The one-way MANOVA is an omnibus test statistic and cannot tell which specific groups are significantly different from each other (Laerd Statistics, 2017). Determining which of the groups differ from each other is necessary and important; therefore, a post-hoc test was conducted. Where the MANOVA observed the dependent variables simultaneously, the ANOVA at the univariate level observes each dependent variable separately.

A separate ANOVA was conducted for each dependent variable with each ANOVA evaluated at an alpha level of .025. To account for the familywise error rate of the probability that a family of comparison contains at least one Type I error, the Bonferroni procedure was applied (Howell, 2011, p. 431). Howell stated that this "multiple comparisons procedure is conducted in which the familywise error rate is divided by the number of comparisons (p. 433). Therefore, the alpha level was adjusted to .025. The assumption of homogeneity of variances was tested and satisfied for Mr. Peanut via Levene's Equality of Variances, F (181) = .1.67, p = .13; Mental Paper-Folding, F (181) = .90, p = .50; Mental Rotation, F (181) = .60, p = 73. Therefore, the assumption level was not violated. However, the assumption of homogeneity of variances for Manikin was not equal across groups, F (181) = 2.70, p = .020. The significance level was p = .02 < the alpha .05 (see Table 7).

Table 7

Levene's Test of Equality of Variances by Grade Level

	F	*df*	*p*
Manikin	2.70	181	.020
Mental Paper-Folding	.90	90	.50
Mr. Peanut	1.67	181	.13
Mental Rotation	.60	90	.73

There was a statistically significant difference between the Mr. Peanut spatial visualization test and grade level, F (6, 181) = 3.50, p = .003, partial Eta squared (η^2) = .10, with seventh Grade (M = 6.04) scoring higher than fourth grade (M = 3.96). There was not a statistically significant difference between grade level on Manikin spatial visualization test and grade level, F (6, 181) = 2.07, p = .06, partial Eta squared (η^2) = .06. There was not a statistically significant difference between grade level on Mental Paper Folding spatial visualization test and grade level, F (6, 181) = 2.40, p = .03, partial Eta squared (η^2) = .07. There was not a statistically significant difference between grade level on the Mental Rotation spatial visualization test and grade level, F(6, 181) = 1.50, p = .11, partial Eta squared (η^2) = .05 (see Table 8).

Table 8

ANOVA Results for Spatial Visualization Tests Compared to Grade Spans

Variable	*F*	*df*	*p*	Partial Eta^2	Observed Power
Manikin	2.07	6	.060	.064	.74
Mental Paper Folding	2.40	6	.031	.073	.81
Mr. Peanut	3.50	6	.003*	.103	.94
Mental Rotation	1.50	6	.107	.048	.57

Note. * $p < .02$.

In conclusion, the *p* level of spatial visualization test Manikin was not statistically significant, $p = .06$, the *p* level of spatial visualization test Mental Paper-Folding was not statistically significant, $p = .03$, and the *p* level of the spatial visualization test Mental Rotation was not statistically significant, $p = .107$. The difference between male and female spatial relations skills noted from the Mr. Peanut spatial visualization test was significant, $p = .003$.

Summary

In summary, Chapter Four delineated the research questions and null hypotheses and provided a thorough report of the statistical measures coupled with analyses and outcomes of the resulting spatial visualization tests comparing male and female students' scores from each of the grade spans.

At Research Site One, 189 permission packets were distributed. The packets returned included 121 positive responses to participate. At Research Site Two, 146 permission packets were distributed with 95 returned packets with consent to participate. In summary, 335 permission packets were distributed resulting in 216 (64%) returned packets giving authorization to participate in the research project. Of the total 216 participants, 106 were male and 110 were female. However, when the actual testing occurred, the number of participants decreased to 188 students: 86 males (46%) and 102 females (54%) due to absences, family trips, or behavioral issues resulting in student dismissal. Table 4 outlines the research sites' demographics. The data were analyzed in two phases using SPSS Version 23 for Null Hypotheses One through 13 to determine if a difference existed between the mean scores of the males and females' spatial visualization assessments in grades two through eight, and at what level there was a significant difference.

Results suggested that mostly non-significant differences existed for spatial visualization abilities between males and females. The sole example of a significant difference between male and females was noted on the Mr. Peanut test in the fourth and fifth grades, partial Eta Squared (η^2) = .10, reflecting a medium effect size. Therefore, Null Hypothesis seven, H_07 was rejected. A significant difference was noted with the analysis of the impact of grade levels. Students in the seventh grade scored significantly higher on the Mr. Peanut spatial visualization test with a partial eta squared value of .103 suggesting a small to medium effect size.

Using the multivariate analysis of variance (MANOVA), an analysis was conducted for Null Hypotheses 13 that combined H_01- H_012 to determine the impact gender has on spatial relation skills in grades two through eight to determine whether groups differ on more than one dependent variable. There was a statistically significant difference between grade level when considered together on the variables of spatial visualization tests (Manikin, Mental Paper-Folding, Mr. Peanut, and Mental Rotation), F (24, 622) = 2.19, $p < .001$; Wilk's $\Lambda = .754$, partial Eta Squared (η^2) = .068.

The second analysis used a one-way analysis of variance (ANOVA) to compare the amount of between-groups variance in the spatial visualization test scores of the male and female participants with the amount of within-groups variance or a statistically significant effect on the dependent variables of the test scores. The ANOVA tests revealed the *p* level of Mr. Peanut spatial visualization test was significant ($p = .003$) at Grade four with males scoring lower than females, while the Manikin, Mental Paper-Folding, and Mental Rotation were not statistically significant. Therefore, Null Hypothesis $H_0 13$ was rejected.

CHAPTER FIVE: CONCLUSION

Overview

Chapter Five provides a summary, discussion and interpretations of the research findings, the implications of the study in terms of relevant literature, limitations of the study, and recommendations for future research.

The purpose of this study was to examine gender differences across three types of mathematical spatial ability; spatial perception, spatial visualization, and mental rotation involving group comparisons in a population of second through eighth grade students.

Results suggested the overall spatial visualization abilities of males and females were not significantly different in the second- through eighth-grade population. The sole example of a significant difference between male and females was noted on the Mr. Peanut test in the fourth and fifth grades, partial Eta Squared (η^2) = .10, reflecting a medium effect size. Conversely, seventh grade students scored highest of all grades on the Mr. Peanut spatial visualization test with a partial eta squared value of .103, suggesting a small to medium effect size.

Results of this present dissertation study revealed that males did not outperform females in mathematical spatial ability. Older students did score higher suggesting a developmental role in acquiring mathematical spatial ability.

Discussion

Summary of the Results

Four research questions were used in this study:

RQ1: Is there a difference in the mean scores of spatial visualization tests between male and female students in second and third grades in the area of geometric spatial visualization?

RQ2: Is there a difference in the mean scores of spatial visualization tests between male and female students in fourth and fifth grades in the area of geometric spatial visualization?

RQ3: Is there a difference in the mean scores of spatial visualization tests between male and female students in sixth through eighth grades in the area of geometric spatial visualization?

RQ4: How do gender and age of students in the second through eighth grades impact geometric spatial visualization?

Research Question One

Test results revealed no statistically significant differences between males and females for mathematical spatial abilities. The results suggested gender differences were not noted at this developmental stage for students in grades two and three. Based upon the results of the analysis, Null Hypotheses One, Two, and Three were not rejected.

Research Question Two

Tests revealed one sole example of a statistically significant difference between males and females for mathematical spatial abilities in grades four and five. Female students had higher scores measured by the Mr. Peanut test. Null Hypothesis Seven was rejected. Partial Eta squared revealed a medium effect size ($\eta^2 = .10$). The results of the spatial visualization tests Manikin, Mental Paper Folding, and Mental Rotation (Null Hypotheses Five, Six, and Eight) showed no statistically significant differences between the two groups of male and female participants.

Research Question Three

Tests revealed no statistically significant differences between males and females for mathematical spatial abilities in grades six through eight. The results suggested gender differences were not noted at this developmental stage. Based upon the results of the analysis, Null Hypotheses Nine, 10, 11, and 12 were not rejected.

Research Question Four

Data revealed that older seventh grade students scored highest on the Mr. Peanut spatial visualization test and younger, fourth grade students scored lowest. A separate ANOVA (analysis of variance) was conducted for each dependent variable, with each ANOVA evaluated at an alpha level of .025. To account for the familywise error rate of the probability that a family of comparison contains at least one Type I error, the Bonferroni procedure was applied (Howell, 2011, p. 431). Howell stated that this "multiple comparisons procedure is conducted in which the familywise error rate is divided by the number of comparisons" (p. 433). Therefore, the alpha level was adjusted to .025.

There was a statistically significant difference between Mr. Peanut spatial visualization test and grade level, $p = .003$, with seventh grade ($M = 6.04$) scoring highest, males performing higher than females, fourth grade scoring lowest ($M = 3.96$), and females performing higher than males. Based upon the results of the analysis of the spatial visualization test Mr. Peanut in the second analyses of the ANOVA tests, Null Hypothesis 13 was rejected because there was a statistically significant difference in the spatial visualization test scores comparing grade level and gender effects in the grade span of four to five.

Discussion

Relationship to Empirical and Theoretical Literature

The use of visual imagery or visualization has often been suggested as a powerful and influential process in problem representation for solving problems (Kosslyn & Koenig, 1992; Piaget & Inhelder, 1948). This present study explored the role of gender on three types of mathematical spatial ability; spatial perception, spatial visualization, and mental rotation involving group comparisons among three particular grade spans including grades two and three, four and five, and six through eight. The independent variable was gender. The dependent variable was the scores of each of the four spatial visualization assessments. Results suggested that mostly non-significant differences exist for spatial visualization abilities between males and females, but student age was a factor.

Research Question One

A limited amount of literature has been published on mathematical spatial abilities for students in the second and third grades. Hawes, LeFevre, Xu, and Bruce (2015) developed a novel measurement with tangible three-dimensional objects sensitive to developmental differences in four- to eight-year old children recruited from four urban Canadian schools located in low-socioeconomic neighborhoods. Understanding when specific skills of spatial ability emerge, such as mental rotation, how they develop over time, and discerning the types of activities that would further this development were all goals of the researchers. The major difference between this study and previous studies conducted with older children is the use of actual physical 3-D wooden block figures. The stimuli were based on Shepard and Metzler's (1971) 2-D line drawings of 3-D cube figures (Hawes et al., 2015, p. 11). They found that performance on the measures depended on executive functioning, working memory (visuospatial skills), and flexible attention. Their results showed that 2-D and 3-D mental rotations were "correlated with age and executive functioning but not with gender" (Hawes et al., 2015, p. 14). The absence of gender effect on mathematical spatial abilities is consistent with the findings of this present dissertation study.

