A Study of the Impact of a Drawing Intervention on the Spatial Visualization Skills of Sixth Grade Students

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This is dedicated to my parents, Flora and Clarence Smith, who never let me stop believing in my dream. This work is also dedicated to my beloved husband John N. Schmidt, who without his help this would not have been possible. To Dorothy and Thomas Swain, who provided love and support, and to Dr. Dovie L. Kimmins, my best friend, who was my inspiration and has been there for me throughout this process. To all of you, thank you.

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ABSTRACT

Strong spatial visualization skills are considered a vital component of numerous careers and academic fields. The concept of spatial intelligence has changed from being thought of as an innate ability to skills that can be developed. Studies of spatial ability and skills have grown from simply identifying mechanical ability to being a predictor of success in such academic fields as science, technology, engineering, and mathematics. The purpose of this study was to investigate the usefulness of a particular intervention in enhancing spatial visualization skills in sixth grade students, and to better understand how students of varying spatial visualization skills approach and interact with spatial visualization tasks.

Using a quasi-experimental, mixed-methods design with an embedded, explanatory case study, quantitative data were gathered in the form of pre- and post-tests. Statistical analyses revealed no significant differences between the experimental group that had received the *Quick Draw* intervention for a period of six weeks and the control group that did not receive the intervention. In addition, within the experimental group, no significant differences between males and females existed. Qualitative data were gathered in the form of task-based interviews, classroom observations, and written responses. Results revealed that participants with high spatial visualization skills tended to view images holistically. In contrast, participants with low spatial visualization skills tended to view images based on their components or parts. Implications for classroom practice and future research are discussed.

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CHAPTER ONE: INTRODUCTION

Introduction

If a picture paints a thousand words, then the capacity to visualize may be a vital key to students' academic successes in such fields as mathematics and science (Hegarty & Waller, 2005). Over the last century, the field of mathematics education has experienced tremendous advances in understanding the process of teaching and learning mathematics (National Council of Teachers of Mathematics [NCTM], 1989, 2000); however, there is still work to be done. Educators must seek ways of using and implementing information about how students learn to inform and improve best practices in the classroom (Arbaugh et al., 2009). For example, in this current era of fast-paced computer-aided technology, one may wonder how students' spatial intelligence may be enhanced to help them visualize, represent, and solve increasingly complex problems. The ability to visualize makes it possible to compare multiple variables of a problem with a variety of images (Goetsch, Nelson, & Chalk, 1994). Visualization goes beyond imagery; it involves the process of mentally recreating an image of an object using information to create and solve what-if scenarios (Goetsch et al., 1994).

Strong spatial visualization skills are considered a vital component of numerous fields and careers such as mathematics, physics, chemistry, architecture, geosciences, engineering, computer technology, aeronautical design, architecture, and graphic design (Clements & Battista, 1992; Hegarty & Waller, 2005; Olkun, 2003; Sorby, 1999; Suppiah, 2005). Additionally, spatial visualization has been established as a predictor of success in technology and engineering-related disciplines (Sorby, 1999; Strong & Smith, 2002) as well as mathematics and science (Hegarty & Waller, 2005). As a result, researchers are concerned with the development of spatial visualization skills in students (Clements & Sarama, 2009; NCTM, 1989, 2000; National Research Council [NRC], 2006; Sorby, 1999; Wheatley, 1990, 1991; Wheatley & Reynolds, 1999).

This chapter presents a description of the importance of spatial visualization, a brief history of spatial intelligence, a description of spatial intelligence components, an overview of the related literature, and the importance of spatial intelligence and its components in mathematics. Next, the statement of purpose and significance of study is provided. Finally, definitions of key terms are offered.

Spatial Intelligence

The cognitive psychology theory of multiple intelligences divides the human ability of thinking into two primary realms of research: cognitive intelligence and spatial intelligence (Chu & Kita, 2011; Kozhevnikov, Motes, & Hegarty, 2007; Linn & Peterson, 1985; Patkin & Dayan, 2013). Cognitive intelligence primarily involves the concepts of attention, language, memory, and verbal abilities. In contrast, spatial intelligence encompasses myriad “non-verbal cognitive competences which help individuals absorb and decide visual representations” (Patkin & Dayan, 2013, p. 180). Spatial intelligence is the interplay between the mental representations and spatial features of the real world, and one’s ability to apply and transform them into a new or different representation mentally (NRC, 2006). According to a report by the NRC (2006), spatial intelligence serves three functions of how and why something works. First, spatial intelligence serves to capture, preserve, and convey the appearances and relationships among objects. Second, spatial intelligence is the analytical process that enables one to understand the structure of objects (i.e., a description of how something is organized or how things are related). Third, it helps to answer questions about the evolution and function of objects. Through the use of spatial intelligence, one is able to imagine, hypothesize, test, and make predictions of consequences about the function and relationship of real world objects (NRC, 2006).

Numerous terms are used to describe human spatial intelligence throughout the literature, such as spatial ability (e.g., Newcombe, 2013), spatial reasoning (e.g., Clements & Battista, 1992), spatial skills (e.g., Sorby, 1999), spatial thinking (e.g., Clements & Sarama, 2009), spatial sense (e.g., NCTM, 1989; Wheatley, 1990), and visual perceptions (Carroll, 1993). A distinction in educational psychology research is often made, however, between spatial ability and skill, in that ability is defined as innate (i.e., a person is considered to be born with it), and skill is learned or acquired (Sorby, 1999). Therefore, spatial ability is considered a trait that characterizes a person's ability to perform mentally such operations as rotation, perspective, or orientation (NRC, 2006). According to Sarama and Clements (2009), research has shown that children are born with a certain amount of spatial ability, but more importantly, they possess the potential to improve those abilities through feedback and experience over time. In contrast, spatial skills are often learned within the context of specific subjects, such as mathematics or science, and can be supported and nurtured through tools (e.g., the use of computers) and experiences (NRC, 2006). Bishop (1980) theorized that through spatial experiences students might be able to organize and develop better mental imagery during problem solving.

The previously described lack of consistent terminology contributed to the field of mathematics education's implementation of the phrase spatial sense to refer to spatial intelligence. Wheatley (1990) noted that in the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989) the term spatial sense was used to encompass many of the subcomponents of spatial intelligence. Specifically, NCTM used spatial sense to describe the "intuitive feel for one's surroundings and the objects in them" (NCTM, 1989, p. 49). Additionally, the term spatial sense encompasses the aspect of direction, orientation, size, shape, and perspectives of various objects in space, which are considered vital components of a student's spatial intelligence and mathematical ability (NCTM, 1989, 2000). Spatial intelligence is a multifaceted conglomeration of a variety of subcomponents (NRC, 2006; Patkin & Dayan, 2013). In the following section, a brief history of spatial intelligence will be described.

Brief History of Spatial Intelligence

Spatial intelligence and its subcomponents have been a significant area of research since the early 1900's (Eliot & Smith, 1983; Mohler, 2008a). Both Eliot and Smith (1983) and Mohler (2008a) emphasized that the interest in spatial intelligence was spawned by the research of Sir Francis Galton in 1883 concerning mental imagery. However, research publications focusing on spatial intelligence did not officially emerge in the literature until the early 1920's (Mohler, 2008a). There are four phases of research on spatial intelligence that will be briefly described in the following sections.

Phase I. According to Eliot and Smith (1983), the first phase of spatial intelligence research (1904 – 1938) officially began with Spearman's advocating of a two-factor theory of intelligence, based on the correlations observed among existing ability tests. This phase was characterized by researchers trying to provide evidence for or against the existence of a spatial intelligence factor over, above, and separate from that of the general intelligence factor (Eliot & Smith, 1983; Mohler, 2008a). Many early tests of spatial intelligence were centered on performance tasks (e.g., wire bending, taping, and the manipulation of nuts and bolts) (Eliot & Smith, 1983; Hegarty & Waller, 2005). However, these non-language tests of intelligence were not readily accepted even though they were originally developed to help supplement the identification and prediction of academic success. In 1918, a small but significant change occurred which allowed for better acceptance of such non-language exams (Eliot & Smith, 1983). The United States Army initiated a large-scale testing of military personnel to screen and sort them for military service during World War I. The first World War has historical significance in the area of spatial intelligence in that spatial testing was the first of its kind to be administered to a large number of subjects. After World War I, in order to better screen children and place candidates for mechanical or technical occupations, schools and businesses adopted paper-and-pencil versions of these types of U.S. Army exams (Eliot & Smith, 1983).

Phase II. As identified by Eliot and Smith (1983), the second phase of spatial intelligence research spans from 1938 – 1961. This phase was epitomized by the attempt on behalf of researchers to use statistical means to identify the subcomponents of spatial intelligence, to determine how these subcomponents differed, and to conduct large-scale investigations of spatial intelligence. Once again, war played a role in perpetuating the need for such non-language testing. Upon the onset of World War II, spatial exams were needed, not only in the U.S. but also in Allied Europe. Massive testing was done specifically to identify those military personnel that would be flying or maintaining aircraft (Eliot & Smith, 1983). It was during this time that a larger sample spatial test was administered and analyzed, which led to the support of the existence of the subcomponents (some researchers refer to this as factors) of spatial intelligence, notably spatial relations and visualization (Eliot & Smith, 1983; Mohler, 2008a).

It was also during this time that the identifying characteristics of visualization began to take shape as the "ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and the relative changes of positions of objects in space" (Guilford & Lacey, 1947 as cited in Eliot & Smith, 1983, p. 4). Following World War II, psychologists began to apply wartime spatial intelligence tests to screen children for academic or technical schools, which led to new questions concerning age- and sex-related differences (Eliot & Smith, 1983). There was also prolific development of spatial exams during this phase because of increased need and interest in the subject. This ultimately led to the confusion of spatial terminology (Eliot & Smith, 1983). During this period, the use of differing analysis techniques, the inclusion of conflicting factors, and the rapid prolific development of spatial intelligence exams led to the creation of contradictory names and definitions of spatial intelligence (Carroll, 1993; Mohler, 2008a). According to Eliot and Smith (1983), many subcomponents (i.e., factors) were given similar names, or identical names were used to describe different subcomponents by different researchers. By the end of this phase, however, researchers agreed on two facts: spatial ability was considered separate from general intelligence, and it was comprised of various separable subcomponents (Hegarty & Waller, 2005; Mohler, 2008a).

Phase III. As identified by Eliot and Smith (1983), the third phase from 1961 to 1982 had two notable research shifts: the decline in the number of large-scale studies and the increase in the number of studies aimed at identifying sources of variance in performance on spatial tests. This phase was also marked by two major events: "the popularization of Piaget's developmental account of spatial representation . . . [and] the efforts of experimental psychologists, employing an information-processing approach, to explore varieties of inferred process thought to be involved in the solution of block rotation or surface development tasks" (Eliot & Smith, 1983, p. 6). With the publication of Piaget and Inhelder's book *The Child's Conception of Space* (1967), age-related studies of differences in spatial intelligence became the focus of considerable attention by researchers during this phase (Eliot & Smith, 1983; Mohler, 2008a). In addition to Piaget and Inhelder's work on the evolution of a child's development of the concepts of space, another relevant event occurred during this phase that added credence to spatial intelligence: the publication by Educational Testing Service of two editions of the Kit of Cognitive Reference Tests, in 1963 and 1976, which included spatial tests (Eliot & Smith, 1983). It should also be noted that during this phase researchers became interested in differing abilities across not only age but also gender (Mohler, 2008a).

Phase IV. This current phase of research is still unfolding. Thus far, it has been marked by a desire of psychologists to understand spatial intelligence from an information process perspective and what impact technology is having on one's individual ability (Mohler, 2008a). In addition, new areas of spatial intelligence are being explored through the use of modern psychometric research concerning static and dynamic spatial ability (Mohler, 2008a). This current phase is also characterized by the development and implementation of pre-college activities that can aid students in their development of strong spatial intelligence (Sorby, 1999).

Summary. From the dawn of the 20th century, spatial intelligence and its subcomponents have been a significant area of research (Eliot & Smith, 1983; Mohler, 2008a). Research interests ranged from first investigations of the existence of spatial intelligence (Phase I), to aggregating and defining which subcomponents made up spatial intelligence (Phase II), to examining sources of variance in spatial ability (Phase III). Currently (Phase IV), researchers are focusing on understanding and developing ways of applying spatial intelligence research in the classroom (Carroll, 1993; Eliot & Smith, 1983). One fact has been made clear through examination of this brief history of spatial intelligence. While a unified definition of spatial intelligence may elude researchers, a great number and variety of paper-and-pencil tests of spatial intelligence exist because of researchers' interests in how people respond to such tasks. In *An International Directory of Spatial Tests* (1983), Eliot and Smith identified more than 390 different spatial tests spanning the majority of the 20th century. Spatial intelligence is now considered as a separate complex cognitive ability, about which there are still many unanswered questions (Mohler, 2008a). In the following section, some of the subcomponents of spatial intelligence will be described.

Subcomponents of Spatial Intelligence

According to Patkin and Dayna (2013) and Rafi, Samsudin, and Said (2008), spatial intelligence is a conglomeration of several sub-abilities or skills. Spatial intelligence has many non-verbal subcomponents, spread over a variety of abilities, and encompasses a vast variety of non-verbal cognitive competences. These non-verbal cognitive competences are further divisible into independent sub-abilities or skills, which have been categorized into various subcomponents. For example, in a study of spatial intelligence, McGee (1979) concluded that there were only two subcomponents of spatial intelligence: spatial visualization and spatial orientation. Dissimilarly, in a 1985 meta-analysis, Linn and Peterson divided spatial intelligence into three subcomponents: spatial perceptions, mental rotation, and spatial visualization. In contrast, in a 1993 analysis of more than 140 different datasets, Carroll divided spatial intelligence into five subcomponents: spatial visualization, spatial relations, closure speed, flexibility of closure, and perceptual speed. These discrepancies amongst researchers concerning the number and the nomenclature of subcomponents describing spatial intelligence exist throughout the relevant literature (Carroll, 1993; Eliot & Smith, 1983; Yilmaz, 2009). However, regardless of the number of subcomponents of spatial intelligence identified, there has been a plethora of research since the 1930's, which provides support that spatial intelligence and its subcomponents are important as an area of study (Carroll, 1993; Eliot & Smith, 1983; McGee, 1979; Yilmaz, 2008).