Manger & Eikeland (1998) examined gender differences of elementary students with respect to overall mathematical achievement but not spatial ability. Palmquist, Keen, and Jaswal (2017) focused on spatial relations in three-year-old pre-school subjects, but direct comparisons to this present dissertation study could not be made.

With the exception of Hawes et al. (2015), studies on mathematical spatial abilities in second and third grade students were very limited. The present dissertation study captured data that agreed with Hawes et al. and further builds the literature on mathematical spatial ability in second and third grade students.

Research Question Two

A limited amount of literature has been published on mathematical spatial abilities for students in the fourth and fifth grades. Seng and Chan (2000) investigated the nature of spatial ability and its relationship to the mathematical performance of elementary school pupils, 72 boys and 55 girls, ages 10-11 years (fourth and fifth grades). Mathematical spatial abilities for males and females were statistically the same in the sample. Four measurement instruments based on spatial orientation and visualization were used. The boys were found not to be significantly better than the girls in the four spatial tasks.

Sung, Shih, and Chang (2015) focused on fifth graders' (n = 111) basic knowledge of spatial geometry, concentrating specifically on calculating the surface areas of composite solids in their study conducted in Taiwan. In the experimental pre-test/post-test method, participants in the experimental group received SAILS instruction (Surface-Area Instructional and Learning Strategies). This experimental instructional method incorporated Geometer's Sketchpad, MagicBoard, National Library of Virtual Manipulatives, and GeoGebra figurative sketching in conjunction with multiple physical representations to support student's knowledge and experience with different orthogonal views of 2-D and 3-D surface area relationships (p. 119). The pre-test found no statistical differences between males and females. Falvey (2012) studied mathematics achievement factors in grades four, six, and eight but did not study spatial relations. Overall, the literature on mathematical spatial ability in fourth and fifth grades is sparse and this present dissertation study adds to the literature on this topic.

Research Question Three

Tartre's (1990) study showed no male/female differences in spatial visualization. Armstrong (1985) found that 13-year-old girls "performed significantly better than boys in spatial visualization" (p. 18). Capraro (2001) examined the difference between student performances of 287 sixth-grade students on two separate spatial measures: the Geometry Content Knowledge (GCK) Test (Carroll, 1998) and the Spatial Visualization (SVT) subtest of the Differential Aptitude Test (Bennett et al., 1973). Results indicated a statistically significant difference between the ethnic groups for the criterion variable of geometry content knowledge, but no significant differences between males and females in both geometry content knowledge or geometric spatial visualization were found from the regression analysis.

Stewart et al. (2017) studied math performance in terms of gender differences. These authors focused on the assessment scores of students, ages six through 19 years, (n = 3,377), using the Kaufman Test of Education Achievement-Third Edition (KTEA-3) (Kaufman et al., 2014) but did not address mathematical spatial ability.

Yenilmez & Kakmaci (2015) sampled 1011 sixth grade students to determine the relation "between the 6th grade students' spatial visualization success and their spatial intelligence" (p. 193). The Wheatley Spatial Ability Test (1996), a form of the Mental Rotations test, was used with results indicating that a significant difference exists for the gender variable with males more successful than female students (p = .03). Ganley & Vasilyeva (2011) examined math attitudes and spatial skills and the role they both play in predicting math performance of eighth grade students. The results showed that "boys outperformed girls in mental rotation and had more positive attitudes about themselves as math students" (p. 239). The same researchers explored whether the gender difference in science scores of eighth graders in Study 1 (n =113) and Study 2 (n = 73,245) was "mediated by the gender difference in spatial skills (Ganley et al., 2013, p. 1422). Results showed that a significant predictor of mental rotation ability was gender in both physical science and technology/engineering scores but not the life sciences.

Literature that reflects study on mathematical spatial ability for sixth to eighth graders has mixed conclusions. Tartre (1990) and Capraro (2001) noted males and females had equal mathematical spatial ability. Yenilmez & Kakmaci (2015) and Ganley & Vasilyeva (2011) noted males achieved higher for mathematical spatial ability, and Armstrong (1985) noted females achieved higher results.

Overall, this present dissertation study provides the most comprehensive examination of mathematical spatial ability for males and females in the second through the eighth grades and contributes to the literature in an understudies' area.

Research Question Four

To assess Research Question Four, a multivariate analysis of variance (MANOVA) and three analyses of variances (ANOVA) were conducted to compare all male and female students' grade levels on the spatial visualization tests to determine whether groups differ on more than one dependent variable. There was a statistically significant difference between Mr. Peanut spatial visualization test and Grade Level, p = .003, with seventh grade males (M = 6.04) scoring highest and fourth grade scoring lowest (M = 3.96), with females performing higher than males.

Based upon the results of the analysis of the Mr. Peanut spatial visualization test in the analysis of the ANOVA tests, Null Hypothesis 13 was rejected because there was a statistically significant difference in the spatial visualization test scores comparing grade level and gender effects in the grade spans two and three, four and five, and six through eight.

Robinson and Lubienski's (2011) research indicated that females "lose ground in elementary school and regain some in middle school" (p. 283). Other researchers are considering whether test administration conditions are hindering females. In their meta-analysis, Maeda & Yoon (2013) investigated this singularity that could possibly account for discrepancies and threaten validity, specifically using the Purdue Spatial Visualization Test (PSVT: R). From the 40 primary studies integrating 70 effect sizes, results indicated that "male superiority on spatial ability tasks measured by the PSVT: R is related to the implementation of time limits" (p. 69). It is not clear that all the studies examined mathematical spatial ability for students in the second through eighth grades. This present dissertation study provides the most comprehensive examination of mathematical spatial ability in second through eighth grade students.

Learning development and malleability of spatial skills

Based on these findings that suggest mostly non-significant differences exist for spatial visualization abilities between males and females, then the question arises as to the implications of seeking methods to enhance student success, particularly for women, by improving spatial skills through training. Foundational cognitive skills are developed in elementary school, and "spatial thinking should be considered a foundational cognitive skill" (Burte, Gardony, Hutton, & Taylor, 2017, p. 1).

The preponderance of evidence demonstrating the malleability of spatial skills is increasing. Perhaps one of the first initiatives that educators, administrators, and family members can do to ensure that this can occur is to provide opportunities for females to improve their spatial visualization skills. Veurink & Sorby (2011) affirmed that spatial thinking is not a fixed cognitive variable. Sorby's reputation and status as professor emerita of mechanical engineering at Michigan Technological University and visiting professor at Ohio State University carries weight for her discerning perspective. With National Science Foundation funding, Sorby and a colleague developed a spatial visualization course for first-year engineering students who demonstrated a lack of spatial skill strengths (Sorby & Baartmans, 2000; Sorby & Veurink, 2012). Post-test results on the PSVT: R were notable with students' scores at 82 percent compared to an average of 52 percent before taking the class. In Sorby's experience, the gender differences have been "forged in large part by cultural forces and can be overcome. . . that the plasticity of the brain allows women to improve and enhance their spatial abilities once they've been given the right tools" (Sorby et al., 2013, p. 28). Carrodeguas et al. (2013) concurred that the "development of spatial skills by engineering students is directly linked to future success in their work" (p. 428).

The meta-analysis conducted by Uttal et al. (2013) indicated "spatial ability is malleable in people of all ages, and training generally has a positive and continuous impact on them" (p. 361). Developing mental rotation ability through training has also been examined by other researchers resulting in noticeable improvements (Burte et al., 2017; Casey et al., 2008; Harris et al., 2013; Jelinek, Kveton, & Voboril, 2015; Master et al., 2016; Pietsch & Jansen, 2012; Shriki, Barkai, & Patkin, 2017; Turgut, 2015; Wiedenbauer & Jansen-Osmann, 2008; Yoon & Mann, 2017). Effective spatial skills' training and instruction of young children, specifically mental rotation, can be applied through carefully designed lessons and activities targeting the skill

(Hawes, Moss, Chang, & Naqvi, 2013), as these early interventions have the longest and largest lasting effects (Heckman, 2006).

Socio-Cultural Factors

Barriers that could account for the lack of females' interests in STEM education and careers could include nonacademic factors such as the cultural factors in society as a whole. Master et al. (2016) asserted that "cultural stereotypes contribute to educational inequities" (p. 215) in their study focusing on "building bridges between psychological science and education" (p. 215). Providing the interest and motivation for females to major in the fields of computer science and engineering, the two areas of STEM careers where a female shortage exists, seems to be one of the obstacles of recruiting and retaining girls (Thoman, Brown, Mason, Harmsen, & Smith, 2015; Ceci & Williams, 2010). Many of these differences may be driven by possible cultural stereotypes where the STEM careers may be associated with boys such as "math is for boys" (Cheryan, Mater, & Meltzoff, 2015; Nosek et al., 2009).

Differences can also be reflected in regards to cultural-*specific* influences. An example of this influence is seen in writing Chinese characters which serves as a subtle method of spatial training thereby producing better spatial abilities just by practicing the writing forms (Li, Nuttall, & Zhu, 1999). The student learner must attend to each stroke spatially which may facilitate spatial task performance, encompassing mental imagery, vertical and horizontal spatial coordination, and visual memory (Li & Nuttal, 2001).

Long-held cultural beliefs wield much power in affecting students' attitudes and choices, even if "these perceptions are disconnected from reality" (Leslie, Cimpian, Meyer, & Freeland, 2015, p. 262). Seeking to facilitate the assurance of equal treatment, Congress enacted Title IX of the Education Amendments of 1972 to prohibit "sex discrimination in education programs and activities that receive federal financial assistance" (U. S. Dept. of Education, 2017). However, while the purpose of this law was intended to assist women in all aspects of education, Title IX has applied mostly to sports.

Many researchers suggest that parents and schools can provide early play experiences for increasing females' spatial visualization skills, previously thought of as toys and games for boys. Experiences in music (Robichaux, 2003, construction toys such as Erector Sets, Legos, Lincoln Logs, puzzles (Sorby & Baartmans, 2000), playing specific video games (Feng et al., 2007; Sorby & Veurink, 2012), and sports (Pietsch & Jansen, 2012) are all experiential strategies that can be incorporated in the home environment.

Implications

Theoretical. This study was grounded in three main theories. The first was Kolb's (1984) experiential learning theory. The second is the cognitive learning theory, originating most likely with Piaget, including theorists Vygotsky, Gestaltists (Wertheimer, Kohler and Koffka), Bloom, and Bruner. The third is stereotype threat theory based on the research of Steele and Aronson (Aronson & Steele, 1995).