Defining the Three Common Subcomponents

Despite the lack of unanimous agreement among researchers, the three most common subcomponents of spatial intelligence will be used for the purpose of this discussion: spatial orientation, spatial perception, and spatial visualization. Each of these common subcomponents will be described in detail in the following sections.

Spatial orientation. McGee (1979), Linn and Peterson (1985), and Patkin and Dayan (2013) defined spatial orientation as one's capacity to rapidly and accurately rotate a two- or three-dimensional figure while remaining unconfused by the changing appearance of an object from different perspectives. Linn and Peterson (1985) stated that spatial orientation "can be done efficiently using a Gestalt-like mental rotation process analogous to physical rotation of the stimuli" (p. 1485). Spatial orientation requires only the ability to mentally rotate an object while the object remains fixed in space (McGee, 1979; Sorby, 1999; Yilmaz, 2008). According to Carroll (1993), a test of spatial orientation requires that "the subject must imagine that he is reoriented in space, and then make some judgment about the situation" (p. 306) rapidly. Samara and Clements (2009) further explained that spatial orientation "involves understanding and operating on relationships between different positions in space, at first with respect to one's own position and your movement through it, and eventually from a more abstract perspective that includes maps and coordinates at various scales" (p. 161).

Spatial perception. Spatial perception requires one to "determine spatial relationships with respect to the orientation of their own bodies, in spite of distracting information" (Linn & Peterson, 1985, p. 1482). According to Linn and Peterson (1985), spatial perception "can be done efficiently using a gravitational/kinesthetic process" (p. 1485). For example, the water level test utilized by Piaget and Inhelder (1967) (see Appendix A) is often used to measure spatial perception skills (Linn & Peterson, 1985). In this type of test, one must focus on ignoring misleading cues while focusing on the gravitational upright of an object regardless of its orientation (Linn & Peterson, 1985). The distinction between spatial orientation and spatial perception is that spatial orientation emphasizes one's ability to imagine the appearance of an object from different perspectives (Carroll 1993; McGee, 1979; Sarama & Clements, 2009; Yilmaz, 2009), and the time required to reach a solution rather than the accuracy of a solution (Carroll, 1993; Linn & Peterson, 1985). Whereas, spatial perception is defined as one's "ability to determine what the prevailing horizontal and vertical directions are in a scene where distracting patterns are present" (Velez, Silver, & Tremaine, 2005, p. 512).

Spatial visualization. Spatial visualization requires one to perform mental manipulation on two- or three-dimensional objects. These manipulations may consist of a number of mental processes without reference to one's self, such as rotating, twisting, folding, or unfolding. In addition, spatial visualization involves relative changes of position of objects in space or the motion of machinery (Clements & Battista, 1992; Hegarty &Waller, 2005; Linn & Peterson, 1985; McGee, 1979; Sorby, 1999). Unlike spatial orientation, spatial visualization often involves more complicated, multi-step manipulation of information (Linn & Peterson, 1985; Sorby, 1999) in the form of non-verbal internal representations of a perceived object. In contrast to spatial perception and spatial orientation, spatial visualization "can be done efficiently using an analytic process" (Linn & Peterson, 1985, p. 1485). One must retain the mental representation of the object in such a way to be able to mentally manipulate, decompose, compose, rotate, or reorient the actual physical object in a variety of ways (Hoffler, 2010; Risma, Putri, & Hartono, 2013). In contrast, spatial orientation involves the ability to "understand the arrangement of elements within a visual stimulus, primarily with respect to one's body frame of reference" (Hegarty & Waller, 2005, p. 125). Of these three subcomponents, this study will focused on the development of spatial visualization skills.

Despite the presentation of these three subcomponents, it is worth noting that there remains some confusion among researchers regarding the structure of spatial intelligence, due to inconsistencies among investigators in naming the specific spatial ability or skill that they are investigating and the overlapping nature of some subcomponents (Carroll, 1993; Hegarty & Waller, 2005; Mohler, 2008b; Sorby, 1999). Regardless that there is not a consistent definition among researchers as to what constitutes spatial intelligence, it is recognized that the skills that make up spatial intelligence are important for success in many academic fields and careers (Clements & Battista, 1992; Sorby, 1999). The next section will elaborate on the importance of spatial intelligence as it relates to mathematics and education.

Importance in Mathematics and Education

The study of human spatial visualization skills first began in the early 20th century as a means of identifying and predicting academic and vocational success through standardized testing (Eliot & Smith, 1983; Mohler, 2008a). Such studies were an attempt to measure one's mechanical ability for technical occupations (Hegarty & Waller, 2005; Sorby, 1999). Although many psychologists proposed that there is a distinction between visual thinking (i.e., perceptions) and cognitive thinking (i.e., reasoning), perceptual psychologist Rudolf Arnheim (1980) argued that both are necessary in the overall thinking process and that both should be valued in our educational system. To address Arnheim's recommendation, spatial visualization activities such as sketching and mechanical drawing should be encouraged to help students develop a solid foundation in all areas of spatial skills (Sorby, 1999). The goal of increasing a child's spatial visualization skill in mathematics is also considered, by some, to be second in importance only to numerical goals of mathematics instruction (Clements & Battista, 1992; Clements & Sarama, 2009; NCTM, 2000). Further, according to Clements and Battista (1992), the ability to represent and manipulate relevant information in the process of learning and problem solving is an essential component of scientific thought. Researchers such as

Arnheim (1980), Clements and Battista (1992), Olkun (2003), and Sorby (1999) agreed that there has been too little emphasis in the K-12 educational practices of the U.S. on the development of students' spatial visualization skills, and "current geometry curricula do not provide enough opportunities for the development of spatial ability" (Olkun, 2003, p. 1). Further, the NRC (2006) concluded that spatial intelligence and its subcomponents are "presumed throughout the K-12 curriculum but [are] formally and systematically taught nowhere" (p. 131). The power of spatial intelligence is, according to the NRC (2006), underappreciated and underutilized within and across disciplines. In addition, they indicated that although it is true that spatial intelligence and all of its subcomponents are predominant in the teaching and learning of geometry, spatial intelligence and its subcomponents are not, nor should be, limited to any one discipline or subject, but integrated throughout the pre-college curriculum (NRC, 2006).

According to Sarama and Clements (2009), spatial visualization is "an essential human ability that contributes to mathematical ability" (p. 61). Spatial intelligence and its subcomponents are considered by some to be primary building blocks for such mathematical concepts as geometry, measurement, patterning, data presentation, and shapes (Clements & Sarama, 2009; NCTM, 2000). NCTM (2000) recognized the importance of spatial visualization and included it in the K-12 standards for mathematics education. Thus, for example, in grades 6-8, students should be able to "use visualization, spatial reasoning, and geometric modeling to solve problems" (NCTM, 2000, p. 232) by applying such visual skills as drawing geometric objects with specified properties and using both two-dimensional and three-dimensional representations to visualize and solve problems involving surface area and volume (NCTM, 2000).

The NRC (2006) found that in the current educational environment of standards-based curricula, only mathematics and science offered a direct connection to the concept and importance of spatial intelligence in the thinking and reasoning processes (NRC, 2006). However, the NRC noted that the science standards, unlike the mathematics standards, did not address spatial intelligence in terms of thinking and reasoning explicitly or systematically but rather implicitly. In contrast, one is able to find explicit language referring to the concepts of spatial intelligence in the mathematics standards. According to NCTM (2000), spatial sense is a fundamental component of mathematics learning. For example, in order to enhance a student's ability to solve problems and apply geometric thinking, one must be able to mentally build, manipulate, and rotate both two- and three-dimensional representations of objects, and perceive objects from different perspectives (NCTM, 2000). Although the language in the geometry standard specifically refers to the concept of spatial intelligence, in reading the detailed discussion per grade level for all 10 of the mathematics strands, it is obvious that spatial intelligence permeates all of the standards (NRC, 2006). In a tertiary reading of the standards, one will note that there are explicit references to spatial concepts not only in geometry but also in measurement, data analysis, and probability, as well as the representation standards (NCTM, 2000; NRC, 2006). For example, under numbers and operations, if representing numbers using a number line or in data and probability, presenting data in a graphical format could be applications of spatial intelligence (NCTM, 2000; NRC, 2006). Although it is true that the term spatial intelligence is not explicitly stated within the standards, it is clear from reading the standards that the underlying concept is implied throughout (NRC, 2006). Through the development of spatial visualization, students gain a wide variety of skills to enhance their abilities to describe, represent, and interpret the environment around them (NCTM, 2000; NRC, 2006).

Brief Overview of Literature

Spatial intelligence and its many subcomponents have been of interest to researchers for more than 100 years (Carroll, 1993; Eliot & Smith, 1983; Mohler, 2008a). Various spatial skills tests have been developed for determining aspects of one's spatial ability (Eliot & Smith, 1983). Additionally, spatial intelligence has been established as a predictor of success in many academic fields and careers (Eliot & Smith, 1983; Hegarty & Waller, 2005; Sorby, 1999; Strong & Smith, 2002). Although spatial skills have been recognized as important, and the development of spatial skills is essential, evidence within the literature suggests there is too little emphasis being placed on the development of spatial skills in K-12 educational settings in the U.S. (Arnheim, 1980; Clements & Battista, 1992; NRC, 2006; Olkun, 2003; Sorby, 1999). Likewise, it is often presumed that spatial skills are being taught, but according to the NRC (2006), these skills are not being systematically taught within any of the academic fields.

According to much of the research, children's spatial skills may be enhanced through learning experiences (Assessing Women in Engineering Project [AWEP], 2005; Ben-Chaim, Lappan, & Houang, 1988; Bishop, 1980; Goetsch et al., 1994; Kali & Orion, 1996; NRC, 2006; Patkin & Dayna, 2013). However, researchers do not agree on what specific experiences or the length of the experiences that will aid the development of spatial skills (Strong & Smith, 2002; Toptas, Celik & Karaca, 2012; Tzuriel & Egozi, 2010). In one area of disagreement, several researchers, including Clements and Sarama (2009), Kurtulus and Yolcu, (2013), NCTM, (1989, 2000), NRC (2006), Sorby (1999), and Wheatley (1990, 1991), advocate that drawing can help develop students' spatial skills. However, only a few studies utilizing drawing as an instructional intervention to improve middle school students' spatial ability have been conducted to support this, and even fewer with sixth grade students, the population of interest in this study (Parolini, Sorby & Hungwe, 2006; Sorby, Signorella, Veurink & Liben, 2013). Additionally, Clements and Sarama (2009) felt that there is more support for spatial skills in other countries because they expect students to become competent in drawing spatial figures. Having students sketch or draw various figures is believed to help them improve their spatial skills (Brown & Wheatley, 1997; McCoy, Barnett, & Combs, 2013; Richardson & Stein, 2008; Mohler, 2008b; Sorby, 1999; Wheatley, 1990, 1991, 2007).

A second area of disagreement within the literature is the appropriate age for spatial skills intervention and training. Clements and Sarama (2009) felt that early intervention in spatial skills is effective. Support for this can be found in the work of Tzuriel and Egozi (2010) who found that a strategy-oriented intervention using drawing helped first grade children improve their spatial skills on tests of mental rotation. However, these researchers did not investigate spatial visualization. In contrast, Ben-Chaim, Lappan, and Houang (1988) suggested that seventh grade is the optimal age for the teaching of spatial visualization skills based on the results of a study involving fifth through eighth grade students, where seventh grade students showed the most gains. However, few studies have investigated the strategies that students use when tested or trained in spatial skills.

Statement of Purpose

The purpose of this study was twofold. First, using a mixed-methods design, this study examined how sixth grade students are able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. Second, the study examined the differences in gains, if any, with regard to gender. The following research questions were addressed:

1. Is there significant improvement in sixth grade students' overall spatial visualization skills as a result of the *Quick Draw* training? Furthermore, do sixth grade students who receive the *Quick Draw* intervention improve on average more than those who do not?
2. How do students of varying spatial ability approach and interact with spatial visualization tasks?
3. Is there a significant difference in the gains made by students based on gender at this grade level?

Significance of Study

This study contributes to the existing knowledge base regarding middle school students' development of spatial visualization skills by providing insights into how sixth grade students interact with, and benefit from, a drawing intervention. The results of this study provide much-needed insight into students' spatial visualization skills and inform the classroom practice of mathematics educators.

Definition of Terms

Throughout this report, the term *spatial intelligence* is used as the all-encompassing general term that refers collectively to all subcomponents (i.e., spatial orientation, spatial perceptions, and spatial visualization). Specifically, spatial intelligence will be used to refer to the myriad non-verbal cognitive competences, which help individuals perceive the visual world accurately; absorb and decide visual representations creating the image of space whether in one, two, or three-dimensions; and re-create, transform, and modify aspects of visual experiences (Carroll, 1993; Clements & Battista, 1992; Kurtulus & Yolcu, 2013; Patkin & Dayna, 2013). The term *spatial ability* will be used to refer to the innate ability a person is born with before any formal training has accrued (Sorby, 1999). It is the ability one possesses to represent, transform, generate, and recall symbolic, nonlinguistic information (Linn & Peterson, 1985). *Spatial skill* will be used to refer to those spatial aspects that can be learned or acquired through training, education, and experience (Kali & Orion, 1996; Olkun, 2003; Sorby, 1999). The term *spatial visualization* will refer to one's capacity to retain the mental representation of an object so as to perform mental manipulation on two- or three-dimensional objects (e.g., rotating, twisting, folding or unfolding of flat patterns, the relative changes of position of objects in space) using non-verbal multistep manipulation (Jones, Gardner, Taylor, Wiebe, & Forrester, 2011; Linn & Peterson, 1985; McGee, 1979; Sorby, 1999).

Chapter Summary

Strong spatial visualization skills are considered a vital component of numerous careers and academic fields (Clements & Battista, 1992; Hegarty & Waller, 2005; Olkun, 2003; Sarama & Clements, 2009; Sorby, 1999; Suppiah, 2005). The concept of spatial intelligence has changed from being thought of as an innate ability to skills that can be developed (NRC, 2006; Sarama & Clements, 2009; Sorby, 1999). Studies of spatial ability and skills have grown from simply identifying mechanical ability to being a predictor of success in such academic fields as science, technology, engineering, and mathematics (Eliot & Smith, 1983; Hegarty & Waller, 2005; Sorby, 1999; Strong & Smith, 2002). Since the early 20th century, spatial intelligence and its subcomponents (e.g., spatial visualization) have been established as a separate complex cognitive ability worthy of study (Carroll, 1993; Eliot & Smith, 1983; Hegarty & Waller, 2005; Mohler, 2008a). The power of spatial intelligence and its many subcomponents are an underappreciated and underutilized cognitive ability within many classrooms (Arnheim, 1980; NRC, 2006; Sorby, 1999). By utilizing the power of spatial intelligence, specifically spatial visualization skills, there are potential student benefits in the areas of numerical and geometrical applications, as well as encouraging students to explore alternative ways to solve problems (NCTM, 2000; NRC, 2006). This study investigated the usefulness of a particular intervention to help sixth grade students improve spatial visualization skills, and to better understand how students interacted with spatial visualization tasks. The next chapter will address the current body of research as it relates to spatial visualization skills.

CHAPTER TWO: REVIEW OF THE LITERATURE

Introduction

Spatial intelligence is a conglomeration of non-verbal cognitive skills, which helps individuals to perceive, transform, combine, and operate on the world around them using an assortment of subcomponents (Carroll, 1993; Clements & Battista, 1992; Kurtulus & Yolcu, 2013; Patkin & Dayna, 2013). Due to the long history of spatial intelligence over the last century, there is a copious amount of research dedicated to the topic (Carroll, 1993; Clements & Battista, 1992; Eliot & Smith, 1983; Hegarty & Waller, 2005; Linn & Peterson, 1985). The current century finds teachers at a crossroads of implementing standards-based curricula and preparing students for the demands of the ever-increasing technology-based workplace in which one's spatial visualization skill may play an important role (NRC, 2006).

Society often values those things for which there are clear and explicit needs; therefore, it can be argued that two of the most currently valued school subjects are mathematics and science (NRC, 2006). However, underpinning one's success in these subjects is the capacity to think spatially, to imagine and to visualize multiple *what-if* scenarios, thus applying many of the subcomponents of spatial intelligence (NRC, 2006). Additionally, spatial intelligence is recognized as an important skill and is often assumed to be taught across the K-12 curricula; yet it is not formally or systematically acknowledged as part of the current curricula (NRC, 2006). Given the need to develop spatial intelligence in K-12 students, the purpose of this study was to examine how sixth grade students are able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques.

This chapter reviews the research literature that is pertinent to the study of how sixth grade students are able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. This chapter provides a description of the contributions made by prominent educational theorists in the area of spatial intelligence, followed by spatial intelligence as it relates to the STEM domains, the use of drawing as an intervention technique for possible improvement, and research on gender differences and spatial visualization.

Contributions of Educational Theorists

Although there are many theoretical approaches throughout the literature regarding how spatial intelligence is said to develop in children, there is no one theory of spatial intelligence development that encompasses all relevant aspects of spatial intelligence (NRC, 2006; Newcombe & Huttenlocher, 2000). Several learning theories and empirical works "have identified a number of general spatial thinking skills and concepts that are relevant for education in specific domains" (NRC, 2006, p. 272). Throughout the history of spatial intelligence, many well-known educational theorists have made an impact on cognitive and spatial intelligence. Therefore, what follows is an overview of the contributions of fundamental educational researchers who have explored and extended dominant general influences in the concept of spatial intelligence.

Piaget and Inhelder

One may argue that Piaget and Inhelder's work in spatial development is a seminal work in the development of spatial learning theories (Newcombe & Huttenlocher, 2000). Piaget and Inhelder focused on the spatial concepts that children are able to think about and understand at various ages, and their theories concerning spatial intelligence have been extremely influential in cognitive science literature (Battista, 2007; NRC, 2006; Piaget & Inhelder, 1967; Youssef & Berry, 2012). Many of the writings of Piaget and Inhelder have guided the research and development of spatial intelligence for years (Mohler, 2008a; NRC, 2006; Sarama & Clements, 2009; Sorby, 1999; Yilmaz, 2009). Piaget and Inhelder (1967) defined two types of spatial ability: perceptual spatial ability and conceptual spatial ability. Perceptual spatial ability is one's ability to distinguish the spatial relationships between objects, and conceptual spatial ability is one's ability to build and manipulate a mental representation. Piaget and Inhelder are attributed with developing several spatial tests that are still in use which determine a child's spatial ability (Mohler, 2008a; Yilmaz, 2008), as well as describing spatial intelligence development in three stages: topological, projective, and Euclidian (Lefrancois, 2006; Piaget & Inhelder, 1967; Yilmaz, 2009). These three stages are described below.

Topological stage. The topological stage deals with closure and connectedness of two-dimensional space (Piaget & Inhelder, 1967). Topological space, according to Piaget and Inhelder, refers to such concepts as in, out, on, next to, between, open, and closed, which children are able to accomplish by the age of preschool (Piaget & Inhelder, 1967; Sarama & Clements, 2009). Additionally, it is during the topological stage that children acquire two-dimensional skills. However, at this stage children are unaware of spatial orientation and are not able to visualize a scene from another viewpoint (Mohler, 2008a; NRC, 2006; Piaget & Inhelder, 1956, 1967).

Projective stage. The projective stage involves visualizing what objects look like from different viewpoints, or what objects would look like if rotated (Sorby, 1999).

According to Piaget and Inhelder (1967), elementary school children gradually gain the concept of projective and Euclidian space, which continues through adolescence. Once children have obtained a point of view, they are able to understand projections, such as the casting of an object's shadow, rotating of an object, and predicting the shape of a cross section of a three-dimensional object (Mohler, 2008a; NRC, 2006). Furthermore, in the projective stage children learn to transition between two-dimensional and three-dimensional space (Mohler, 2008a). According to Sarama and Clements (2009) and Yilmaz (2009), the Piagetian theories of how children progress spatially involve children building on their notions of space through familiar everyday life experiences.

Euclidian stage. The Euclidian stage, according to Piaget and Inhelder (1967), involves the concepts of parallels, angles, and proportions. In addition, at this stage of spatial development, children are able to visualize the concepts of distance, area, and volume, as well as combine the concept of measurement with their previous skills (Sorby, 1999). In this stage, children have the capacity to explore and analyze complex geometric shapes and to predict the correct shapes of the cross-section of various three-dimensional objects (Boakes, 2009; Kali & Orion, 1996). Additionally, children at this stage of development can transition between two-dimensional and three-dimensional space (Mohler, 2008a). According to Piaget and Inhelder (1967), children progress through each of the stages and should reach the third stage by the age of 12. Although these skills may be acquired by adolescents, some high school and college students may lack this ability (Sorby, 1999; Yilmaz, 2009).

Bruner

Of the many contributions made in the study of education, one cannot overlook the contributions made by Jerome Bruner. Bruner advocated that educators must challenge students to learn and to think, and that learning is not an accumulation of a specific body of memorized facts and correct answers, but is a conglomeration of experiences (Lefrancois, 2008; NRC, 2006). According to Bruner, students need experiences to establish a habit of mind of thinking spatially, and see various opportunities to approach problems by use of their knowledge of spatial thinking (NRC, 2006). In 1959, Bruner used a spatial task to foster students' ability to think by using a paper outline of a map and a pencil, challenging fifth grade students to think spatially utilizing a geography lesson concerning the rational placement of cities, based on the location of natural resources (Bruner, 1959; NRC, 2006). Although one may argue that Bruner's intention was not to teach spatial skills but rather to provide a valuable learning experience for the class, one is clearly able to see that spatial intelligence was a quintessential component to Bruner's geography lesson. What came from this geography lesson was that the students engaged their understanding by encountering new experiences, thus enhancing and increasing their cognitive ability and conceptual skills as a result of interacting with the concept of understanding the spatial task.

Like Piaget, Bruner stressed that children should become engaged in their world. These theorists stressed that children learn through their engagement, and they should construct knowledge based on their experiences. The focus of education should build upon and provide students with rich experiences in the classroom so that their learning potential can be enhanced (Boakes, 2009; Clements & Battista, 1992; Eliot & Smith, 1983, Piaget & Inhelder, 1967). Given the high correlation between children's overall spatial intelligence and their mathematics performance (Clements & Battista, 1992; McGee, 1979; Newcombe, 2013), by incorporating spatial activities and providing students with the opportunity to construct their own knowledge, these activities may be able to enhance their mathematical achievement.

Other Researchers

In addition to the works of Bruner, Piaget, and Inhelder, one will find reference to spatial intelligence smattered amongst the writings of Thorndike, Vygotsky, and more recently Newcombe and Huttenlocher (Mohler, 2008a; NRC, 2006). For example, according to Mohler (2008a), in 1921 Thorndike published a paper describing what he termed *mechanical ability*, which is considered by some to be the starting point of spatial intelligence research. The concept of *mechanical intelligence* was defined by Thorndike to be the ability to visualize the relationship among objects and understand how the physical world works (Mohler, 2008a).

According to Newcombe and Huttenlocher (2000), several of Vygotsky's ideas of cognitive development have become prominent in research involving spatial abilities in the last decade. The Vygotskyan perspective of spatial intelligence states that spatial ability develops and is intrinsically connected to the culture in which one lives (Vygotsky, 1986). Additionally, Vygotsky's theory of the zone of proximal development, when applied to spatial intelligence, can assist students in understanding spatial concepts such as shape and spatial structuring through hands-on, active learning (Vygotsky, 1986). Newcombe and Huttenlocher have sought to unite many theories of Piagetianism, constructivism, Vygotskyanism, and nativism concerning spatial intelligence development into an overarching perspective (Newcombe & Huttenlocher, 2000; Newcombe, Uttal, & Sauter, 2013). Newcombe and Huttenlocher (2000) not only combined several theoretical approaches, but also examined how humans use both spatial coding systems (e.g., code the location of things, navigate the world, and use maps) and spatial representations (e.g., how they mentally represent the material world).

Regardless of the theoretical approach to spatial intelligence development in humans, it is apparent from the literature that spatial intelligence is a highly desirable component of one's overall intelligence. Furthermore, it is a foundational support to many domains such as science, technology, engineering, and mathematics (STEM). This concept of support will be explored further in the next section.

Spatial Intelligence and the STEM Domains

One cannot disagree that mathematical and verbal ability are salient features of one's intellectual ability; however, spatial intelligence has been found to be a keystone in those who choose to enter the spatially demanding fields of STEM (Lubinski, 2010; Miller & Halpern, 2012; NRC, 2006; Newcombe, 2010). According to Lubinski (2010) and based on a review of relevant studies, those individuals who achieve educational and occupational credentials in STEM-related fields have above-normal spatial ability in addition to verbal and mathematical ability. Similarly, Newcombe (2013) stated that even after accounting for both verbal and mathematical ability, students with higher spatial scores are more likely to choose careers in the STEM disciplines. In a robust study entitled Project Talent, Wai, Lubinski, and Benbow (2009) tracked more than 400,000 people who were tested in their high school years and found that those who tested higher in spatial skills were much more likely to choose a career in a STEM-related field than those with lower spatial skills. Newcombe (2010) and Sorby et al., (2013) observed that students with high spatial ability are more likely to be interested in science and mathematics, thus pursuing STEM occupations and advanced academic degrees. Additionally, they felt that early attention to developing children's spatial skills has the potential of enhancing students' interest in mathematics and science, and improving their state-level testing (Newcombe, 2010; Sorby et al., 2013).

Miller and Halpern (2012) stated that the National Science Board in 2010 argued that students who possess high spatial intelligence are an untapped pool of talent critical to the advancement of our current technology-based society. This finding was echoed by Wai, Lubinski, and Benbow (2009) who stated that individuals with high spatial ability, but not necessarily exceptional mathematical or verbal abilities, may be an overlooked resource for STEM domains. Through the systematic implementation of spatial activities across all grade levels and subjects, the potential exists for increasing the availability of those interested in STEM degrees and careers (NRC, 2006).

Newcombe (2010) stated that the past 50 years of research indicated that spatial thinking is a central element to one's success in the STEM fields, and that education should strive to maximize student potential in the areas of spatial skills. Spatial skills can grow when students, parents, and teachers believe that achievement is possible (Newcombe, 2010). However, many students are said to lack experience with spatial tasks, such as mental rotation or spatial visualization, thus training and intervention methods may improve spatial skills for all students (Miller & Halpern, 2012). Compelling evidence that spatial training enhances STEM comes from a set of studies conducted by Sorby on undergraduate engineering and non-engineering students at multiple universities (Sorby, 2009), as well as students in high school and middle school. Many researchers such as Miller and Halpern (2012), NRC (2006), and Newcombe (2010) agree that spatial enriching activities should be embedded into STEM education within the K-12 and college curricula for longer-lasting improvement of spatial skills of all students. Furthermore, Uttal and Cohen (2013) found evidence that supports the claim that spatial training can improve interest and attainment in STEM careers and degrees because it is believed to provide sufficient scaffolding to help students to get through the early challenging college courses and reduce the odds of eventual abandonment. Further, Uttal and Cohen (2013) stated that based on their review of existing evidence regarding the relationship between spatial skill and STEM achievement, training at a younger age could provide substantial advantages to the increase in those interested in STEM degrees and careers.

Drawing Intervention

Given the plethora of spatial skill intervention techniques that have been reported throughout the literature (Ben-Chaim et al., 1988; Casey et al., 2008; Clements & Battista, 1992; Kali & Orion, 1996; Kurtulus & Yolcu, 2013; Linn & Peterson, 1985; Olkun, 2003; Patkin & Dayan, 2013; Samsudin, Rafi, & Hanif, 2011; Sanz de Acedo Lizarraga & Ganuza, 2003; Sorby, 1999; Uttal & Cohen, 2012; van Garderen, 2006), there appears to be no consensus among researchers as to which spatial skills intervention technique has the greatest potential impact on student spatial visualization skills (Newcombe & Frick, 2010). However, several researchers including Piaget (1967), Sorby (1999, 2009), Sorby, Signorella, Veurink, and Liben, (2013), Brown and Wheatley (1997), and Wheatley (1992), have advocated the use of drawing as a means of enhancing students' spatial visualization skills. According to Clements and Sarama (2009), students in the U.S. score lower on spatial visualization tasks because the education system, as compared to that of Japan or China, places little emphasis on both visual representations and students' expectations in competence of drawing. It is believed that there exists more cultural support for these types of activities in other countries (Sarama & Clements, 2009).