Kolb (1984)**,** educational theorist and pioneer of the experiential learning theory, proposed that "learning is the process whereby knowledge is created through the transformation of experience" (p. 38). Kolb's recurrent model consists of four stages which include concrete experience, active experimentation, abstract conceptualization, and reflective observation. Many other researchers are beginning to explore the idea that the differences in early childhood experiences provided for males and females may reveal implications for gender disparities. Wong (2017) addressed the importance of targeting accuracy in a study with 182 Hong Kong kindergarten through third grade children that required students to throw Velcro balls at the center of a target using their dominant hand. Two other components of the study focused on counting and the completion of a spatial anxiety questionnaire. Gender differences were statistically significant in favor of males in the counting and targeting task activity.

Experiences that enhance fine motor skills such as block-building activities, play with construction toys and puzzles to develop spatial-reasoning and visualization skills have been investigated to find a correlation with later math achievement (Casey et al., 2008; Terlecki, Newcombe & Little, 2008; Liben, 2014; Nazareth, Herrera, & Pruden, 2013; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017). Providing rich spatial experiences for children in early childhood seem to certainly be a possible factor in the acquisition of enhanced mathematical visualization skills. In light of the results of the present study, perhaps the female students participated in more diverse experiences that heightened their spatial thinking skills.

The cognitive learning theory deals with the manner in which learners use their particular modes of processing in order to "acquire, retain, and retrieve information," (Blanton, 1998, p. 171) and metacognition which deals with thinking about one's ability, skills, and understanding. Thompson (1998) suggested that students tend to choose information which seems easier to manage and comprehend during the cognitive processing of information, at which point the constructed information is stored as mental schema in the long-term memory. Mnguni (2014) believed there are three overlapping visual modes of cognitive processing: the internalization of visual models (IVM), the externalization of visual models (EVM), and the conceptualization of visual models (CVM). According to Mnguni, "once information has been successfully internalized, CVM follows" (p. 4). The stage where students depend on "short and long-term memories to conceptualize visual information (CVM) is the process of interpreting incoming visual information against prior knowledge" (p. 5). Finally, the externalization of visual models

(EVM) involves the awareness of "expressing mental visual models (which occurs in the mind) as external visual models in the form of drawings or verbal descriptions" (Mnguni, 2014, p. 6).

The importance of working memory has shown up in other studies. In Finland, Vuontela et al. (2003) focused on the audio-spatial and visuospatial working memory of six- to 10-year-old children and the underlying brain structures supporting these processes. The results showed that "auditory and visual working memory performance in school-aged children improves with age, suggesting functional maturation of the underlying cognitive processes and brain structures" (Vuontela et al., 2003, p. 78). Agreeing with this thought, Casey et al. (2008) stated the "ability to produce more complex structures appears to develop in correspondence with an increase in a child's capacity to mentally represent hierarchical spatial relations" (p. 275) or said another way, these skills are developed with "increasing complexity," and in turn, children's cognitive ability is advanced to "differentiate and integrate hierarchical spatial elements" (p. 275).

This theory supports the present study's results of the statistically significant difference between the Mr. Peanut spatial visualization test and grade level, $p = .003$, with seventh grade ($M = 6.04$) scoring highest and fourth grade scoring lowest ($M = 3.96$), with females performing higher than males in the fourth grade. The spatial test, Mr. Peanut, assesses visuo-spatial memory of colored information and the location of the colored circles on the figure of Mr. Peanut. Its inclusion in the sequence of the study's assessments tracks the element of spatial working memory which has been presented as a significant aspect of spatial performance (Shah & Miyake, 1996).

Stereotype threat theory centers on the psychological factor of being "at risk of conforming, as a self-characteristic, a negative stereotype about one's social group" (Aronson & Steele, 1995). The theory deals with the assumption that psychological factors on the student level may present a "psychological predicament rooted in stereotypical images of certain groups as intellectually inferior" (AAUW, 2013). As stated earlier (Ryan & Ryan, 2005), any time the stereotype threat was activated the females underperformed and were more depressed. Their assertion of even moderately well-achieving females could experience this phenomenon, and conditions for this threat can already be in place by 11 or 12 years old. Accordingly, they declare that while males tend to attribute their success to their innate ability, females often credit their success to effort and luck.

Stewart et al. (2017) proposed a connection between math anxiety, spatial ability, and math performance for females creating low expectations for success, apprehension, low self-esteem anxiety, and lower test performance results in their study of math anxiety in relation to sense-of-direction and spatial ability. Perhaps this qualifying factor explains why females lose confidence in their mathematical abilities as they progress in school, stemming from "the stereotyping that students are exposed to in school environment, the media, and even at home that portrays boys as more innately gifted and math as a gift rather than a developed skill" (p.49). Without denying that biological factors may play a role in some math domains, psychology also plays a big role," as Joshua Aronson suggests (AAUW, 2013, p. 41). The manner in which individuals view their own abilities in the issue of self-assessment holds meaning for the choices they make. Rather than confronting the problem, such as a negative stereotype, perhaps girls and women may possibly "avoid the stereotype by avoiding math and science altogether" (AAUW, 2013, p. 41).

Empirical Implications

The results of this study suggest that mostly non-significant differences exist for spatial visualization abilities between males and females. The sole example of a significant difference between male and females was noted on the Mental Rotation test in the fourth and fifth grades, yet this was accompanied with a Cohen's *d* of .07, reflecting a very small effect size. A significant difference was noted with MANOVA and ANOVA analysis of the impact of grade levels. Students in the seventh grade scored significantly higher on the Mr. Peanut spatial visualization test with a partial eta squared value of .103 suggesting a small to medium effect size. Contrary to previous studies, males did not outperform females for each of the grade spans in the specific spatial visualization test measure of Mental Rotations.

A statistically significant difference was indicated between grade level when considered together on the variables of the four spatial visualization tests with the "gap," or the earliest emergence of gender difference, demonstrated at grade four instead of grade six, as reported from previous research results (Linn & Petersen, 1985; Voyer et al., 1995; Shepard & Metzler, 1971). Prior research indicates a significant male advantage is shown on the mental rotation task by the age of 4.5 years, according to the study of Levine, Huttenlocher, Taylor, and Langrock (1999). However, the present research does not clearly support gender inequities in favor of males.

Considering the present research results of mostly non-significant differences existing for spatial visualization abilities between males and females, the findings demonstrated that valuable information has been collected that may shed light on this pervasive topic of gender differences in mathematical spatial visualization and guide decision-making for all stakeholders in the academic world. The bulk of previous literature has focused on research using participants at the high school and college levels with few studies implemented at the elementary level. Evidence collected for this study reveals more encouraging results for females in the realm of spatial ability, specifically the measurement of mental rotation. In addition, these results raise questions for the researcher in understanding the reasons that may have produced these thought-provoking outcomes.

This study has implications for the educational community by contributing to the knowledge base of determining the factors and variables that may influence gender differences in spatial visualization.

Conclusion

The purpose of this causal-comparative group design study was to examine gender differences across three types of spatial ability; namely, spatial perception, spatial visualization, and mental rotation involving group comparisons among males and females and three particular grade spans: two and three, four and five, and six through eight. In this design, researchers collect data about variables that they have conceptualized to be in a causal relationship to each other, but there is no intervention as in experimental research (Gall et al., 2007).

This study is important for the academic community because it contributes to the body of research focusing on gender differences and the gap shown at the specific grade level in mathematics spatial visualization skills. In this study, the gender gap was evidenced at the fourth-grade level (about nine years old) as compared to prior research where the gender gap was most prevalent at the sixth-grade level (about 11 years old).

Limitations

There are several limitations that exist for this research study in terms of understanding the gender differences in grade spans two and three, four and five, and sixth through eighth at two rural research sites. The limitations encountered in this study include the absence of the disaggregation of the data based on race, ethnicity, special-needs population, Limited-English population, academically-gifted population, at-risk status, or socioeconomic status (SES); the limited sample size; the use of convenience sampling; the limitations of two different types of rural schools participating; and the limitation attributed to the assessment instruments.

Because this causal comparative study focused on gender differences in mathematical spatial ability and the existence of a gender gap as theorized in the research literature, the primary concern of the project related to the variables of gender and grade level of the students. The research did not account for potential variables such as race, ethnicity, special-needs population, students with limited-English skills, academically/talented and gifted students, students with at-risk status, or the socioeconomic status (SES) of the students.

The sample size is another limitation of the research. The researcher used the Stephen Olejnik chart for estimating sample size in conducting the statistical analyses (Gall et al., 2007). To determine sample size with three groups (grades two and three, four and five, sixth through eighth) with approximately 42-54 participants in each group and a total of 188 participants would yield a medium effect size of 0.70 statistical power. The study followed these guidelines. However, Gall et al. (2007) indicated that the "larger the sample, the more likely the research participants' scores on the measured variables will be representative of population scores" (p. 176).

Another limitation is the use of convenience-sampling versus random grouping for the defined population of the study. For the convenience and proximity of the researcher, the participants were in an adjacent county and in a similar district as the researcher. In addition, the student participants were chosen based on their place in a particular grade level. Students were grouped at the beginning of the year; therefore, the use of random grouping of the participants was not feasible. The use of convenience sampling threatens the ability to generalize the findings of the study to the population.

Additionally, the participation of two different types of rural schools in the study; one public school and one public charter school where both populations were primarily Caucasian is another limitation. However, the ethnic population of Research Site One showed more diversity with 64% White, 29% Black, 6% Hispanic, 0.9% Multi-Racial, and 0.4% Native American students as compared to Research Site Two with a predominantly White (95%) population and (5%) Black students. Lack of diversity and demographic variables are factors that may affect the generalizability of the results.

Accounting for the differences in teacher methods and techniques is a limitation that could explain the lack of ability to determine differences in teaching tactics, teaching style and techniques, classroom management practices, and even test preparation strategies and methods. The differences of the teachers' personal teaching style and method of delivery could provide advantages or disadvantages for the students' understanding of the mathematical content prior to the implementation of the study.

Finally, a limitation could be attributed to the assessment instruments. Student participants were not familiar with the online spatial visualization assessments, which may have impacted them in affective ways, causing some students to perform poorly on the tests. However, there were short, practice sessions that helped familiarize students to the process of the test-scripts.

Recommendations for Future Research

Future studies could focus on using a sample inclusive of a more diverse population replicated in a variety of demographics and geographical regions. This study did not identify students in the exceptional children/special education and minority subgroups. Representing these special populations in forthcoming research could provide valuable feedback to determine if there were greater weaknesses or strengths within these populations. Both sites were rural, with the majority of students categorized as low socioeconomic status. More research could be conducted to include suburban/urban populations. Recognizing the outcomes of these subgroups could provide richer data for more in-depth reflection.