In contrast, educators in the U.S. often downplay the importance of spatial skills and view spatial skills and visual thinking as secondary to verbal and mathematical, and may regard them as childish (Clements & Sarama, 2009; Sorby, 2009). However, drawing should not be underestimated in its potential for benefits, as it has consistently been shown to be a significant factor in the development of students' spatial skills as compared to direct instruction and multimedia techniques (Miller & Halpern, 2012; Sorby, 2009). By asking students to visualize and draw various configurations of shapes, such activities promote spatial skills (NCTM, 1989, 2000). Drawing requires students to perform several cognitive operations, such as mentally generating an image, transforming it, and reconstructing it on paper (Miller & Halpern, 2012; Wheatley, 2007).

According to Piaget and Inhelder (1967), making a drawing is an act of representation, not of perception. Inaccurate drawings may reflect the inadequacy of mental tools for spatial representations. Throughout their study *The Child's Conception of Space* (1967), Piaget and Inhelder used drawings to analyze students' spatial abilities. Furthermore, Clements and Battista (1992) stated that students with high spatial ability tended to translate various problems into some form of drawing to help them solve problems. Additionally, many mathematical topics such as geometry require strong spatial visualization skills, but often students find it difficult to visualize two- and three-dimensional objects (Risma et al., 2013). According to Newcombe (2013), relevant research has revealed several reasons why active drawing has a positive influence on students' spatial ability. Drawing is said to enhance student engagement and deepen their understanding by requiring them to reason and make ideas explicit while supporting their ability to communicate spatial concepts and ideas (Newcombe, 2013).

In a series of studies by Wheatley and colleagues involving the use of an intervention drawing technique, (i.e., *Quick Draw*), a variety of students at different grade levels showed improvement in their ability to transform and represent spatial information (Brown & Wheatley, 1997; Wheatley, 1992; Wheatley, Brown, & Solano, 1994). While conducting research for the Mathematics Learning Project at the Florida State University Laboratory School, Wheatley and his colleagues used several problem-centered learning activities, including *Quick Draw,* to engage students in problem-centered learning. They conducted several investigations across various grade levels exploring how students gave meaning to their mathematical and spatial experiences (Wheatley, 1992). The *Quick Draw* intervention program, with its heavy reliance on mental imagery and drawing, is designed to promote students' spatial sense within the mathematics curriculum, with a primary focus on representing and transforming spatial information, according to the NCTM standards (NCTM, 2000; Tzuriel & Egozi, 2010; Wheatley, 2007). In a recent publication *High-Yield Routines: Grades K-8* (McCoy et al., 2013), *Quick Draw* activities were considered a high-yield routine that can enhance the spatial skills of students and allow students the opportunity to apply and use mathematical structure to think about and describe how they saw an image.

According to Yousseff and Berry (2012), there is a trend within the relevant literature that has caused some researchers to question the role of drawing in the development of spatial skills, given the widespread proliferation of advanced graphics technology in our society. However, the salient aspects of drawing cannot be underrated (Lane, Seery, & Gordon, 2009; Mohler, 2008b; Olkun, 2003; Sorby, 1999). Through drawing activities, students are able to practice composing, decomposing, recombining, and transforming visual images into a new image that can be useful in problem solving (Brown & Wheatley, 1997; NCTM, 1989; Sorby, 1999). In a comparison study using pencil-and-paper drawing versus 3-D computer modeling, Sorby (1999) reported that the use of computer modeling with engineering students was not found to develop spatial skills as well as the traditional visualization skill-building technique of drawing. Miller and Halpern (2012) stated that in a recent meta-analysis by Uttal and colleagues, spatial experiences such as sketching can robustly improve students' spatial skills. Additionally, the NRC (2006) stated that despite the increasing penetration of technology into the American school system, students need a variety of both low- and high-technology support systems to develop their spatial skills. According to the NRC (2006), to build spatial skills around technology alone would be a mistake, in that it would restrict the opportunities for students to learn and use spatial skills across the curriculum. Both low- and high-technology tools offer students the power to improve their spatial skills, and activities such as drawing can be easily implemented and provide the basic fundamental building blocks for spatial skills (NRC, 2006). Routines such as *Quick Draw* can easily be incorporated into the daily classroom routine, which provides support and scaffolding for improving students' geometric vocabulary and understanding, as well as enhancing their spatial skills and structures of mathematics (McCoy et al., 2013). Having students in middle school make drawings of various objects and elaborate on their understanding through discussion can have potential positive benefits to students' spatial visualization skills (McCoy et al., 2013; Newcombe, 2010). Additionally, by systematically building such techniques into the existing curriculum across multiple disciplines such as mathematics and science, the results could have the capacity of improving the U.S. education system (NRC, 2006; Newcombe, 2010).

Gender Difference and Spatial Visualization

Since the mid-1970's, investigational research concerning spatial intelligence and its subcomponents (e.g., spatial orientation, spatial perceptions, and spatial visualization) has focused on, among other things, gender differences. In 1974, a book by Maccoby and Jacklin entitled *The Psychology of Sex Differences* motivated researchers' interest in the differences between male and female spatial ability. Maccoby and Jacklin reviewed 32 studies with respect to spatial visualization and found that five of the studies had significant differences favoring males, while three studies had a significant difference favoring females (as cited by Linn & Peterson, 1985). In response to Maccoby and Jacklin's review of prior research, there has been a prolific amount of research concerning various observed gender differences in spatial intelligence.

In 1985, Linn and Peterson performed a meta-analysis of the spatial intelligence research conducted between 1974 and 1982 to determine the magnitude of gender differences. Their review determined that males performed better on certain spatial ability tests, such as those involving mental rotation (i.e., spatial orientation) (Linn & Peterson, 1985). According to Linn and Peterson's seminal review, gender differences in spatial ability were considered large on tasks involving mental rotation, and small for tasks involving spatial visualization (Linn & Peterson, 1985). More specifically, they found that males and females tended to perform equally well on tests of spatial visualization (Linn & Peterson, 1985; Patkin & Dayan, 2013). Linn and Peterson stated that their meta-analysis of spatial visualization supported the previous findings of Maccoby and Jacklin in that males performed better and that "[gender] differences in spatial visualization do not change across the life span" (p. 1490). However, some research appears to rebuke this statement (Miller & Halpern, 2012; Mohler, 2008a; Salthouse et al., 1990; Yilmaz, 2009).

Prior to Maccoby and Jacklin's study, spatial ability was regarded as an innate ability and thus immune from training effects (Rafi et al., 2008). In the 30 years since Linn and Peterson's meta-analysis, there is some evidence that the differences between male and female spatial abilities may be changing due to the increase of spatial experiences of females (Mohler, 2008a; Yilmaz, 2009). Although Linn and Peterson stated that gender differences with regard to spatial visualization do not change across one's life span, other researchers such as McGee (1979) stated that "[gender] differences on tests of spatial visualization and orientation as well as on numerous tasks requiring these abilities do not reliably appear until puberty" (p. 909). Samsudi and colleagues (2011) and Sanz de Acedo Lizarraga and Ganuza (2003) found that age tends to mediate gender differences in spatial ability in that girls can be found to possess higher abilities at a young age, but these begin to lessen as they approach adolescence. However, there is research that suggests that gender differences favoring males across a wide range of spatial tasks, including spatial visualization tasks, may exist in children as young as four years of age (Casey et al., 2008; Tzuriel & Egozi, 2010). According to Mohler (2008a), educational experiences have been found to improve spatial skills in children as young as nine years of age. Nevertheless, some researchers such as Newcombe and Sherman have attributed much of this early gender difference in young children to their experiences and playing with spatial toys such as blocks (as cited in Casey et al., 2008).

According to research, spatial visualization tasks can be solved using a range of mental processes, and one's performance on such tasks depends on the development of the meta-strategies one uses while performing these types of tasks (Linn & Peterson, 1985). Researchers appear to agree, in some respect, that age, education, training, and experience can increase one's spatial skill; however, what type of training experiences and length of experiences has not been firmly established (Baki, Kosa, & Guven, 2001; Casey et al., 2008; Linn & Peterson, 1985; Mohler, 2008a; Parolini et al., 2006; Sanz de Acedo Lizarraga & Ganuza, 2003).

Developing spatial visualization skills is thought by many to be an important component for improving students' achievement in science, mathematics, engineering, and technology, due to the high level of predictability between students' spatial visualization abilities and their potential for academic success (Eliot & Smith, 1983; Hegarty & Waller, 2005; NRC, 2006; Patkin & Dayan, 2013; Sherman, 1980; Sorby, 1999, 2009). Clements and Sarama (2009) felt that early intervention in spatial skills is effective. Support for early intervention can be found in the work of Tzuriel and Egozi (2010) whose findings differed from previous training studies which had indicated that spatial performance levels of males and females rose in parallel and that the gender gap is maintained. Tzuriel and Egozi (2010) found that a strategy-oriented intervention using drawing helped first grade children improve their spatial skills on tests of mental rotation (i.e., spatial orientation).

Additional evidence of the narrowing of the gender gap is reported in the study by Miller and Halpern (2012), who stated that Uttal and colleagues found a consensus, amongst 217 studies, indicating that spatial training can narrow the gender gap of spatial skills. In a study of middle school students, Sorby found that girls who experienced intervention training at the middle school level enrolled in subsequent mathematics and science courses (Sorby, 2009; Uttal & Cohen, 2012). In a study involving 98 secondary school pupils using a web-based virtual environment involving spatial visualization and mental rotation tasks, Samsudin, Rafi, and Hanif (2011) found a significant increase in spatial visualization and mental rotation as a result of eight weeks of spatial training. Their findings seemed to support the premise that gender differences in cognitive tasks of this nature are getting smaller. In a large study involving 1,000 socioeconomically diverse students in fifth through eighth grades, Ben-Chaim, Lappan, and Houang (1988) found that regardless of gender, students' spatial visualization skills improved as a result of spatial visualization task training. They also found seventh grade students made the greatest gains, and they suggested that this was an optimal age for teaching spatial visualization. Newcombe (2007) found that gender differences were not unchallengeable and felt that they could be virtually eliminated given proper intervention (as cited in Tzuriel & Egozi, 2010). Additionally in a longitudinal study, Sorby (2009) found that college-level students who participated in spatial training activities had a significantly higher gain in their spatial skills as measured by standardized testing instruments. Additionally, those who participated in the spatial training had higher grades in introductory mathematics, science, and engineering courses, as compared to those students who did not receive spatial training (Sorby, 2009). Collectively these studies appear to support the premise that through proper intervention tasks, spatial visualization skills can be improved and the differences between the genders may be narrowed.

The preponderant amount of evidence seems to suggest that, regardless of previous findings by Maccoby and Jacklin that gender differences in spatial visualization do not change across the life span, there is evidence to support the notion that training can improve one's spatial visualization skills (Ben-Chaim et al., 1988). Based on a review of the literature one can conclude that there is a typical but not universal finding that males' performance on spatial visualization tasks is higher than females (Ben-Chaim et al., 1988; Maccoby & Jacklin, 1974; Sherman, 1980). Spatial visualization skills develop over a period of time through a wide variety of real-world, recreational, and educational experiences (Baki et al., 2011; Newcombe, 2013; Newcombe & Frick, 2010). According to Battista (1990), the ultimate goal of studying gender differences should not be to determine if such differences exist, but to design an effective intervention strategy to help all students succeed by improving their spatial skills. Additionally, research indicates that everyone can benefit from enhanced spatial training regardless of ability, age, or gender (McGee, 1979; Newcombe, 2013; Newcombe & Frick, 2010; Wai et al., 2009; Youssef & Berry, 2012).

Chapter Summary

This chapter presented the relevant literature that informs this study of examining how sixth grade students were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. Given that there has been shown to exist a high correlation between spatial intelligence and mathematical performance (Clements & Battista, 1992), the need to incorporate spatial activities into the K-12 mathematics classroom could potentially have dividends of increasing students' interests in the STEM fields (Lubinski, 2010; Miller & Halpern, 2012; NRC, 2006; Newcombe, 2010). By adding drawing activities such as *Quick Draw* into the daily classroom routine, educators may be able to assist students in developing and enhancing their spatial skills (McCoy et al., 2013; NCTM, 2000; Wheatley, 2007). *Quick Draw* activities provide students the opportunity to give meaning to their experiences and apply the use of mathematical structure (McCoy et al., 2013; Wheatley, 2007). In addition to enhancing student's spatial intelligence, *Quick Draw* activities may also increase their interest in mathematics and science (Newcombe, 2010; Sorby et al., 2013). With regard to gender, incorporating spatial activities into the classroom according to various researchers may narrow, if not eliminate, the gender gap (Ben-Chaim et al., 1988; Miller & Halpern, 2012; Newcombe, 2007; Samsudin et al., 2011). Even though spatial visualization skills and spatial intelligence develop over a long period of time through a wide variety of real-world, recreational, and educational experiences (Baki et al., 2011; Newcombe, 2013; Newcombe & Frick, 2010), educators can help to enhance their development by incorporating high-yield routines into the educational experience of students (McCoy et al., 2013). The next chapter will provide information regarding the methods used in this study of how sixth grade students were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques.

CHAPTER THREE: METHODOLOGY

Introduction

Spatial ability and its subcomponents, specifically spatial visualization, have been established as a predictor of success in the areas of science, technology, engineering, and mathematics (Hegarty & Waller, 2005; NRC, 2006; Sorby, 1999). Additionally, students' spatial visualization may improve through experience (Hungwe, Sorby, Drummer, & Molzon, 2007). However, researchers do not agree on the type, appropriate age, or duration of experiences that will enhance students' spatial visualization skills (Tzuriel & Egozi, 2010). To this end, the purpose of this study was twofold. First, using a quasi-experimental, mixed-methods design, the study examined how sixth grade students were able to benefit, if at all, from spatial visualization *Quick Draw* intervention techniques. Second, the study examined the differences in gains, if any, with regard to gender. This chapter provides a description of the research design, research context and participants, instruments and data sources, and procedures, as well as the methods performed for data analysis and the limitations of the study.

Research Design

This study used an embedded mixed-methods approach to examining how sixth grade students were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. Mixed-methods research is applicable to a wide range of disciplines and is effective when a single data set, whether quantitative or qualitative, is not sufficient in answering the research questions (Creswell & Plano Clark, 2011). The mixed-methods design allows one to collect a richer and stronger array of evidence than a single research design method (Yin, 2014). Therefore, this study used a mixed-methods design to examine how sixth grade students were able to benefit from spatial visualization intervention tasks in addition to how students of varying ability approached and interacted with such tasks. The sections that follow describe the type and design of the study. The first section defines the study as an embedded mixed-methods study; the second section defines the explanatory case study design; and the third section discusses the multiple holistic case design.