Future researchers could replicate the study allowing students to participate in only one of the spatial visualization assessments that showed a statistical significant difference in the present study: Mr. Peanut. The focus would be more specific, and could possibly offer more insight in understanding the reasons why a discrepancy exists.

Further exploring the existence of gender, cultural, and environmental factors could be done in qualitative study. A qualitative component, such as interviews or short surveys, could pose questions related to classroom techniques. Jacobson (2015) probed this question of students' perceptions (grades three, four, and five) of their teachers' behaviors in relation to their individual mathematical ability and the gender bias that may be prevalent in the school environment. Jacobson asserted that gender bias, the attitude or belief that one gender or sex is of higher power than the other can "lead to unfair difference in the treatment of men or women because of their sex or gender" (p. 11). Results showed there was a statistically significant relationship between gender and how students perceive their teacher's gender equity behavior, but also between gender and students' perceptions regarding their own mathematical ability as demonstrated by the Math and Me Survey (p. 88).

Each student's voice is important, individually and collectively; therefore, offering a component for student reflection could be a recommendation for future research. With the emphasis placed on 2001 No Child Left Behind legislation, AYP goals, and currently, Common Core Standards and Objectives, follow-up studies could examine the collective scores of students who participate in End of Grade Tests and North Carolina's mandated *m*Class Reading initiatives as compared to the spatial visualization assessments for observing a correlation between the scores. These comparisons would give the findings a greater practical application for future researchers to gain insight into gender differences in achievement.

Summary

The purpose of this study was to compare the effects of gender differences across three types of mathematical spatial ability; namely, spatial perception, spatial visualization, and mental rotation involving group comparisons among three particular grade spans: two and three, four and five, and six through eight. A second purpose of the study was to determine at what level, if any, that the spatial visualization discrepancy occurs between girls and boys. By examining the effects of gender differences in mathematical spatial visualization ability, this study adds to the body of research relating to gender discrepancies beginning with elementary students which affects the skill-sets needed at the secondary and collegiate levels. Additional research needs to be conducted on the subject with this similar population in order to elucidate the reasons why gender gaps exist, the sources of the gaps, and the methods of change that can be executed to ameliorate the issue to promote impartiality and fairness for all, and move all students along on their continuum of learning. The collective efforts of families, schools, and the greater community can focus on practical methods to create environments for promoting encouragement and inspiration that would amend the negative stereotypes that hinder the capacity of females in the demanding STEM fields of advancement. This research study helps to guide educational practice and decision-making for all stakeholders.

References

Adanez, G.P., & Velasco, A. D. (2002). Predicting academic success of engineering students in technical drawing from visualization test scores. *Journal of Geometry and Graphics, 6*(1), 99-109.

Akasah, Z. A., & alias, M. (2006). *Bridging the spatial visualization skills gap throughengineering drawing using the whole-to-parts approach.* Paper presented at the 17thAustralasian Association of Engineering Education Conference (AAEE06). Auckland, New Zealand: University of Technology New Zealand.

American Association of University Women. (2013). *The simple truth about the gender pay gap.* Brown and Churches. Washington, DD: Author.

American Psychological Association. (2010). *Publication manual of the American Psychological Association* (6th ed.). Washington, DC: Author.

Anastasi, A. (1958). *Differential psychology: Individual and group differences in behavior* (3rd ed.). New York: Macmillan.

Armstrong, J. M. (1985). A national assessment of participation and achievement of women in mathematics. In S. F. Chipman, L. R. Brush & D. M. Wilson (Eds), *Women and Mathematics: Balancing the Equation* (pp. 59-94). Hillsdale, N. J.: Erlbaum.

Aronson, J., & Steele, C. (1995). Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology,* 69, 797-811.

Ashcroft, M., & Moore, A. (2009). Mathematics anxiety and the affective drop in performance. *Journal of Psychoeducational Assessment*, 27, 197-205.

Bai, D. L., & Bertenthal, B. I. (1992). Locomotor status and the development of spatial search skills. *Child Development,* 63, 215-226.

Baillargeion, R. (2008). Innate ideas revisited: For a principle of persistence in infants' physical reasoning. *Perspectives On Psychological Science*, *3*, 2-13.

Bayrak, M. E. (2008). *Investigation of effect of visual treatment on elementary school student's spatial ability and attitude toward spatial ability problems* (Unpublished master's thesis). Middle East Technical University, Ankara, Turkey.

Battista, M. T., Wheatley, G. H., & Talsma, G. (1981). The importance of spatial visualization and cognitive development for geometry learning in pre-service elementary teachers. *Journal for Research in Mathematics Education*, *13*, 332-340.

Bednarz, S. (2005). Spatial literacy: Nearly the final frontier continuing the voyage of discovery. Keynote presentation at The Place of GIS in the Curriculum Conference, Leicester, England. Retrieved from http://www.tees.ac.uk/events/2005/gis05/gis05.htm#swb

Benbow, C. P. (1988). Sex differences in mathematical reasoning ability in intellectually talented preadolescents: Their nature, effects, and possible causes. *Behavioral and Brain Science,* 11, 169-232.

Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1973). *Differential aptitude tests: Space relations (Form A).* New York: The Psychological Corporation.

Bertenthal, B. I., Campos, J. J., & Barrett, K. (1984). Self-produced locomotion: An organizer of emotional, cognitive, and social developments in infancy. In R. Emde & R. Harmon (Eds.), *Continuities and discontinuities in development* (pp. 175-210). New York: Plenum.

Blank, R. (2013). *Getting girls into stem education*. Retrieved April 27, 2013 http://www.stemschool.com/articles/getting-girls-into-stem-education-a-womens-history month-event/

Blanton, B. (1998). The application of the cognitive learning theory to instructional design *International Journal of Instructional Media*, *25*(2), 171-177.

Blazhenkova, O., & Kozhevnikov, M. (2010). Visual-object ability: A new dimension of non-verbal intelligence. *Cognition*, 117 (3), 276-30.

Boakes, N. (2009). Origami instruction in the middle school mathematics classroom: Its impact on spatial visualization and geometry knowledge of students. *Research in Middle Level Education, 32*(7), 1-11. ISSN 1940-4476

Breyfogle, M., & Lynch, C. (2010). Van Hiele revisited. *Mathematics Teaching in the Middle School*, 16(4), 232-238.

Brinkman, E. H. (1966). Programmed instruction as a technique for improving spatial visualization. *Journal of Applied Psychology*, 50, 179-184.

Brown, R. P., & Josephs, R. A. (1999). A burden of proof: Stereotype relevance and gender differences in math performance. *Journal of Personality and Social Psychology, 76*(2), 246-257.

Bulf, H., Macchi, C., & de Hevia, M. (2014) Are numbers, size and brightness equally efficient in orienting visual attention? Evidence from an eye-tracking study. PLoS ONE 9:e99499

Burte, H., Gardony, A., Hutton, A., & Taylor, H. (2017). Think3d!: Improving mathematics learning through embodied spatial training. *Cognitive Research: Principles and Implications, 2,* 1-18.

Bruner, J. (1960). *The Process of Education*. Cambridge, Massachusetts: Harvard University Press.

Cadinu, M., Maass, A., Frigerio, S., Impagliazzo, L., & Latinotti, S. (2003). Stereotype threat: The effect of expectancy on performance. *European Journal of Social Psychology*, 33, 267-285.

Capraro, R. M. (2001). *Exploring the influences of geometric spatial visualization, gender, and ethnicity on the acquisition of geometry content knowledge*. Paper presented at the Annual Meeting of the Southwest Educational Research Association (New Orleans, LA, February 1-3, 2001). Retrieved March 23, 2013 from http://search.ebscohost.com.ezproxy.liberty.edu.

Carrodeguas, C . M., Garcia-Dominguez, M., Hernan-Perez, A. S., Martin-Gutierrez, J., & Roca Gonzalez, C. (2013). Improving spatial skills: An orienteering experience in real and virtual environments with first year engineering students. *Procedia Computer Science, 25*, 428-435.

Carroll, W. M. (1998), Geometric knowledge of middle school students in a reform-based mathematics curriculum. *School Science and Mathematics*, 98, 188-197.

Carter, R., & Woldstad, J. (1985). Repeated measurements of spatial ability with the Manikin test. *Human Factors*, *27*(2), 209-219.

Casey, B., Andrews, N. Schindler, H., Kersh, J., Samper, A., & Copley, J. (2008). The development of spatial skills through interventions involving block building activities. *Cognition and Instruction*, *26*, 269-309.

Ceci, S. J., & Williams, W. M. (2010). Sex differences in math-intensive fields. Current *Directions in Psychological Science*, *19*, 275-279.

Chang, G., Morreale, P., & Medicherla, P. (2010). Applications of augmented reality systems in education. In D. Gibson & B. Dodge (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010* (pp. 1380-1385). Chesapeake, VA: AACE.

Cheng, Y., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, *15*(1), 2-11.

Cheryan, S., Mater, A., & Meltzoff, A. N. (2015). Cultural stereotypes as gatekeepers: Increasing girls' interest in computer science and engineering by diversifying stereotypes. *Frontiers in Psychology*, *6*, 49.

Clearfield, M. W. (2004). The role of crawling and walking experience in infant spatial memory. *Journal of Experimental Child Psychology*, *89*, 214-241.

Clements, D. H. (1998). Geometric and spatial thinking in young children. *Research in Education.* Arlington, VA: National Science Foundation.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cramer, D. (1998). *Fundamental statistics for social research*. Abingdon, England: Routledge.

Crowley, M. (1987). The van Hiele model of the development of geometric thought', in M.M. Lindquist and A.P. Shulte (eds), *Learning and Teaching Geometry, K-12*, National Council of Teachers of Mathematics, 1987 Yearbook, Virginia, pp. 1–16.

Cvencek, D., Meltzoff, A. N., & Greenwald, A. G. (2011). Math–gender stereotypes in elementary school children. *Child Development*, *82*, 766-779.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Psychology General*, *122*, 371-396.

De Lisi, R., & Wolford, J. L. (2002). Improving children's mental rotation accuracy with computer game playing. *The Journal of Genetic Psychology: Research and Theory on Human Development*, *163*(3), 272-282.

Denmark, F. L., Rabinowitz, V. C., & Sechzer, J. A. (2005). *Engendering psychology: Women and gender revisited* (2nd ed). Boston: Pearson / Allyn & Bacon.

Department of Commerce. (2011). Women in STEM: A gender gap to innovation. *Economics and Statistics Administration*. Retrieved from www.esa.doc.gov/Reports/women-stem-gender-gap-innovation

De Ribaupierre, A., & Bailleux, C. (1995). Development of attentional capacity in childhood: A longitudinal study. In: Weinert, F. E. & Schneider, *Working memory performance and competencies: Issues in growth and development* (pp. 45-57). Mahwah, NJ: Lauwrence Erlbaum.

Draine, S. (2017). *Millisecond Software, LLC*. Retrieved from https://www.millisecond.com

Ekstrom, R. B., French, J. W., & Harman, H. H. (1979). Cognitive factors: Their identification and replication. *Multivariate Behavioral Research Monographs*, *79*(2), 3-84.

Englund, C. E., Reeves, D. L., Shingledecker, C. A., Thorne, D. R., Wilson, K. P., & Hegge, F. W. (1987). Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB). Design and Specification of the Battery (No. NHRC-87-10). Naval Health Research Center San Diego, CA.

Etaugh, C. A., & Bridges, J. S. (2010). *Women's lives: A psychological exploration* (2nd ed.). Boston: Allyn & Bacon.

Falvey, L. (2012). Gendered patterns in high achievement in mathematics for grades 4, 6, and 8. *Graduate Research Overview*, Rhode Island College Digital Commons, Paper 63.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, 18, 850-855.

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

Fennema, E., & Sherman, J. A. (1978). Sex-related differences in mathematics achievement and related areas for further study. *Journal for Research in Mathematics Education*, *9*, 189-203.

French, A., Macedo, M., Poulsen, J., Waterson, T., & Yu, A. (2017). Multivariate analysis of variance (MANOVA). Retrieved from https://www.academia.edu/7751963/Multivariate_Analysis_of_Variance_MANOVA

Frenzel, A. C., Goetz, T., Pekrun, R., & Watt, H. M. G. (2010). Development of mathematics interest in adolescence: Influences of gender, family and school context. *Journal of Research on Adolescence*, *20*, 507-537.

Fruchter, B. (1954). Measurement of spatial abilities: History and background. *Educational and Psychological Measurement*, *14*, 387-395.

Fuys, D., Geddes, D., & Tischler, R. (1988), The van hiele model of thinking in geometry among adolescents, *Journal for Research in Mathematics Education*, Monograph 3. Reston, VA: National Council of Teachers of Mathematics.

Gall, M. D., Gall, J. P., & Borg, W. R., (2007). *Educational research: An introduction* (7th ed.). New York: Allyn & Bacon.

Galton, F. (1880). Mental imagery. *Fortnightly Review* 28 : 312-24. Retrieved http://www.galton.org/psychologist/index.html

Ganley, C., Mingle, L., Ryan, A., Ryan, K., Vasilyeve, M., & Perry, M. (2013). *An examination of stereotype threat effects on girls' mathematics performance*. Developmental Psychology. Advance online publication. doi: 10.1037/a0031412

Ganley, C. M., & Vasilyeva, M. (2011). Sex differences in the relation between math performance, spatial skills, and atttitudes. *Journal of Applied Developmental Psychology*, *32*(4), 235-242.

Gardner, H. (1983). *Frames of mind.* New York: Basic Books.

Geary, D, Gilger, J., & Elliot-Miller, B. (1992). Gender differences in three-dimensional mental rotation: A replication. *Journal of Genetic Psychology*, *153*, 115-117.

Goldberg, W. A. (Ed.). (2010). *Current directions in gender psychology*. Boston: Allyn & Bacon.

Gong, G., He, Y., & Evans, A., (2011). Brain connectivity: Gender makes a difference. *The Neuroscientist*, *17*(5), 575-91.

Guay, R. (1976). *Visualization tests*. West Lafayette: Purdue Research Foundation.

Gupta, B. (2012). Virtual reality. *COMPUSOFT: International journal of advance computer technology*, *1*(1), 13-17.

Gur, R., Alsop, D., Glahn, D., Petty, R., Swanson, C., Maldjian, J., Turetsky, B., Detre, J., Gur, R. E. (2000). An fMRI study of sex differences in regional activation to a verbal and a spatial task. *Brain and Language*, *74*, 157-170.

Halpern, D. F. (2000). A different answer to the question, "Do sex-related differences in spatial abilities exist?" *American Psychologist*, *41*, 1014-1015.

Harris, J., Hirsh-Pasek, K., & Newcombe, N. S. (2013). A new twist on studying the development of dynamic spatial transformations: Mental paper folding in young children. *Mind, Brain and Education, 7*, 49-55.

Hatfield, M. M., Edwards, N., & Bitter, G. (1997). *Mathematics methods for elementary and middle school teachers.* Boston: Allyn and Bacon.

Hawes, Z., LeFevre, J., Xu, C., & Bruce, C. D. (2015). Mental rotation with tangible three dimensional objects: A new measure sensitive to developmental differences in 4- to 8 year-old children. *Mind, Brain & Education*, *9*(1), 10-18. doi: 10.1111/mbe.12051

Hawes, Z., Moss, J., Chang, D., & Naqvi, S. (2013). Math for young children: A professional development model that bridges cognitive science and mathematics education. In M. Martinez & A. Castro Superfine (Eds.), *Proceedings of the 35h Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education.* Chicago, IL: University of Illinois at Chicago.

Heckman, J. J. (2006). Skill formation and the economics of investing in disadvantaged children. *Science*, *312* (5782), 1900-1902.

Hegarty, M., Kozhevnikov, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, *32*, 175-191.

Hegeleson, V. S. (2005). *Psychology of gender* (2nd ed.). Upper Saddle River: Pearson.

Higbee, J. L., & Thomas, P. V. (1999). Affective and cognitive factors related to mathematics achievement. *Journal of Developmental Education*, 23(1).

Hill, C., Corbett, C., & St. Rose, A. (2010). *Why so few? Women in science, technology, engineering and mathematics.* Washington, D. C.: AAUW.

Hilmar, N., & Amponsah, B. (1998). Gender differences in spatial abilities and spatial activity among university students in an Egalitarian educational system. *Sex Roles*, 38, 1009-1024.

Hoffler, T. N. (2010). Spatial ability: Its influence on learning with visualizations—a meta-analytic review. *Educational Psychological Review, 22*, 245-269.

Horobin, K., & Acredolo, L. P. (1986). The role of attentiveness, mobility history, and separation of hiding sites on stage IV search behavior. *Journal of Experimental Child Psychology*, *41*, 114-127.

Howell, D. C. (2011). *Fundamental statistics for the behavioral sciences* (7th ed.). Belmont, CA: Thomason/Wadsworth.

Huguet, P., & Regner, I. (2007). Stereotype threat among schoolgirls in quasi-ordinary classroom circumstances. *Journal of Educational Psychology*, *99*(3), 545-560.

Hyde, J. S. (2014). Gender similarities and differences. *Annual Review of Psychology* *65*(1), 373-398.

Ivinson, G. (2014) How gender became sex: mapping the gendered effects of sex-group categorisation onto pedagogy, policy and practice. *Educational Research*, I(2), 155-170, doi: 10.1080/00131881.2014.898912

Jacobson, D. (2015). Elementary students' perceptions of gender equity in mathematics classes (Unpublished doctoral dissertation). Lynchburg, VA: Liberty University.

Jelínek, M., Květon, P., & Vobořil, D. (2015). Innovative testing of spatial ability: interactive responding and the use of complex stimuli material. *Cognitive Processing, 16*, 45-55.

Kaufman, A. S., Kaufman, N. L. (2014). *Kaufman Test of Educational Achievement—Third Edition (KTEA—3*). Bloomington, MN: Pearson.

Kaufmann, H., Schmalstieg, D., & Wagner, M. (2000). Construct 3D: A virtual reality application for mathematics and geometry education. *Education and Information Technologies 5*(4), 263-276.

Kaufmann, H., & Schmalstieg, D. (2003). Mathematics and geometry education with collaborative augmented reality. *Computers & Graphics, 27*(3), 339-345.

Kell, H. J., Lubinski, D., Benbow, C., & Steoger. J. (2013). Creativity and technical innovation: spatial ability's unique role. *Psychological Science, 24*(9), 1831-1836.

Kellogg, R. T. (1995). *Cognitive Psychology*. Thousand Oaks, CA: Sage Publications, Inc.

King, H. (2006). Understanding spatial literacy: Cognitive and curriculum perspectives. *Planet*, 17(1), 26-28.

Kolb. D. A. and Fry, R. (1975). 'Toward an applied theory of experiential learning; in C. Cooper (ed.) *Theories of Group Process*, London: John Wiley.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development.* Englewood Cliffs, NJ: Prentice-Hall.

Kosslyn, S., & Koenig, O. (1992). *Wet mind: The new cognitive neuroscience*. New York: Free Press.

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition, 29*(5), 745-756.

Laerd Statistics. (2017) – MANOVA test using SPSS. Retrieved from https://statistics.laerd.com/spss-tutorials/one-way manova Test-using-spssstatistics.php

Lee, K. (2012). The future of learning and training in augmented reality. *Insight: A Journal of*

Scholarly Teaching, *7*, 31-42.

Leslie, S., Cimpian, A., Meyer, M., & Freeland, E. (2015). Expectations of brilliance underlie gender distributions across academic disciplines. *Science*, *347*, 262-265.

Levy, J. (1969). Possible basis for the evolution of lateral specialization of the human brain. *Nature*, *24*, 614-615.

Levine, S. C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology*, *35*(4), 940-949.

Li, C., & Nuttal, R. (2001). Writing Chinese and mathematics achievement: A study with Chinese-American undergraduates. *Mathematics Education Research*, *13*(1), 15-27.

Li, C., Nuttall, R., & Zhu, W. (1999). Writing Chinese characters and success on mental rotation test. *Perceptual and Motor Skills*, *88*, 1261-1270.

Liben, L. (2014). The stem gender gap: The case for spatial interventions. *International Journal of Gender, Science, and Technology*, *7*(2), 133-150.

Liben, L., & Downs, R. (1989). Understanding maps as symbols. In H. W. Reese (Ed.) *Advances in child development and behavior* (Vol. 22, pp. 145-201). New York: Academic Press.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*, 1479-1498.

Lips, H. (2008). *Sex and gender: An introduction* (6th ed.). Boston: McGraw-Hill.

Lucas, D. J. (2011). The effects of a service-learning introductory diversity course on pre-service teachers' attitudes toward teaching diverse student populations (Unpublished doctoral dissertation). Lynchburg, VA: Liberty University.

Lucas, J. A., & Alwens, R. B. (2000). Investigation of gender, group composition, and instructional influences on spatial performance. Retrieved from Penn State-Erie-*VIZ:* The visualization assessment and training website.

McCrink, K., & Galaba, J. (2015). The impact of symbolic and non-symbolic quantity on spatial learning. *PLoS One, 10*(3). doi: 10.1371/journal.pone.0119395

McCrink, K., Shaki, S., & Berkowitz, T. (2014). Culturally-driven biases in preschoolers' spatial search strategies for ordinal and non-ordinal dimensions. *Cognitive Development, 30*: 1-14.