Embedded Mixed-Methods Study

An embedded mixed-methods design allows the researcher to combine the collection and analysis of both quantitative and qualitative data within a traditional quantitative research design or qualitative research design, which lends support to aspects of the experimental design (Creswell & Plano Clark, 2011). The embedded mixed-methods research design is helpful in examining the different foci of the research questions addressed in this study (Creswell & Plano Clark, 2011). Likewise, the embedded mixed-methods design lends itself to examining the reactions of participants during the intervention process (Creswell & Plano Clark, 2011). The current study utilized a traditional, quantitative research design, with an embedded explanatory case study. Embedding the explanatory case study within the research design enables one to address a broader, more complicated research question than a case study alone (Yin, 2014).

Explanatory Case Study

According to Creswell (2013) and Yin (2014), qualitative research involves multiple methods that are interactive, humanistic, and involve active participation. Qualitative research emerges from the data, is not tightly prescribed, and thus lends itself to the gathering of multiple forms of data (Creswell, 2013; Yin, 2014). One of the purposes of this study was to examine how students of varying spatial ability approached and interacted with spatial visualization tasks; therefore, the explanatory case study method was employed. According to Yin (2014), the function of an explanatory case study is to explain how or why. As a result, the explanatory case study method was well-suited for this study. The researcher focused on a select number of participants, to be described later, to allow an in-depth examination and obtain detailed data (Patton, 2002) of how students of varying ability approached and interacted with the *Quick Draw* intervention. Along with the quantitative information, the explanatory case study method allowed the researcher to probe deeper into explaining how students of varying spatial visualization skills interacted with spatial tasks through a series of interviews. A case study alone would not have been able to show the impact regarding the influence of the *Quick Draw* activity with respect to the participants' spatial visualization skills. Thus, the explanatory case study was embedded within the traditional quantitative research design.

Multiple Holistic Case Design

For the case study, the units of analysis were four individuals identified with varying spatial ability. Two individuals of high spatial visualization skill and two individuals of low spatial visualization skill served as the multiple cases in the study. According to Yin (2014), a multiple case study can provide information concerning the differences amongst subgroups (e.g., high spatial ability, low spatial ability) within a study. Additionally, by involving multiple holistic cases, according to Yin (2014), the data will be more compelling and therefore regarded as more robust.

Research Context and Participants

This study took place in a Southeastern, suburban public middle school servicing students in sixth through eighth grades, with a majority of the students being white (74%) and less than half of the total student population being eligible for free or reduced lunch programs (38%). During the 2014 – 2015 academic year, there were 218 sixth grade students enrolled in the school; 51% male (111) and 49% female (107). The participants for this study were a convenience sample of sixth grade students enrolled in one teacher's sixth grade mathematics classes during the fall of 2014. Based on the researcher's experiences, sixth grade is a pivotal year for some school systems, such as the one chosen for this study, in that at the end of the school year students are assessed for placement in advanced honors classes (e.g., Algebra I). As a result, this study involved sixth grade students in one teacher's intact classes.

The host teacher taught five sections. Three of these were randomly selected to serve as the experimental group, and the remaining two sections acted as the control after examinations were completed and overall scores calculated. The chosen school used inclusion for those students who required special education services. The host teacher had two inclusion classes; therefore one was randomly assigned to each of the groups (i.e., experimental and control). Table 1 provides demographic information on the experimental and control groups.

Table 1

Demographic Information of Experimental and Control Groups

	Experimental (n = 43)		Control (n = 34)	
	Number	Percentage	Number	Percentage
Race/Ethnicity				
Asian	4	9	2	6
African American	2	5	4	12
Caucasian	34	79	26	76
Latino	2	5	2	6
Other	1	2	0	0
Gender				
Male	22	51	18	53
Female	21	49	16	47

A purposeful sample of four participants from the experimental group was selected to participate in the semi-structured, task-based interviews. After calculating participants' individual and overall test scores, a pool of potential case-study participants was identified. To create the pool, participants were first identified as having either high or low spatial visualization skill. Participants were identified high in spatial visualization skill if their total overall scores on the five exams were one standard deviation above the class mean. Likewise, participants identified as low in spatial visualization skill were one standard deviation below the class mean. This procedure for identifying participants with high and low spatial visualization skills has been used in previous studies (personal communication with Dr. Sorby, June 3, 2014). Next, participants were ranked within the pools based on their raw scores and, along with teacher recommendation, a subset consisting of two students with high spatial visualization skill and two students with low spatial visualization skill were purposefully selected to be case-study participants. More information will be provided on each case study participant in Chapter Four.

Instruments and Data Sources

Both quantitative and qualitative data were collected with the expectation that the combination of both sets of data would strengthen the results in a more rigorous analysis. The following sections describe the quantitative and qualitative instruments and data sources used in this study.

Quantitative Instruments

As previously stated, there are more than 390 different testing instruments designed to measure spatial skills (Eliot & Smith, 1983), and many of the exams are designed to measure a single component of spatial skills. Therefore, several authors have advocated for the use of multiple spatial exams for testing spatial skills. For example, Hungwe et al. (2007), Kali and Orion (1996), Patkin and Dayan (2013), and Samsudin, Rafi, and Hanif (2011), used multiple testing instruments with students in order to obtain an accurate portrayal of a student’s level of spatial skill. Therefore, in this study five exams were used to test students’ spatial visualization skills. What follows is a brief description of each of these instruments.

Purdue Spatial Visualization Test: Rotations (PSVT:R) (modified). Guay (1977) developed the PSVT:R to assess a person’s ability to visualize rotated solids. The original test consisted of 30 items, which were scored on the percentage correct from questions ranging in difficulty levels. The PSVT:R requires one to identify a rotation of an object and apply the same rotation to a new object (Battista, Wheatley, & Talsma, 1982; Eliot & Smith, 1983; Hamlin, Veurink, & Sorby, 2009). During the fall of 2005, Gorska and Sorby (2008) administered a subset of PSVT:R to middle school students in the U.S. Of the 30 original questions, a subset of 10 problems varying in difficulty level was selected from the test (Hamlin et al., 2009; Hungwe et al., 2007; Gorska & Sorby, 2008). In their study, Gorska and Sorby (2008) found the modified version of the PSVT:R to be an applicable and reliable (Cronbach alpha = 0.64) instrument for measuring middle school students' spatial skills. Because this shortened, modified PSVT:R instrument was found to be applicable and reliable for testing middle school students' skill in visualizing rotated solids, it was selected for use in the current study.

Mental Cutting Test (MCT) (modified). The MCT was first developed as part of a university entrance examination in the U.S. in 1939 (College Entrance Examination Board [CEEB], 1939). The original test consisted of 25 items and was timed for 20 minutes. The MCT requires the students to choose, from among five options, the correct cross-section of a three-dimensional figure that has been cut by an indicated imaginary plane (Gorska & Sorby, 2008). The MCT is designed to measure how well a student visualizes the two-dimensional plane after cutting a three-dimensional object (Hamlin et al., 2009). During the fall of 2006, Gorska and Sorby (2008) administered a subset of the MCT to middle school students in the U.S. Of the 25 original questions, a subset of 10 problems varying in difficulty level was selected from the test (Hamlin et al., 2009; Hungwe et al., 2007; Gorska & Sorby, 2008). In their study, Gorska and Sorby (2008) found the modified version of the MCT to be an applicable and reliable (Cronbach alpha = 0.67) instrument for measuring middle school students' spatial skills. Because this shortened, modified MCT instrument was found to be applicable and reliable for testing middle school students' skills in visualizing the two-dimensional plane after cutting a three-dimensional object, it was selected for use in the current study.

Differential Aptitude Test: Space Relations (DAT:SR) (modified). Bennett, Seashore, and Wesman (1973) developed the DAT:SR test for academic and vocational screening purposes for grades 8-12 (Eliot & Smith, 1983). The original test consisted of 60 items and was a timed test (25 minutes) (Eliot & Smith, 1983). The DAT:SR requires one to fold a two-dimensional pattern into a three-dimensional figure (Eliot & Smith, 1983; Gorska & Sorby, 2008). During the fall of 2005 and 2006, Gorska and Sorby (2008) administered a subset of items from the DAT:SR test to middle school students in the U.S. Of the 60 original questions, a subset of 10 items varying in difficulty level was selected from the test (Hungwe et al., 2007; Gorska & Sorby, 2008). In their study, Gorska and Sorby (2008) found the modified version of the DAT:SR to be an applicable and reliable (Cronbach alpha = -0.68) instrument for measuring middle school students' spatial skills. Because this shortened, modified DAT:SR instrument was found to be applicable and reliable for testing middle school students' skill to fold a two-dimensional pattern into a three-dimensional figure, it was selected for use in the current study.

Lappan Test (modified). The Lappan Test was developed in 1981 for the assessment of spatial visualization skills aimed at the middle school level (Ben-Chaim et al., 1988; Gorska & Sorby, 2008). The original test was an untimed test consisting of 32 questions of three types of representations: "two-dimensional flat view, three-dimensional corner view, and 'map plan,' which includes the description of the base of the building by squares and numbers in each square to tell how many cubes are to be placed on that square" (Ben-Chaim et al., 1988, p. 55). The Lappan Test assesses one's understanding of the basics of isometric sketching and orthographic projection, in order to further assess how well one is able to visualize different views of a given object

(Hamlin et al., 2009; Gorska & Sorby, 2008). To reflect engineering standards of graphical representations, Gorska and Sorby (2008) modified the original design of the test. During the fall of 2005 and 2006, Gorska and Sorby administered a subset of the modified Lappan Test questions to middle school students in the U.S. Of the original 32 questions, a subset of 10 problems varying in difficulty level was selected from the test (Hungwe et al., 2007; Gorska & Sorby, 2008). In their study, Gorska and Sorby (2008) found the modified version of the Lappan Test to be an applicable and reliable (Cronbach alpha = -0.63) instrument for measuring middle school students' spatial visualization skills. Because this shortened, modified Lappan Test instrument was found to be applicable and reliable for testing middle school students' skills in understanding isometric sketching and orthographic projection, it was selected for use in the current study.

Wheatley Spatial Ability Test. Wheatley developed the Wheatley Spatial Ability Test in 1978 for the assessment of mentally rotating and comparing various two-dimensional figures (Wheatley, 1996). "This dimension of spatial ability has been shown to be highly related to students' mathematical understanding and potential for mathematical thinking" (Wheatley, 1996, p. 2). The test consists of 100 items in which students must decide if the figures will match each of five congruent figures by rotating them in a plane; however, the figure may not be reflected (Clements, Battista, Sarama, & Swaminathan, 1997; Wheatley, 1996). "The test is timed to discourage use of analytic strategies in responding to items. Students have eight (8) minutes to answer 100 questions with a yes or no" response (Wheatley, 1996, p. 1). The test is a valid and reliable instrument for determining middle school students' spatial visualization skills (Erbilgin & Fernandez, 2004; Wheatley, 1996).

Qualitative Instruments and Data Sources

To examine how students of varying spatial ability approach and interact with spatial visualization tasks, several qualitative instruments were utilized: background questionnaires, task-based interview protocols, classroom observation protocols, and the researcher. A brief description of each of these instruments follows.

Background questionnaire. In addition to academic experiences, researchers have found that several non-academic activities such as playing video games, sports, or working with construction toys may influence or have an impact upon the development of spatial visualization skills (Deno, 1994; Newcombe, 2010; Samsudin et al., 2011; Sorby, 1999; Tzuriel & Egozi, 2010; Youssef & Berry, 2012). Therefore, along with basic demographic information, the background questionnaire (see Appendix B) was created by the researcher in order to collect data concerning favorite toys, video or computer games, and favorite sport(s).

Task-based interview protocols. The task-based interview protocol (see Appendix C) was designed by the researcher to reveal students' spatial visualization thinking processes while performing a spatial activity (i.e., *Quick Draw*) using the think-aloud process. The questions were designed to elicit responses from the participants by asking them to think aloud while they solved a *Quick Draw* activity. The think-aloud process allowed the researcher to understand the thought process of the participant as he or she drew the given image (van Someren, Barnard, & Sandberg, 1994). By utilizing the think-aloud method, the participants could better explain their methods of attempting tasks. The questions during the task-based interview aimed to elicit what the participants saw, how they saw it, what they saw first, as well as what word, image, or phrase helped them to remember how to draw what they saw. The semi-structured interview allowed the researcher to probe and ask clarifying questions, as needed, if responses to interview questions were brief in regard to the participants' thought processes about the spatial visualization task (Merriam, 2009). In addition, participants' responses directed the order of the activities and provided questions to be asked during the individual interviews. A total of four task-based interview protocols are included.

Classroom observation protocols. Observations are a powerful tool in qualitative research and made it possible for the researcher to gather multiple forms of data, thus allowing for triangulation of the data (Yin, 2014). As the nonparticipant observer, classroom observations served three purposes: to observe the teacher's implementation of the intervention techniques; to observe the class as they interacted with the intervention; and to observe a subset of selected participants in order to determine their interest and interaction with the classroom activities over the course of a period of six weeks.

Teacher observation. Observations of the teachers' implementation of the *Quick Draw* intervention were conducted to ensure fidelity to the procedures as described by Wheatley (2007) in *Quick Draw: Developing Spatial Sense in Mathematics*. Additionally, classroom observations were used to document the type of probing questions the teacher asked during the intervention (see Appendix D).

Class observation. The second purpose of classroom observations was to document the overall class interaction with the intervention (see Appendix E). The researcher paid particular attention to such behaviors as participant interest, body language, gestures, and verbal description of the displayed images to ascertain how they may have developed over the six-week period.

Case study observation. The third purpose of classroom observations was to document the behaviors of the case study participants including interest, body language, gestures, and verbal description of images (see Appendix F). Additionally, the observations of the class and the case study participants were used to inform the researcher on the content of probing follow-up questions to be asked during subsequent interviews (see Appendix C, interview protocols 2, 3, and 4).

Notebook. Throughout the six-week study, all participants were asked to respond to the *Quick Draw* images daily and keep them in a notebook provided to them by the researcher. These physical artifacts were collected to provide documentation, insight, and a broader perspective into how the class interacted with the *Quick Draw* activity (Merriam, 2009; Yin, 2014).

The researcher. The researcher served as an instrument of the study (Creswell, 2013). The researcher's background is provided in order to establish credibility. The researcher is a female pursuing a Doctor of Philosophy in Mathematics and Science Education, with 15 years of public school teaching experience, teaching seventh and eighth grade. Ten of those 15 years were spent teaching eighth grade, advanced honors geometry. The researcher holds two master's degrees: a Master of Science in Teaching and a Masters in City and Regional Planning. Additionally, the researcher served as an adjunct faculty at the university for 20 years and has taught various undergraduate courses in mathematics. The researcher studied qualitative research in a class at the university and served as a researcher on studies utilizing qualitative research methods. These professional experiences have prepared and qualified the researcher for serving in this role as an instrument in the current study.

Procedures

This section explains the procedures utilized during the study. A focus of this study was a specific case, bounded by place and time, using multiple sources of data as required by case study design (Corbin & Strauss, 2008; Creswell, 2013; Merriam, 2009; Yin, 2014). The bounded system used for this study was a sixth grade class at a suburban middle school over the course of six weeks in the fall of 2014. What follows is a description of how the students were selected to participate in the study, classroom observations, individual interviews, and post-test procedures.

Pretesting and Selection of Groups

Upon approval of the Institutional Review Board (IRB) (see Appendix G), the researcher described the study to potential participants, satisfying the requirements set forth by the Institutional Review Board (IRB) concerning parental consent. In September 2014 after fulfilling the IRB requirements of obtaining parental consent, all sixth grade students in the host teacher's classroom were tested using the previously described instruments (i.e., PSVT:R (modified), MCT (modified), DAT:SR (modified), Lappan Test (modified), Wheatley Spatial Ability Test). One should note that only the data of those students who returned the signed parental consent forms were used in the analysis. Of the 101 students enrolled in the host teachers' mathematics classes, 80 agreed to participate in the study. Additionally some students were removed from the study due to absences, leaving 77 students who were both pre- and post-tested. Participants completed the pre-tests during three 45-minute sessions in mid-September. The researcher was responsible for testing and scoring all spatial tests.

Participant Initial Interview

Case-study participants participated in a series of four task-based interviews in order to document how students of varying spatial ability approach and interact with spatial visualization tasks. These interviews offered valuable insight into what strategies were utilized and how sixth grade students approached and solved spatial visualization tasks. The researcher served as the interviewer for all interviews. An interview protocol with items selected from the *Quick Draw* activities was used to document and assess students' thinking and strategies when solving spatial visualization tasks (see Appendix C). The initial interview was in week two, after the introduction to the project. The initial interview was used to gain familiarity with the participants and to establish a baseline of how these participants thought about spatial visualization tasks through a task-based, think-aloud *Quick Draw* activity, similar to the one to be utilized in the next class period.

Quick Draw Intervention

Beginning in October 2014, the host teacher engaged the experimental groups in *Quick Draw* activities during each school day for six consecutive weeks. These activities were conducted at the beginning of every class period, lasting approximately five minutes (see Appendix H). These activities required the participants to draw what they saw, emphasizing the past tense, because participants made their drawings using the mental picture they constructed after the figure was removed from sight (Wheatley, 2007). These activities were not necessarily in conjunction with the host teachers' mathematical objective of the day. In addition to the intervention activities, class time was used for observations of the teacher and participants as described in the next section.

Typical *Quick Draw* activity. *Quick Draw* is designed to help students create powerful mental imagery (Wheatley, 2007). In this study, *Quick Draw* was used as a whole-class lesson opener activity (Wheatley, 2007). With *Quick Draw,* a figure such as the one shown in Figure 1 was shown to participants for a few seconds via PowerPoint using the built-in three-second timer on the *Quick Draw* image slides. Participants were then asked to draw what they saw. The past tense is used because participants must have drawn the figure from their constructed mental image (Wheatley, 2007). The participants were given a second look at the image, and then an opportunity to redraw or make corrections to their original image, if necessary. Once all participants completed their drawings, the host teacher encouraged the class to discuss the image and share their strategies and thoughts about how they saw and drew the image (see Appendix H). Additionally, the participants described how they conceptualized the shape during the viewing stage, and what word or image they used to help them during the reconstruction of the image.

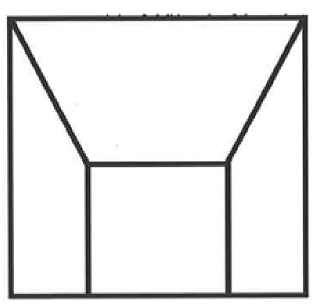


Figure 1. Example of a *Quick Draw* figure.

Weekly activities. *Quick Draw* activities are divided into seven levels with a total of 168 images varying in difficulty. From these seven levels, the researcher selected activities starting with simple designs and increasing in complexity over the course of the first five weeks of the study (Wheatley, 2007); see Appendix I for the schedule of the weekly *Quick Draw* activities selected. During the sixth week, the *Quick Draw* intervention was modified to include challenging participants to rotate some of the prior figures 90 degrees.

Observations

Observations were planned according to Table 2 using the observational protocols. The Teacher Observation Protocol (see Appendix D) was used during teacher observation, the Whole Class Interaction Protocol (see Appendix E) was used during classroom observations, and the Case Student Interaction Protocol (see Appendix F) was used during observations of the case study participants.

Table 2

Weekly Observation Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1	Teacher	Teacher	Whole class	Whole class	Case students
Week 2	Whole class	Case students	Whole class	Case students	Whole class
Week 3	Teacher	Case students	Case students	Case students	Whole class
Week 4	Whole class	Case students	Case students	Case students	Whole class
Week 5	Case students	Whole class	Case students	Case students	Case students
Week 6	Case students	Case students	Case students	Whole class	Teacher

Participant Individual Interviews

The researcher interviewed case study participants individually four times throughout the course of the study. The initial interview as previously described was in week two; subsequent interviews occurred after the second and fourth weeks, and near the conclusion of the study. As in the first interview, to the extent possible, subsequent interviews utilized the method of selection of similar tasks used in the classroom, to ascertain what the participant was thinking during the construction of their images.

Like the first interview, the remaining interviews were task-based, in which participants were asked to think aloud about how they drew the image that was displayed (see Appendix C). These interviews were used to document and ascertain if these participants' thinking changed as a result of the classroom intervention and follow-up discussions over time.

In addition to a task, the final interview included questions to ascertain the participants' perceptions of the impact of *Quick Draw* on their spatial skills (see Appendix C). Participants in the case study were asked about any significant changes in their abilities or beliefs that changed about their spatial visualization skills, as a result of their experiences with the *Quick Draw* activities. The final interview was used to determine how the participants' view of their spatial visualization had changed as a result of the classroom intervention and follow-up discussions.

Post-test Administration

After six weeks, participants from both experimental and control groups completed the identical post-measures of the testing instruments (i.e., PSVT:R (modified), MCT(modified), DAT:SR (modified), Lappan Test (modified), and the Wheatley Spatial Ability Test). These post-tests were completed during two 45-minute sessions in early December on consecutive days one week after the last classroom intervention during the first week of December 2014.

Data Analysis

Quantitative Data Analysis

The primary, quantitative research question for the proposed study was: Is there significant improvement in sixth grade students' average overall spatial visualization skill as a result of participating in the *Quick Draw* training specified in this document? Furthermore, do sixth grade students who receive the *Quick Draw* intervention improve on average more than those who do not? The overall scores on the Pre- and Post-test were the average of the scaled and equally weighted spatial visualization subtests (i.e., PSVT:R (modified), MCT (modified), DAT:SR (modified), Lappan Test (modified), and the Wheatley Spatial Ability Test). The overall Pre- and Post-test scores were paired for each student, and the difference in these overall scores (subtracted in the order of Post-test minus Pre-test) were coded as to whether the student was in the treatment group or the control group (i.e., having received the intervention or not, respectively). It was determined that the resulting differences in the overall scores of the experimental group Pre-test Total scores represented scores sampled from a distribution that was approximately normal; however, the control group Pre-test Total scores were not representative of a sample from a normal distribution. Therefore, non-parametric methods were used to detect if there were differences in the median. Additionally it was determined that the Post-test Total scores of both the experimental and control groups represented samples from a normal distribution. However the data was analyzed using non-parametric methods for consistency of the analysis.

The secondary, quantitative research question was: Is there a significant difference in the gains made by students based on gender at this grade level? To address this research question the data were analyzed using a two-sample *t*-test because it was determined that for the experimental group both female and male Pre-test Total and Post-test Total scores represented scores sampled from a distribution that was approximately normal.

Qualitative Data Analysis

The guiding qualitative question for this proposed study is: How do students of varying spatial ability approach and interact with spatial visualization tasks? To begin the analysis process, the researcher transcribed each case study interview in order to write a case record for each case study participant, including the major information that was utilized in the case study analysis (Patton, 2002). Additionally, both classroom observations and various artifacts collected during the course of the study were inserted into the case record in order to develop a broader perspective concerning participants' spatial visualization skills (Yin, 2014).

The case records for each individual case study participant were used to construct a final holistic case study narrative of each participant, illuminating the focus of the inquiry regarding how the participants interacted with the *Quick Draw* activities (Merriam, 2009; Patton, 2002). Furthermore, the individual case studies were compared and contrasted through content analysis in order to generate within-case themes, patterns, and findings (Patton, 2002). In addition to within-case analyses, a cross-case analysis was utilized to build a general explanation concerning the shared similarities and themes of how sixth grade students of varying spatial ability approach and interact with spatial visualization tasks (Creswell, 2013; Merriam, 2009; Yin, 2014). The resulting themes from within- and cross-case analyses were described, interpreted, and presented as findings.

Limitations

Given the context for this research, the sample was one of convenience and not truly random. Because of this and the inherent uniqueness of the one setting of this study, the results may not generalize to different settings. However, for the qualitative analysis the intent is not to generalize but to support transferability of results by providing thick descriptions (Merriam, 2009). Another limitation of the current study was the reliance on the researcher as an instrument; therefore, all interpretations of the interview are the product of the researcher's lens, although grounded in data (Yin, 2014). Likewise, it is assumed that the participants' responses are authentic and uninfluenced by the researcher. Additionally during the course of the study it was determined that some of the participants were enrolled in art class during the six-week implementation period, and it is not clear as to how this might have influenced the results of the study.

Chapter Summary

The embedded, mixed-methods research design is helpful in examining the different foci of the research questions addressed in this study (Creswell & Plano Clark, 2011). Likewise, the method lends itself to examining the reactions of participants during the intervention process (Creswell & Plano Clark, 2011). Along with the quantitative information, the case study research is supportive in exploring how students of varying spatial visualization skill interact with spatial task. Overall, data was collected through instruments such as the modified PSVT:R, MCT, DAT:SR, Lappan Test, and the Wheatley Spatial Ability Test, as well as four one-on-one task-based interviews, classroom observations, and written responses to classroom activities. All data, quantitative and qualitative, were analyzed to provide in-depth answers to the research questions addressed in this study. The next chapter will provide a detailed analysis of the quantitative and qualitative data collected, analyzed, and used in this study of how sixth grade students were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques.

CHAPTER FOUR: RESULTS

Introduction

The study of spatial visualization skills, which first began in the early 20th century as a means of identifying and predicting academic and vocational success through standardized testing, has grown into a vital component of numerous careers and academic fields (Clements & Battista, 1992; Eliot & Smith, 1983; Hegarty & Waller, 2005; Mohler, 2008a; Olkun, 2003; Sarama & Clements, 2009; Sorby, 1999; Suppiah, 2005). The current study investigated the usefulness of the *Quick Draw* intervention to help sixth grade students improve their spatial visualization skills, and to better understand how students approach and interact with spatial visualization tasks. This chapter provides the results of both the quantitative and qualitative data analysis for the purpose of determining how sixth grade students were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques, including an examination of the gains if any with regard to gender. This embedded mixed-methods study gathered both quantitative and qualitative data from sixth grade classes at a Southeastern suburban middle school over a period of six weeks. This chapter provides an analysis of the data acquired during the study, including the pre/post-testing and four case study results. The research questions guiding this study were:

1. Is there significant improvement in sixth grade students' overall spatial visualization skill as a result of the *Quick Draw* training? Furthermore, do sixth grade students who receive the *Quick Draw* intervention improve on average more than those who do not?

2. How do students of varying spatial ability approach and interact with spatial visualization tasks?
3. Is there a significant difference in the gains made by students based on gender at this grade level?

This chapter is presented in sections addressing each of the research questions. The first section will be devoted to the quantitative analysis, organized as follows: results of the Pre-test instruments including any Pre-test differences found between the treatment and control groups; results of the Post-test; the analysis of the paired difference of the Post- minus Pre-test results; and the analysis of the experimental group by gender. Following these quantitative results, the qualitative results will be presented. These results will include the analysis of each case followed by the cross-case analysis.

Quantitative Results

Pre-test

A total of 77 students (43 experimental, 34 control) completed the Pre- and Post-tests for each of the selected instruments: PSVT:R (modified); MCT (modified); DAT:SR (modified); Lappan Test (modified); and Wheatley Spatial Ability Test. Each subtest was scored on a scale of 0 to 10. Of these tests, the Wheatley Spatial Ability Test is the only test scored on a continuous scale; all other scores are discrete. Additionally, the Pre-test Total score was calculated by equally weighting all five subtests for a total of 100%. The descriptive statistics for the individual Pre-test scores for the experimental and control groups are provided in Table 3.

Table 3

Descriptive Statistics for the Individual Subtest Pre-test Instruments

	Experimental (*n*=43)			Control (*n*=34)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Pre PSVT:R	3.14	2.01	3.00	3.91	2.21	4.00
Pre MCT	3.05	1.85	3.00	3.41	1.54	3.00
Pre DAT:SR	3.53	1.75	3.00	3.18	1.71	3.00
Pre LAPP	2.67	1.90	3.00	2.35	1.57	2.00
Pre WSAT	4.15	2.32	3.85	4.44	2.33	4.08

An analysis of all participant data was accomplished using SPSS computer software. Table 4 provides the descriptive statistics for the Pre-test Total scores of the experimental and control groups. Additionally, the last line of Table 4 provides the corresponding *p*-value for the groups based on the Shapiro-Wilk normality test. It was determined that the experimental group Pre-test Total scores represented scores sampled from a distribution that was approximately normally distributed; however, the control group Pre-test Total scores were not representative of a sample from a normal distribution.