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 6*(5), 889-918.

McGlone J. (1980). Sex differences in human brain asymmetry: a critical survey. *Behavioral and Brain Sciences*, 3(2), 215-227.

McGuiness, D. (1993). Gender differences in cognitive style: Implications for mathematics performance and achievement. In L. A. Penner, G. M. Batsche, H. M. Knoff & D. L. Nelson (Eds), *The Challenge in Mathematics and Science Education: Psychology's Response* (pp. 251-274). Washington, DC: American Psychological Association.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences.* Stanford, CA: Stanford University Press.

Maeda, Y., & Yoon, S. (2013). A meta-analysis on gender differences in mental rotation ability measured by the purdue spatial visualization tests: Visualization of rotations (PSVT:R). *Educational Psychology Review, 25*(1), 69-94.

Maier, P. H. (1998). *Spatial geometry and spatial ability: How to make solid geometry solid?* In F. Cohor-Fresenborg, K. Reiss, G. Toener, & H. G. Weigand (Eds.), Selected papers from the Annual Conference of Didactics of Mathematics 1996, Osnabreck, 63-75.

Manger, T., & Eikeland, O. (1996). The effects of spatial visualization and students' sex on mathematical achievement. *British Journal of Psychology*, *89*, 17-25.

Mansfield, H. (1985). Projective geometry in the elementary school. *Arithmetic Teacher*, *32*, 15-19.

Marcus, B. (2014). *Mentors help create a sustainable pipeline for women in STEM*. Retrieved https://www.forbes.com/sites/bonniemarcus/2014/03/28/mentors-help-create-a-sustainable-pipeline-for-women-in-stem/#3fbc47bc53d3

Martin-Gutierrez, J., Saorin, J., Contero, M., Alcaniz, M., Perez-Lopez, D., Ortega, M. (2010). Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics*, 34: 77–91.

Master, A., Cheryan, S., & Meltzoff, A. N. (2016). Computing whether she belongs: Stereotypes undermine girls' interest and sense of belonging in computer science. *Journal of Educational Psychology*, *108*, 424-437.

Meserve, B. E. (1973). Geometry as a gateway to mathematics. In A. G. Howson (Ed.), *Developments in mathematical education.* Cambridge: University Press.

Metz, S., Donohue, S., & Moore, C. (2012). Spatial skills: A focus on gender and engineering. In B. Bogue & E. Cady (Eds.). *Apply Research to Practice (ARP) Resources*. Retrieved from http://www.engageengineering.org/associations/11559/files/ARP_SpatialSkills.pdf

Meyers, L.S., Gamst, G., & Guarino, A.J. (2006). *Applied multivariate research design and interpretation*. Thousand Oaks, CA: SAGE Publications.

Mnguni, L. (2014). The theoretical cognitive process of visualization for science education. *Springer Plus*, *3*, 184.

Mohler, J. (2008). A review of spatial ability research. *Engineering Design Graphics Journal*, *72*(3), 19-30.

Moses, B. E. (1980). *The relationship between visual thinking tasks and problem-solving performance*. Paper presented at the Annual Meeting of the American Educational Research Association, Boston, MA. (ERIC Document Reproduction Service No. ED 187 734).

Morra, S. (1994). Issues in working memory measurement: Testing for M capacity. *International Journal of Behavioral Development*, *17*, 143-159.

Motes, M. A., Malach, R., & Kozhevnikov, M. (2008). Object-processing neural efficiency differentiates object from spatial visualizers. *NeuroReport*, *19*(17), 1727-1731.

Moyer, R., & Landauer, T. (1967). Time required for judgements of numerical inequality. *Nature*, *215*, 1519-1520.

Muehlenhard, C. L., & Peterson, Z. D. (2011). Distinguishing between sex and gender: History, current, conceptualizations, and implications. *Sex Roles*, *64*, 791-803.

Nagy-Kondor, R. (2007). *Spatial ability of engineering students.* Annales Mathematicae et Informatica, *34*, 113-122.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: NCTM.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: National Council of Teachers of Mathematics.

National Governors Association Center for Best Practices. (2010). *Common Core State Standards*. National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington D.C. Retrieved from http://www.corestandards.org/

National Science Foundation. (2013). TABLE 5-1. *Bachelor's degrees awarded, by sex and field: 2001-2010.* Women, Minorities, and Persons with disabilities in science and Engineering: 2013, Division of Science Resources Statistics. Retrieved from http://www.nsf.gov/statistics/wmpd/2013/sex.cfm.

Nazareth, A., Herrera, A., & Pruden, S. M. (2013). Explaining sex differences in mental rotation: role of spatial activity experience. *Cognitive Processing*, *14*(2), 201-204.

Newcombe, N. (2013). Cognitive development: changing views of cognitive change. W*IREs Cognitive Science*, *4*, 479-491.

Nguyen, H. H. D., & Ryan, A. M. (2008). Does stereotype threat affect test performance of minorities and women? A meta-analysis of experimental evidence. *Journal of Applied Psychology*, 93(6), 1314-1334.

No Child left Behind Act of 2000, Pub. L. No. 107-110 (2001).

North Carolina Department of Public Instruction. (2003). *Standard course of study goals & objectives.* Raleigh, NC: NCDPI.

North Carolina Department of Public Instruction. (2012). *Title I, part a handbook: Tools and tips a for title i directors.* Retrieved from www.ncpublicschools.org

Nosek, B. A., Smyth, F. L., Sriram, N., Lindner, N. M., Devos, T., Ayala, A., . . . & Greenwald, A. G. (2009). National differences in gender-science stereotypes predict national sex differences in science and math achievement. *Proceedings of the National Academy of Sciences*, *106*, 10593-10597.

Olkun, S. (2003). Making connections: Improving spatial abilities with engineering drawing activities. *International Journal of Mathematics teaching and Learning*. Plymouth, UK: Center for Innovation in Mathematics teaching, University of Plymouth.

Orde, B. J. (1996). A correlational analysis of drawing ability and spatial ability. *Dissertation Abstracts International*, *57*(5), 1943.

Pak, R. (2001). A further examination of the influence of spatial abilities on computer task performance in younger and older adults. *Proceedings of the Human Factors and Ergonoics Society 45th Annual Meeting*, Minneapolis, MN, 1551-1555.

Palmquist, C. M., Keen, R., & Jaswal, V. K. (2017). Visualization instructions enhance preschoolers' spatial problem-solving. *British Journal of Developmental Psychology*. doi:10.1111/bjdp.12205

Payne, R. (2005). *A framework for understanding poverty*. Highland, TX: Aha! Process.

Peters, M., & Battista, C. (2008). Applications of mental rotation figures of the Shepard and Metzler type and description of a mental rotation stimulus library. *Brain and Cognition*, *66*(3), 260-264.

Piaget, J., & Inhelder, B. (1948). *The child's conception of space*. New York: W. W. Norton & Co.

Pietsch, S., & Jansen, P. (2012). Different mental rotation performance in students of music, sport and education. *Learning and Individual Differences*, *22*(1), 159-163.

President's Commission on Excellence in Special Education (2002, July). *A new era: Revitalizing special education for children and their families*. (Electronic version). Jessup, MD: U.S. Department of Education, Education Publications Center. Retrieved from U.S. Department of Education Website http://www.ed.gov/inits/commissionsboards/whspecialeducation/index.html

Rafi, A., Samsudin, K. A., & Said, C. S. (2008). Training in spatial visualization: The effects of training method and gender. *Educational Technology & Society, 11*(3), 127-140.

Reiss, A., Abrams, M., Singer, H., Ross, J., & Denckla, M. (1996). Brain development, gender and IQ in children: A volumetric imaging study. *Brain*, 119, 1763-1774.

Rilea, S. L., Roskos-Ewoldsen, B., & Boles, D. (2004). Sex differences in spatial ability: A lateralization of function approach. *Brain and Cognition*, 56, 332-343.

Robichaux, R., & Rodrigue, P. (2003). Using origami to promote geometric communication. Mathematics Teaching in the Middle School, 9(4), 222–229.

Robinson, J. P., & Lubienski, S. T. (2011). The development of gender achievement gaps. *AERA Journal*, *48*, 268-302.

Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object set: The role of surface detail in basic-level object recognition. *Perception, 33*, 217-236.

Rosser, R. A. (1980). *Acquisition of spatial concepts in relation to age and sex*. Final Report on Grant No. NIE-6-79-0091 from the National Institute of Education, Dept. of Education, University of Arizona.

Rovet, J. (1983). Cognitive and neuropsychological test performance of persons with abnormalities of adolescent development: A test of Waber's hypothesis. *Child Development*, *54*, 941-942.

Ryan, K. E., & Ryan, A. M. (2005). Psychological processes underlying stereotype threat and standardized math test performance. *Educational Psychologist*, *40*(4).

Salthouse, T. A. (1987). Sources of age-related individual differences in block design texts. *Intelligence*, *11*, 256-262.

Scali, R. M., Brownlow, S., & Hicks, J. L. (2000). Gender differences in spatial task performance as a function of speed or accuracy orientation. *Sex Roles*, *43*(5): 359-376.

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology, 85*(3), 440-452.

Schulte, A. C., Easton, J. E., & Parker, J. (2009). Advances in treatment integrity research: multidisciplinary perspectives on the conceptualization, measurement, and enhancement of treatment integrity, *School Psychology Review*, *38*(4).

Seefeldt, C., & Wasik, B.A. (2006). *Early education: Three-, four-, and five-year-olds go to School* (2nd ed.). Upper Saddle River: Pearson Education.

Seng, S., & Chan, B. (2000). Spatial ability and mathematical performance: gender differences in an elementary school. *Nature Biotechnology*, *18*, 1087-0156.

Seng, S., & Yeo, A. (2000). *Spatial visualization ability and learning style preference of low achieving students.* Retrieved from http://search.ebscohost.com.ezproxy.liberty.edu

Shadish, W.R., Cook, T.D., & Campbell, D.T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. New York: Houghton Mifflin.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, *125*(1), 4-27.

Shaki, S., Fischer, M., & Petrusic, W. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychon Bulletin Review*, *26*, 328-331.

Shapiro, S., & Wilk, M. (1965). An analysis of variance test for normality. *Biometrika*, *52*, 591-611.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701-703.

Sherman, J. (1978). *Sex-related cognitive differences: An essay on theory and evidence*. Springfield, IL: Charles C. Thomas.

Shriki, A., Barkai, R., & Patkin, D. (2017). Developing mental rotation ability through engagement in assignments that involve solids of revolution. *The Mathematics Enthusiast, 14*.

Sims V., & Mayer R. (2002). Domain specificity of spatial expertise: the case of video game players. *Applied Cognitive Psychology*, *16*(1), 97-115.

Spatial Intelligence & Learning Center. (2017). SILC Tests & Instruments. Retrieved from www.spatiallearning.org.

Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education*, *89*(3), 301-307.

Sorby, S. A., Casey, B., Veurink, N., & Dulaney, A. (2013). The role of spatial training in improving spatial and calculus performance in engineering students. *Learning and Individual Differences*, *26*, 20-29.

Sorby, S. A. (1998). *Developing 3-D visualization skills.* Paper presented at the annual meeting of the Engineering Design Graphics Division, Madison, Wisconsin.

Sorby, S. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, *(31)*3.

Sorby, S. A., & Veurink, N. L. (2012). Spatial skills among minority and international engineering students. Paper presented at 2012 ASEE Annual Conference, San Antonio, Texas.

Sorby, S. A. & Veurink, N. L. (2014). Development of Spatial Visualization Skills through Engineering Curricula

Spearman, C. (1927). *The abilities of man*. London: Macmillan.

Stewart, C., Root, M., Koriakin, T., Choi, D., Luria, S., Bray, M., Sassu, K., Maykel, C., O'Rourke, P., and Courville, T. (2017). Biological gender differences in students' errors on mathematics achievement tests. *Journal of Psychoeducational Assessment*, *35*(1-2) 47 –56.

Sung, Y., Shih, P., & Chang, K. (2015). The effects of 3D-representation instruction on composite-solid surface-area learning for elementary school students. *Instructional Science*, *43*, 115-145.

Sutton, K., & Williams, A. (2008). Developing a discipline-based measure of visualization. *UniServe Science Proceedings*, 115-20.

Szapkiw, A. (2011). *Statistics guide*. Liberty University, EDUC 712, Fall, 2011.

Tartre, L. A. (1990). Spatial skills, gender, and mathematics. In E. Fennema & G. C. Leder (Eds), *Mathematics and Gender* (pp. 27-59). New York: Teachers College Press.

Terlecki, M., Newcombe, N., & Little, M. (2008). Durable and generalized effects of spatial experience on mental rotation: Gender differences in growth patterns. *Applied Cognitive Psychology*, *22*(7), 996-1013.

Thoman, D., Brown, E., Mason, A., Harmsen, A., & Smith, J. (2015). The role of altruistic values in motivating underrepresented minority students for biomedicine. *Bio Science*, *65*, 183-188.

Thompson, P. W. (1998). Constructivism, cybernetics, and information processing: Implications for research on mathematical learning. *Constructivism in Education*. Erlbaum, Hillsdale: 123-134.

Thorndike, E. L. (1921). On the organization of the intellect. *Psychological Review*, *72*(3), 141-151.

Towle, E., Mann, J., Kinsey, B., O'Brien, E., Bauer, C., & Champoux, R. (2005). Assessing the self-efficacy and spatial ability of engineering students from multiple disciplines. *ASEE/IEEE Frontiers in Education Conference*, *31*(3), 459-80.

Turgut, M. (2005). Individual differences in the mental rotation skills of Turkish prospective teachers. *The Teacher Attribute Journal*, *5.*

Turos, J., & Ervin, A. (2000). Training and gender differences on a Web-based mental rotation task. *The Penn State Behrend Psychology Journal*, *4*(2), 3-12.

Twamley, E. (2009). The role of gender identity on the effects of stereotype threat: an examination of girls' math performance in a single-sex classroom. *Psychology Honors Project.* Paper 15. Retrieved from http://digitalcommons.macalester.edu/psychology_honors/15

Unger, R. K. (1979). Toward a redefinition of sex and gender. *American Psychologist*, *34*, 1085-1094.

United States General Accounting Office. (2011). *A report from the federal inventory of STEM education*. Office of Science and Technology.

University of Chicago School Mathematics Project. (2017). [Website]. Retrieved from http://ucsmp.uchicago.edu/resources/van-hiele/

Uttal, D. H., Meadow N. G., Tipton E., Hand L. L., Alden A. R., Warren C., & Newcombe N. S. (2013). The malleability of spatial skills: a meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352-402. 10.1037/a0028446

U. S. Census Bureau. (2013). Censtats.census.gov/pub/Profiles.shtml. Retrieved from http://www.census2013.org. Retrieved from *http://www.factfinder.census.gov/home/saff/main.html?_lang=en*

U. S. Department of Education, National Center for Education Statistics. (2014). *Digest of education statistics* (2013 ed.). Retrieved from https://nces.ed.gov/

U.S. Department of Education, National Center for Education Statistics. (2012). *Digest of education statistics* (2011 ed.). Retrieved from https://nces.ed.gov/

U. S. Government Office. (2017). Retrieved from https://www.gpo.gov/fdsys/pkg/USCODE 2010-title20/pdf/USCODE-2010-title20-chap38.pdf

Vandenberg, S. G., & Kuse, A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47*, 599-604.

VanGarderen, D. (2002). Visual imaging and mathematical work problem solving by students of varying abilities. *Learning Disabilities Research & Practice, 18*, 246-254.

Van Hiele, P.M., (1986). *Structure and Insight. A theory of Mathematics Education,* Academic Press Inc.

Vasilyeva, M., & Huttenlocher, J. (2003). Early development of scaling ability. *Developmental Psychology*, *40*, 682-690.

Verdine, B., Golinkoff, R., Hirsh-Pasek K., &Newcombe, N. (2017). Spatial skills, their development, and their links to mathematics. *Monographs of the Society for Research in Child Development*, *82*(1), 7-30.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, *117*, 250-270.

Vuontela, V., Steenari, M., Carlson, S., Koisisto, J., Fjallberg, M., & Aronen, E. (2013). Audiospatial and visuospatial working memory in 6–13 year-old school children. *Learning and Memory*, *10*, 74-78.

Waber, D. P. (1976). Sex differences in cognition: A function of maturation rates. *Science, 192*, 572-574.

Webb, R. M., Lubinski, D., & Benbow, C. P. (2007). Spatial ability: A neglected dimension in talent searches for intellectually precocious youth. *Journal of Educational Psychology*, *99*(2), 397-420.

Wiedenbauer, G., & Jansen-Osmann, P. (2008). Manual training of mental rotation in children. *Learning and Instruction*, *18*(1), 30-41.

Wetzel, D. (2009). *Teaching strategies in math for ESL students*. Retrieved from http://continuingeducation.suite101.com/article/cfm/teachingmathtoESLstudents

Wheatley Spatial Ability Test. (1996). The Wheatley spatial ability test form B. West Lafayette, IN: Purdue University.

Williams, A., Sutton, K., & Allen, R. (2008). *Spatial ability: Issues associated with engineering and gender*. Paper presented at the 19th Annual Conference for the Australasian Association for Engineering Education, 2008.

Wong, W. (2017). The space-math link in preschool boys and girls: Importance of mental transformation, targeting accuracy, and spatial anxiety. *British Journal of Developmental Psychology, 35*, 249-266.

Wood, J. T. (1999). *Gendered lives: Communication, gender, and culture* (3rd ed.) Belmont: Wadsworth.

Yenilmez, K., & Kakmaci, O. (2015). Investigation of the relationship between the spatial visualization success and visual/spatial intelligence capabilities of sixth grade students. *International Journal of Instruction*, *8*(1), 189-201.

Yoon, S., & Mann, E. (2017). Exploring the spatial ability of undergraduate students: Association with gender, STEM majors, and gifted program membership. *Gifted Child Quarterly*, *1*(4), 313-327.

APPENDIX A: REQUEST USAGE OF ONLINE ASSESSMENTS FORM

Dissertation Research Information

sharon morris [redacted]om>

03/12/17 at 8:20 PM

To :sales@millisecond.com

CC: Mattson D J (School of Education)

Millisecond Personnel,

I gladly stumbled upon your site today, and believe I found for what I was searching. I am a doctoral student at Liberty University in Virginia, USA. I live in North Carolina, and I am conducting my research at two sites in rural North Carolina.

Recruitment is complete. Permission packets went home to 350 participants. I received **206** signed forms giving permission for their child to participate. The students are in grades 2-8. I am in the midst of attempting to collect data. I have been working through another university to access their online assessments, but there have been major problems downloading the old Authorware and plug-ins at my research sites. Tech folks at the research sites and the university site have been attempting to remedy the situation during the past two weeks, which has slowed my progress considerably.

My research is focused on determining if there is a gender difference between the spatial skills, and if there is, at what level the difference is concentrated.

I am interested in the following tasks:
*Mental Rotation Task for Children (mouse)
*Mental Folding Test for Children (MFTC)
*Spatial Processing task-Manikin task
*Mr. Peanut task

According to your website, I would need to purchase an individual *Inquisit* Web License. At the two research sites, there are numerous computer labs including Chromebook carts. How do I handle the large number of computers and the license agreement? Would the best method involve a small number of computers; i.e. 25 in one computer lab? I am a novice researcher involved in this dissertation journey. I would like the least expensive pathway for this data collection to be successful. Your company would be highlighted in the final presentations at the specific districts, and given knowledge of the assessment system, school personnel would likely look at your website for future assessment purposes.

Another question relates to downloading the data. Since my research questions relate to gender differences and specific grade level gaps, is there a method to collect this information before the tests begin? Will the student participants need a code or other materials?

Thank you for your support. I look forward to your feedback.

Sincerely,
Sharon W. Morris
Doctoral Candidate
Liberty University
Lynchburg, VA

B[redacted] Elementary Teacher
[redacted], NC

APPENDIX B: SCHOOL DISTRICT PARTICIPANT ASSENT FORM

August 25, 2016

Dr. C[redacted] M[redacted]
Assistant Superintendent
[redacted]

Dear Dr. M[redacted],

As a graduate student in the education department at Liberty University, I am conducting research as part of the requirements for a doctoral degree in Curriculum and Instruction. The title of my research project is *The Effect of Gender on Spatial Ability and Spatial Reasoning Among Students in Grades 2-8*, and the purpose of my research is to examine gender differences across three types of spatial ability; namely, spatial perception, mental rotation, and spatial visualization.

I am writing to request your permission to conduct my research in the M[redacted] County School District at one school: J[redacted] Elementary School (K-5) to recruit participants for my research study.

Participants will be asked to go to a specific web-address used in cooperation with *Millisecond/Inquisit*, and click on the link provided to participate in the spatial skills activities. The data will be used to determine if there is a significant difference of spatial visualization skills between male and female students. Participants will be presented with informed consent information prior to participating. Taking part in this study is completely voluntary, and participants are welcome to discontinue participation at any time.