Table 4

Pre-test Total Scores

	Experimental	Control
n	43	34
Mean	3.31	3.46
Standard Deviation	1.36	1.67
Median	3.40	3.11
Shapiro-Wilk *p*-values	0.121	0.048

Due to the non-normal distribution of the control Pre-test Total scores, non-parametric methods were used to detect if there were differences in the median Pre-test Total scores at the beginning of the intervention. The Kruskal-Wallis test (H = 0.20, *df* = 1, $p = 0.66$) revealed no significant differences between the experimental group and the control group median Pre-test Total scores of participants at the beginning of the intervention. This established that the two groups possessed the same overall spatial visualization ability at the start of the intervention.

The Shapiro-Wilk test of normality was run on the five Pre-subtest scores with mixed results, thus non-parametric methods were again used to examine the difference in the subtest scores for the experimental and control groups. A Kruskal-Wallis test was run on each of the five subtests, and no significant difference was found to exist between the individual subtest scores of the experimental and control groups at the beginning of the intervention (see Table 5).

Table 5

Kruskal-Wallis Test Results of Individual Subtest Pre-test Scores

	Experimental *Mdn*	Control *Mdn*	H	*p*
Pre PSVT:R	3.00	4.00	2.12	0.15
Pre MCT	3.00	3.00	1.10	0.30
Pre DAT:SR	3.00	3.00	0.81	0.37
Pre LAPP	3.00	2.00	0.43	0.51
Pre WSAT	3.85	4.08	0.37	0.55

Post-test

The Post-test was administered during the first week of December 2014, one week after the final intervention. The descriptive statistics for the individual subtest Post-test instruments scores for the experimental and control groups are provided in Table 6.

Table 6

Descriptive Statistics for the Individual Subtest Post-test Instruments

	Experimental (*n*=43)			Control (*n*=34)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Post PSVT:R	4.00	2.33	4.00	4.26	2.38	5.00
Post MCT	3.16	1.57	3.00	3.35	1.45	4.00
Post DAT:SR	4.02	2.41	4.00	3.79	1.59	4.00
Post LAPP	3.23	1.86	3.00	2.71	1.61	2.00
Post WSAT	5.77	2.61	5.80	6.24	2.62	6.60

Table 7 provides the descriptive statistics for the Post-test Total scores of the experimental and control groups. Additionally, the last line of Table 7 provides the corresponding *p*-value for the groups based on the Shapiro-Wilk normality test.

Table 7

Post-test Total Scores

	Experimental	Control
n	43	34
Mean	4.04	4.07
Standard Deviation	1.53	1.41
Median	3.94	4.07
Shapiro-Wilk *p*-value	0.793	0.694

Although it was determined that Post-test scores for both the experimental and control groups were normally distributed, the data was analyzed using non-parametric methods for consistency of the analysis. The Kruskal-Wallis test (H = 0.00, *df* = 1, *p* =

0.99) revealed no significant difference between the medians of the treatment group and the control group on the Post-test Total scores of participants at the end of the intervention.

Even though the Post-test Total scores of both the experimental and control groups represented samples from a normally distributed population, only one of the subtests was found to be normally distributed for both groups: the PSVT:R. A Kruskal-Wallis test was run on each of the five subtests, and no significant difference was found to exist between the individual subtest scores of the experimental and control groups at the end of the intervention (see Table 8).

Table 8

Kruskal-Wallis Test Results of Individual Subtest Post-test Scores

	Experimental *Mdn*	Control *Mdn*	H	*P*
Post PSVT:R	4.00	5.00	0.40	0.52
Post MCT	3.00	4.00	0.36	0.55
Post DAT:SR	4.00	4.00	0.07	0.79
Post LAPP	3.00	2.00	1.28	0.26
Post WSAT	5.80	6.60	0.79	0.37

Post-test minus Pre-test Paired Differences Analysis

In order to control for individual student differences in spatial visualization abilities at the beginning and the end of the intervention, the individual Pre-test and Post-test scores were matched by student scores for the subtest scores and the Total scores. The descriptive statistics of the differences (subtracted in the order of Post-test minus Pre-test scores) for the subtest experimental and control groups are provided in Table 9.

Table 9

Descriptive Statistics for the Differences in the Individual Subtest Instruments

	Experimental (*n*=43)			Control (*n*=34)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Diff PSVT:R	0.86	1.68	1.00	0.35	2.16	0.00
Diff MCT	0.12	1.26	0.00	-0.06	1.81	0.00
Diff DAT:SR	0.49	2.12	0.00	0.62	1.76	1.00
Diff LAPP	0.56	1.89	1.00	0.35	1.82	1.00
Diff WSAT	1.63	1.85	1.70	1.70	1.70	2.15

Table 10 provides the descriptive statistics for the Post-test Total minus Pre-test Total difference in scores of the experimental and control groups. Additionally, the last line of Table 10 provides the corresponding *p*-value for the groups based on the Shapiro-Wilk test of normality. It was determined that the differences in the Post-test Total minus Pre-test Total score for the experimental group was sampled from a normal distribution; however, the total difference in the Post-test Total minus Pre-test Total score for the control group was not.

Table 10

Differences in Post-test Total Score Minus Pre-test Total Score

	Experimental	Control
n	43	34
Mean	0.73	0.61
Standard Deviation	0.83	0.92
Median	0.80	0.79
Shapiro-Wilk *p*-values	0.056	0.026

In order to determine if there was significant improvement in sixth grade students' overall spatial visualization skill as a result of the *Quick Draw* intervention, the matched pairs difference (Post-test minus Pre-test) for the experimental group was examined using a Wilcoxon Signed Rank test. The test revealed statistically significant higher differences in the total median scores for the experimental group following participation in the *Quick Draw* intervention ($z = -4.34$, $p < 0.001$) with a medium-to-large effect size ($r = 0.47$). The median score of the overall Test Total increased from Pre-test (*Mdn* = 3.40) to Post-test (*Mdn* = 3.94). Additionally, the experimental group was found to have made significant improvement on the PSVT:R ($z = -3.019$, $p = 0.003$), the LAPP ($d = -1.93$, $p = 0.05$) and the WSAT ($z = -4.40$, $p < 0.001$) tests (see Figure 2).

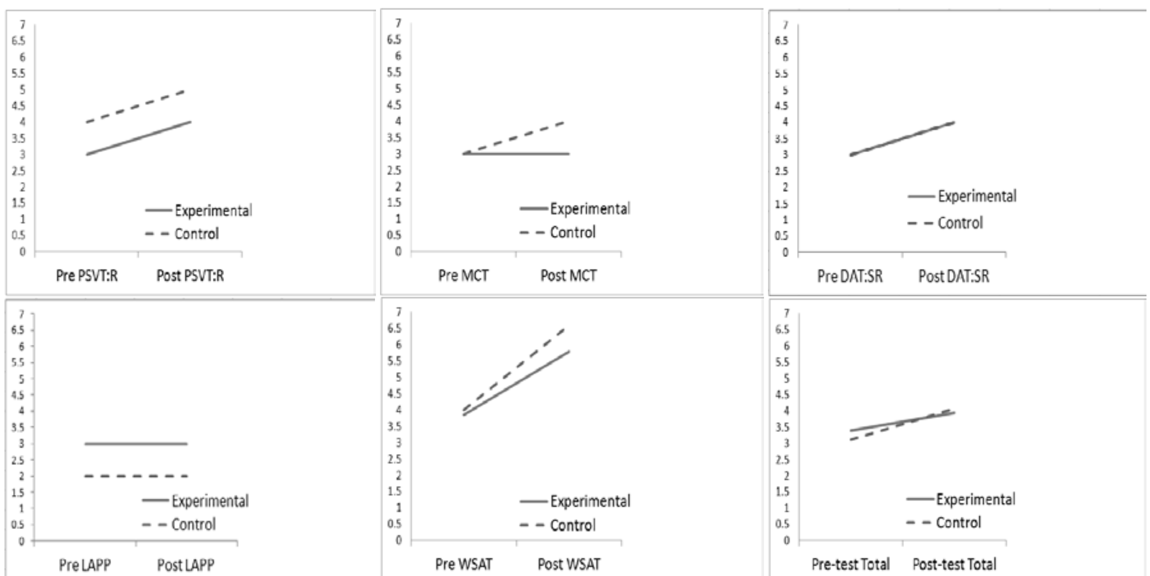


Figure 2. Median Pre-test and Post-test scores for each subtest and Total.

It should be noted that the Wilcoxon Signed-Rank test of the differences for the control group of the Post- minus Pre-test scores also revealed that the control group had a statistically significant higher difference between the Post- and Pre-test total scores ($z = -3.26$, $p = 0.001$), with a medium effect size ($r = 0.39$). Additionally, the control group was found to make significant improvement on the DAT:SR ($z = -2.11$, $p = 0.035$) and WSAT ($z = -3.967$, $p < 0.001$) tests.

To determine if sixth graders who received the *Quick Draw* intervention improved on average more than those who did not, the differences in the experimental group total test score and the control group total test score were compared using a Kruskal-Wallis test. The test revealed that there was no statistically significant differences in the overall test scores of the two groups (H = 0.14, p = 0.704).

Gender Comparison Experimental Group

Pre-test for gender. To determine if there was a significant difference in spatial visualization gains made by sixth grade level students based on gender, the differences between males and females in the experimental group were analyzed. There were 43 participant Pre-test and Post-test scores for the experimental group: 21 females and 22 males. The descriptive statistics for the individual subtest Pre-test scores for the experimental group based on gender are shown in Table 11.

Table 11

Descriptive Statistics of Subtest Pre-testing Instruments Based on Gender for Experimental Group

	Female (*n*=21)			Male (*n*=22)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Pre PSVT:R	2.81	1.83	3.00	3.45	2.15	3.50
Pre MCT	2.90	1.33	3.00	3.18	2.26	3.00
Pre DAT:SR	3.90	1.81	4.00	3.18	1.65	3.00
Pre LAPP	2.67	1.83	3.00	2.68	2.01	3.00
Pre WSAT	4.71	2.46	5.05	3.61	2.10	2.83

Table 12 provides the descriptive statistics for the Pre-test Total scores of the experimental group based on gender. Additionally the last line of Table 12 provides the corresponding p-value for the Shapiro-Wilk normality test for each gender.

Table 12

Pre-test Total Scores of Experimental Group Based on Gender

	Females	Males
n	21	22
Mean	3.40	3.22
Standard Deviation	1.37	1.38
Median	3.52	3.22
Shapiro-Wilk *p*-values	0.600	0.061

Figure 3 shows the variation in Pre-test subscores and total score by gender. Of particular note is how much higher the females' scores were on the WSAT at the beginning of the study. The variabilities are somewhat averaged out in the total score. The males' Total Pre-test score was slightly lower, though not significant, than the females based on means (and medians) prior to the *Quick Draw* intervention as shown in Figure 3.

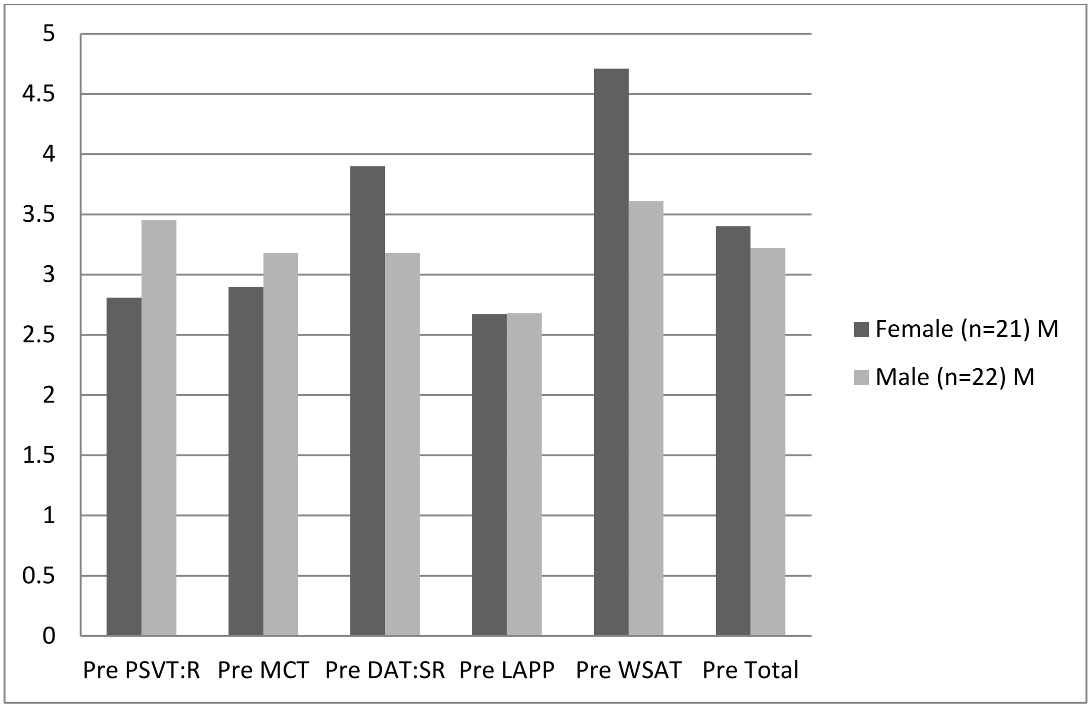


Figure 3. Experimental Pre-test averages on individual testing instruments based on gender.

An analysis at the beginning of the study determined that both females and males in the experimental group Pre-test Total scores represented scores sampled from a distribution that was approximately normal. Therefore, a two-sample *t*-test based on gender was performed on the Pre-test total. There was no significant difference in the average scores for females (*M* =3.40, *SD* =1.27, *Mdn* = 3.52) and males (*M* = 3.22, *SD* =1.38, *Mdn* = 3.23) in the Total Pre-test scores $t(41) = 0.42$, $p = 0.68$.

Post-test for gender. The descriptive statistics of the experimental group subtest Post-test scores based on gender are shown in Table 13.