Thank you for considering my request. If you choose to grant permission, please provide a signed statement on approved letterhead indicating your approval with the appropriate signature(s).

Sincerely,
Sharon W. Morris
Bath, N.C
Doctoral Candidate
Liberty University, Lynchburg, VA

APPENDIX C: SCHOOL PARTICIPANT ASSENT FORM

August 25, 2016

Ms. D[redacted] M[redacted], Principal
[redacted]

Dear Ms. M[redacted],

As a graduate student in the education department at Liberty University, I am conducting research as part of the requirements for a doctoral degree in Curriculum and Instruction. The title of my research project is *The Effect of Gender on Spatial Ability and Spatial Reasoning Among Students in Grades 2-8*, and the purpose of my research is to examine gender differences across three types of spatial ability; namely, spatial perception, mental rotation, and spatial visualization.

I am writing to request your permission to conduct my research at [redacted] Charter School in [redacted] County to recruit participants for my research study in grades 6-8.

Participants will be asked to go to a specific web-address used in cooperation with Millisecond/Inquisit, and click on the link provided to participate in the spatial skills activities. The data will be used to determine if there is a significant difference of spatial visualization skills between male and female students. Participants will be presented with informed consent information prior to participating. Taking part in this study is completely voluntary, and participants are welcome to discontinue participation at any time.

Thank you for considering my request. If you choose to grant permission, please provide a signed statement on approved letterhead indicating your approval with the appropriate signature(s).

Sincerely,
Sharon W. Morris
Bath, N.C

Doctoral Candidate
Liberty University
Lynchburg, VA.

APPENDIX D: IRB APPROVAL FORM

LIBERTY UNIVERSITY
INSTITUTIONAL REVIEW BOARD

January 6, 2017

Sharon Morris
IRB Approval 2597.010617: The Effect of Gender on Spatial Ability and Spatial Reasoning among Students in Grades 2-8

Dear Sharon Morris,

We are pleased to inform you that your study has been approved by the Liberty University IRB. This approval is extended to you for one year from the date provided above with your protocol number. If data collection proceeds past one year, or if you make changes in the methodology as it pertains to human subjects, you must submit an appropriate update form to the IRB. The forms for these cases were attached to your approval email.

Thank you for your cooperation with the IRB, and we wish you well with your research project.

Sincerely,

G. Michele Baker, MA, CIP
Administrative Chair of
Institutional Research
The Graduate School

LIBERTY
UNIVERSITY

Liberty University | Training Champions for Christ since 1971

APPENDIX E: EXPLANATION OF STUDY LETTER—SITE 1

January 25, 2017

[redacted] Elementary School
[redacted] Drive
[redacted], NC 27846

Dear Parent/Guardian:

As a graduate student in the School of Education at Liberty University, I am conducting research as part of the requirements for an Educational Doctorate degree. The purpose of my research is to better understand second through eighth grade students' visualization skills as they pertain to the Common Core Mathematics Goal Four, and I am writing to invite your child to participate in my study. This study will attempt to determine gender differences and identify how teachers can increase visualization skills by using different instructional strategies.

If you are willing to allow your child to participate, he or she will be asked to complete four spatial visualization assessments in a computer-based online format. It should take approximately 30 minutes to complete the procedures listed. Your child's participation will be completely anonymous, and no personal, identifying information will be required.

A consent document is attached to this letter. The consent document contains additional information about my research. For your child to participate, complete and return the consent document to your child's teacher by February 7, 2017.

Thank you for your support.

Sincerely,

Sharon W. Morris

Sharon W. Morris
Teacher-[redacted] Schools

APPENDIX F: EXPLANATION OF STUDY LETTER-SITE 2

January 25, 2017

[redacted] School
6344 East [redacted] Road
[redacted], NC 27892

Dear Parent/Guardian:

As a graduate student in the School of Education at Liberty University, I am conducting research as part of the requirements for an Educational Doctorate degree. The purpose of my research is to better understand second through eighth grade students' visualization skills as they pertain to the Common Core Mathematics Goal Four, and I am writing to invite your child to participate in my study. This study will attempt to determine gender differences and identify how teachers can increase visualization skills by using different instructional strategies.

If you are willing to allow your child to participate, he or she will be asked to complete four spatial visualization assessments in a computer-based online format. It should take approximately 30 minutes to complete the procedures listed. Your child's participation will be completely anonymous, and no personal, identifying information will be required.

A consent document is attached to this letter. The consent document contains additional information about my research. For your child to participate, complete and return the consent document to your child's teacher by February 7, 2017.

Thank you for your support.

Sincerely,

Sharon W. Morris

Sharon W. Morris
Teacher-[redacted] County Schools

APPENDIX G: PARENT/GUARDIAN CONSENT FORM

The Liberty University Institutional
Review Board has approved
this document for use from
1/6/2017 to 1/5/2018
Protocol # 2597.010617

PARENT/GUARDIAN CONSENT FORM

Project Title: The Effect of Gender on Spatial Ability and Spatial Reasoning among Students in Grades 2-8

Sharon W. Morris
Liberty University--School of Education

Your student is invited to be in a research study of spatial ability and spatial reasoning in mathematics. He or she was selected as a possible participant because of their grade level, second through eighth grades. I ask that you read this form and ask any questions you may have before agreeing to allow him or her to be in the study.

Sharon W. Morris, a doctoral candidate in the Department of Education at Liberty University, is conducting this study under the supervision of Dr. D. J. Mattson.

Background Information: If your child is in this study, we will ask questions about various shapes and images like the ones that may be studied in math class or drawn for art class. It is a way for us to better understand the best ways for teaching these subjects. We want to find the most effective methods to help students learn about shapes and images and by allowing your child to participate in this study, you will help us reach this goal.

Procedures: If you agree to allow your child/student to be in this study, I would ask him or her to do the following things:

1. Return the signed consent form to the homeroom teacher within 7-10 days of receiving the form.
2. When all forms are collected, a time will be arranged, and the homeroom teacher will administer the spatial visualization computer assessments in the designated computer lab.
3. The four online assessments will take approximately 30-35 minutes. These scores will be used as measures of mathematical achievement and cognitive ability.

Risks and Benefits of being in the Study: The risks involved in this study are minimal, no more than you would encounter in everyday life. Participation in this study does not pose any foreseeable psychological risks or harm to the participants.

There are no direct benefits to participating in this study. However, information gained from this research will provide benefits for researchers and educators to better understand the spatial abilities of students, and how to increase their skills for future success in economic aspirations.

Compensation: Your child/student will not be compensated for participating in this study.

Confidentiality: The records of this study will be kept private. In any sort of report I might publish, I will not include any information that will make it possible to identify a subject.

Research records will be stored securely and only the researcher will have access to the records.

- All records will be kept confidential and will not be released without the district's/school's consent.
- All data will be stored in a locked file cabinet until destroyed.
- The identity of each participant will be kept private and all identifying information will be destroyed after initial research data is collected.

Voluntary Nature of the Study: Participation in this study is voluntary. Your decision whether or not to allow your child/student to participate will not affect his or her current or future relations with Liberty University, [redacted] Elementary, or [redacted] Charter School. If you decide to allow your child/student to participate, he or she is free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions: The researcher conducting this study is Sharon W. Morris. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact her at 252-964-4338/www.sharonwmorris@yahoo.com. You may also contact the researcher's faculty advisor, Dr. D. J. Mattson, at www.djmattson@liberty.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the Institutional Review Board, 1971 University Blvd, Green Hall 1887, Lynchburg, VA 24515 or email at irb@liberty.edu.

Please notify the researcher if you would like a copy of this information to keep for your records.

Statement of Consent: I have read and understood the above information. I have asked questions and have received answers. I consent to allow my child/student to participate in the study.

(NOTE: DO NOT AGREE TO ALLOW YOUR CHILD/STUDENT TO PARTICIPATE UNLESS IRB APPROVAL INFORMATION WITH CURRENT DATES HAS BEEN ADDED TO THIS DOCUMENT.)

____

Signature of Parent Date

____

Signature of Investigator Date

APPENDIX H: CHILD ASSENT FORM

ASSENT OF CHILD TO PARTICIPATE IN A RESEARCH STUDY

What is the name of the study and who is doing the study?
The Effect of Gender on Spatial Ability and Spatial Reasoning among Students in Grades 2-8. The researcher is Sharon W. Morris.

Why are we doing this study?
We are studying how boys and girls in different grades see shapes.

Why are we asking you to be in this study?
You are being asked to be in this study because you are in 2nd, 3rd, 4th, 5th, 6th, 7th, or 8th grade.

If you agree, what will happen?
If you are in this study you will participate in four tests about geometric shapes and space. You will be asked questions about various shapes and images like the ones you may study in math class or draw for art class. It is a way for us to better understand the best ways for teaching these subjects. We want to find the most effective methods to help students learn about shapes and images and by participating in this study, you will help us reach this goal. It will take approximately 30 minutes during your school day.

Do you have to be in this study?
No, you do not have to be in this study. If you don't want to, it's OK to say no.

Do you have any questions?
You can ask questions any time. We are happy to answer questions!

Writing your name and date below means you want to be in the study.

____

Name Date

Sharon W. Morris at smorris@beaufort.k12.nc.us, or sharonwmorris@yahoo.com or
Dr. D. J. Mattson, Faculty Advisor at djmattson@liberty.edu.

Liberty University Institutional Review Board,
1971 University Blvd, Green Hall 1887, Lynchburg, VA 24515
or email at irb@liberty.edu.

APPENDIX I: REQUEST PERMISSION TO USE TEST IMAGES FORM

Katja Borchert <[redacted]@millisecond.com>

- 07/19/17 at 8:33 PM

To

- sharon morris

Message body
hi Sharon,

of course, you can include images of the tasks in your dissertation!
We unfortunately don't have images of all the task readily available but you can run the tasks in Inquisit Lab with the Inquisit monkey feature 'generate screen captures' (menu Experiment -> 'generate screen captures'). This way you don't have to sit there and work your way through the experiment yourself.

If you don't have Inquisit Lab installed you can use the trial version of Inquisit Lab (simply download it from our website. I think even if the trial version is expired, this feature is still working.

hope this helps,
all the best,
katja

On Wed, Jul 19, 2017 at 8:05 AM, sharon morris <[redacted]> wrote:

Hi, Katja!

I hope you are doing well. I have a question about including a snapshot image of each of the four scripts/tests in my dissertation. I would like to request permission to include them in the write-up. Full credit will be given to Inquisit/Millisecond. Is there a method to download the images without going into the script or do you have a file with separate images?

Thank you so much for your assistance.

Blessings,
Sharon W. Morris
Doctoral Candidate
Liberty University

-
Katja Borchert, Ph.D.
Senior Consultant at Millisecond Software LLC