Table 13

Descriptive Statistics of Subtest Post-testing Instruments Based on Gender for Experimental Group

	Female (*n*=21)			Male (*n*=22)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Post PSVT:R	3.81	1.75	4.00	4.18	2.81	4.00
Post MCT	3.29	1.10	3.00	3.04	1.94	2.00
Post DAT:SR	4.76	2.51	5.00	3.32	2.12	3.00
Post LAPP	3.19	1.75	3.00	3.27	2.00	2.50
Post WSAT	6.35	2.52	7.30	5.22	2.63	5.23

Table 14 provides the descriptive statistics for the Post-test Total scores of the experimental groups based on gender. Additionally, the last line of Table 14 provides the corresponding *p*-value for the Shapiro-Wilk normality test.

Table 14

Post-test Total Scores of Experimental Group Based on Gender

	Females	Males
n	21	22
Mean	4.28	3.81
Standard Deviation	1.34	1.69
Median	4.20	3.86
Shapiro-Wilk *p*-values	0.981	0.699

Figure 4 shows the variation in Post-test subscores and total score by gender. Once again, the females' score on the WSAT at the end of the study remained higher than the males' score. The variabilities are somewhat averaged out in total score. The males' Total Post-test score remained slightly lower, though not significant, than the females' based on means (and medians) after the *Quick Draw* intervention as shown in Figure 4.

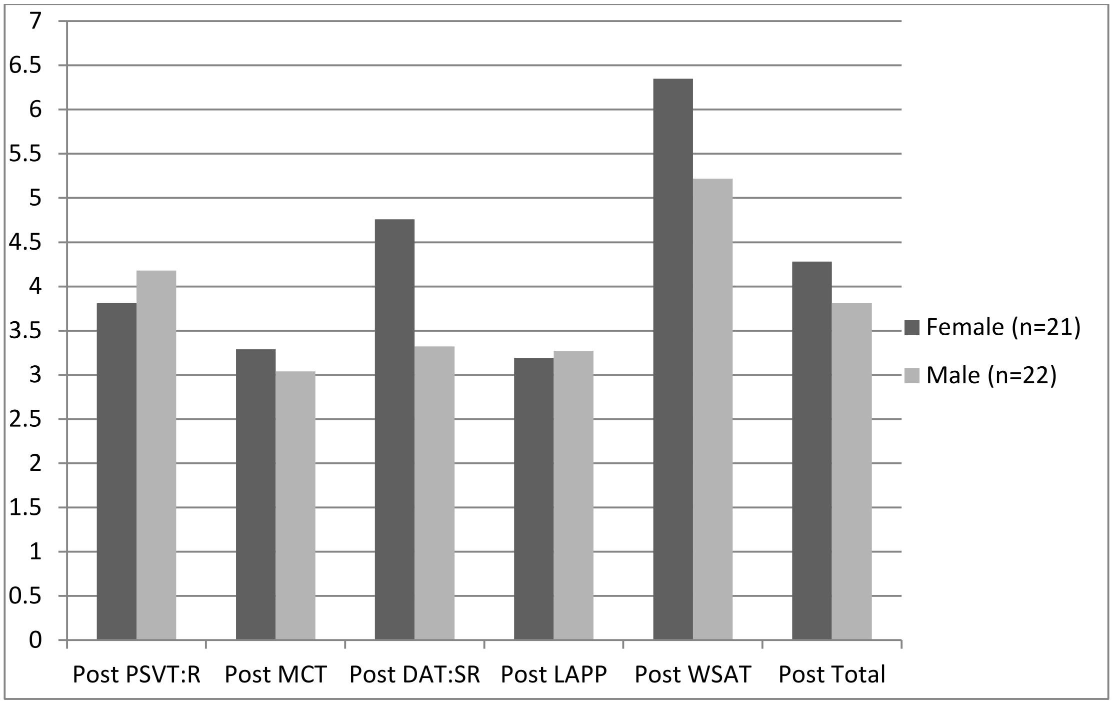


Figure 4. Experimental Post-test averages on individual testing instruments based on gender.

An analysis at the end of the study determined that both females and males in the experimental group Post-test Total scores represented scores sampled from a distribution that was approximately normal. Therefore, a two-sample *t*-test based on gender was performed on the Post-test total. There were no significant difference in the scores for females (M = 4.28, SD = 1.34, Mdn = 4.20) and males (M = 3.81, SD = 1.69, Mdn = 3.86) in the Total Post-test scores ($t(41) = 1.01$, $p = 0.318$).

Post-test minus Pre-test difference. In order to control for individual student differences in spatial visualization abilities at the beginning and the end of the intervention, the individual Pre-test and Post-test scores were matched by student scores for the subtest scores and the Total scores. The descriptive statistics of the differences (subtracted in the order of Post-test minus Pre-test scores) for females and males of the experimental group subtests are provided in Table 15, with the last line showing the differences by gender for the Total score.

Table 15

Descriptive Statistics for the Individual Difference in the Sub-testing and Total-testing Instruments Based on Gender

	Female (*n*=21)			Male (*n*=22)		
	M	*SD*	*Mdn*	*M*	*SD*	*Mdn*
Diff PSVT:R	1.00	1.87	1.00	0.73	1.52	0.50
Diff MCT	0.38	1.16	1.00	-0.14	1.32	0.00
Diff DAT:SR	0.86	2.08	1.00	0.14	2.14	0.00
Diff LAPP	0.52	1.63	0.00	0.59	2.15	1.00
Diff WSAT	1.65	1.49	1.70	1.61	2.18	1.50
Diff Test Total	0.88	0.65	0.83	0.59	0.96	0.68

To better understand the gains represented in Table 15, consider the Diff PSVT:R female average gain of 1.00. A gain of 1.00 represents an average improvement of 1 point out of 10 points, which is equivalent to an increase of 10% in a participant's score. To determine if there was a significant difference in the gains made by students based on gender at the sixth grade level, the differences among the males and females of the experimental group were analyzed using a two-sample *t*-test (i.e., a matched pairs *t*-test). The test revealed that there was no significant difference in the average scores for females (M = 0.88, SD = 0.64, Mdn = 0.83) and males (M = 0.59, SD = 0.96, Mdn = 0.68) at this grade level ($t(41) = 1.18$, $p = 0.24$).

As a comparison, there were no significant differences found in the average gains in the total test score based on gender made in the control group at this grade level ($t(32) = 0.22$, $p = 0.83$). When examining the amount of improvement for this sample based on gender by comparing the experimental group females to males, one finds that the males improved their combined total score slightly more than half a unit (0.59 or approximately 6%), whereas the females improved almost an entire unit (0.88 or approximately 9%) (see Figure 5).

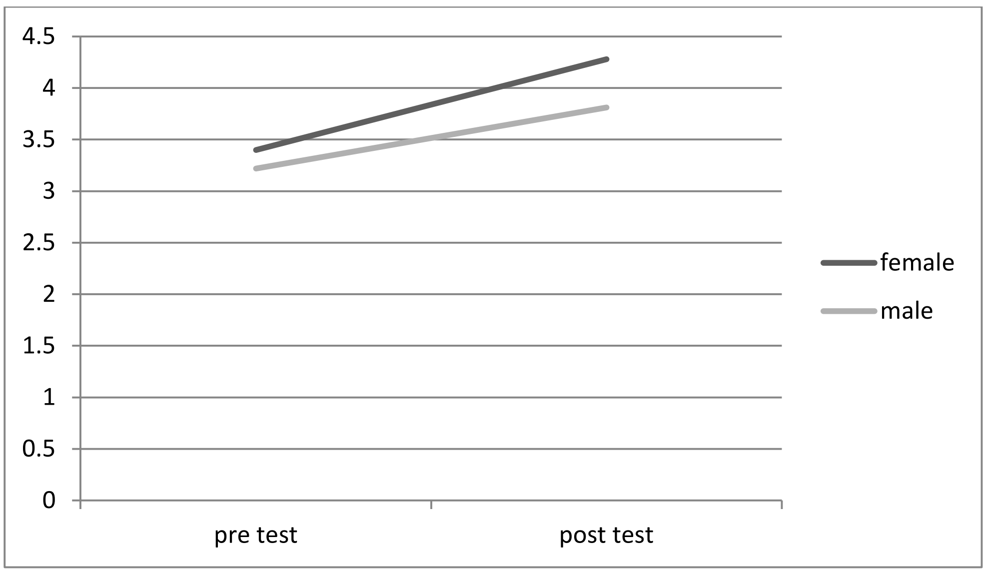


Figure 5. Mean Pre-test Total and Post-test Total scores by gender.

Quantitative Summary

The two-fold purpose of this study was to investigate the usefulness of the *Quick Draw* intervention in sixth grade students' ability to improve their spatial visualization skills and to better understand how sixth grade students approach and interact with spatial visualization tasks through an embedded mixed-methods design. This section presented the results of the two quantitative research questions.

The research addressed the following quantitative questions: is there significant improvement in sixth grade students' overall spatial visualization skill as a result of the

Quick Draw training; furthermore, do sixth grade students who receive the *Quick Draw* intervention improve on average more than those who do not? In answering the first part of the research question, concerning improvement of those who received the intervention, the Wilcoxon Signed Rank test revealed a statistically significant higher difference total median score in the experimental group following participation in the *Quick Draw* intervention. However, when examining the control group differences, there was also a statistically significant higher difference between the Post- and Pre-test. To determine if sixth graders who received the *Quick Draw* intervention typically improved more than those who did not, the difference in the experimental group total test score and the control group total test score was compared, and no significant difference in the overall test scores was revealed.

In determining if there was a significant difference in the gains made by students based on gender at the sixth grade level, analysis of the Post- minus Pre-test scored paired differences were analyzed. The analysis revealed that there was no significant difference among the participants based on gender at this grade level. In the next section, results related to the qualitative question of how do sixth grade students of varying spatial ability approach and interact with spatial visualization tasks will be presented.

Qualitative Results

The current study aimed to better understand how students interact with spatial visualization tasks. This section provides the results of the qualitative data analysis. More specifically, this section addresses the guiding question: how do students of varying spatial ability approach and interact with spatial visualization tasks? A purposeful sample of four participants from the experimental group was selected based on their total test scores and teacher recommendation to participate in semi-structured, task-based interviews. Two participants, Ann and Al, were chosen from those identified as possessing high spatial visualization skills (i.e., one standard deviation above the total class mean), and two participants, Carl and Opal, were chosen from those identified as possessing low spatial visualization skills (i.e., one standard deviation below the total class mean). These four participants completed a series of four task-based interviews in order to document how students of varying spatial ability approach and interact with spatial visualization tasks, to determine if their thinking changed as a result of the classroom intervention, and to examine what impact the *Quick Draw* activities had on their spatial skills, if any.

This section is subdivided into the four individual case study narratives. Within each case, participants' processes for solving spatial visualization tasks featured in their task-based interviews will be described followed by an analysis of data drawn from other data sources. Although additional interview questions were asked during the task-based interviews, the analysis of these responses will be included in the analysis of the other data sources. The presentation of the four cases will be followed by a cross-case analysis of the high and low spatial visualization participants. Included in the cross-case analysis is a discussion of the shared similarities regarding how the participants of varying spatial ability approached and interacted with spatial visualization tasks.

Ann's Case

At the time of the study, Ann was an 11-year-old Caucasian girl who enjoyed playing with and building with Tinker Toys as a younger child (Demographic Survey, 9/8/2014). On her demographic survey, Ann indicated that she played football and soccer, although her preference was soccer (Task-based interview 1, 10/16/2014). In addition, she indicated that playing video games such as *Call of Duty*, a three-dimensional warfare interactive role-playing online game, was one of her favorite pastimes. She liked working with Photoshop on the computer and drawing as a way to pass the time, even though she had never had private lessons (Demographic Survey, 9/8/2014). In thinking about her drawing experiences, Ann said that she often recreated the illustrations taken from a book by looking at it (Task-based interview 1, 10/16/2014). Academically, Ann enjoyed all of her subjects; however, she stated that she liked mathematics the least because she did not feel that she was good at it (Task-based interview 1, 10/16/2014). Additionally, Ann was an extremely conscientious student (Teacher recommendation, 10/3/2014). When asked about the *Quick Draw* activities, she said she enjoyed them because she liked to draw (Task-based interview 1, 10/16/2014). As previously stated, Ann's overall Pre-test score was found to be one standard deviation above the experimental group's average indicating that she possessed high spatial visualization ability (see Table 16).

Table 16

Ann's Individual Subtest and Total Pre-test Instruments Scores Compared to the Class Average

	Ann's scores	Experimental (n=43)		
		M	*SD*	*Mdn*
Pre PSVT:R	6	3.14	2.01	3.00
Pre MCT	5	3.05	1.85	3.00
Pre DAT:SR	6	3.53	1.75	3.00
Pre LAPP	3	2.67	1.90	3.00
Pre WSAT	9.85	4.15	2.32	3.85
Pre Test Total	5.97	3.31	1.36	3.40

The subsequent sections concerning Ann provide a thorough description of her approach to each of the four task-based interviews, followed by a summary of the important themes found in her interviews. Next, sections describe Ann's classroom observations and other data sources, followed by an overall summary of the overarching themes found in both Ann's task-based interviews and classroom observations.

Task 1. To begin the first task-based interview, Ann viewed the image (see Appendix J) for the full three seconds and began by drawing "a bigger box in the shape of a square" (Task-based interview 1, 10/16/2014) about two inches in size. She drew a smaller box in the shape of a square in the upper $\frac{1}{4}$ of the left hand corner of the bigger box. She then connected the lower right corner of the smaller square with the lower right corner of the larger square with a diagonal line segment (see Figure 6).

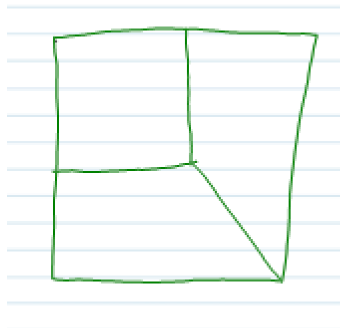


Figure 6. Ann's drawing of *Quick Draw* Task 1.

When asked if she needed a second look at the figure, Ann replied, "Probably" (Task-based interview 1, 10/16/2014). Upon viewing the figure a second time, however, she expressed in a confident manner, "It's the same" (Task-based interview 1, 10/16/2014), and she did not redraw the figure.

When asked to describe what she saw, Ann stated that it resembled "a kite, but they didn't get the whole thing, they only got the bottom triangle with a string" (Task-based interview 1, 10/16/2014). When the folder first opened, she said that she saw "two boxes with a line connecting them" (Task-based interview 1, 10/16/2014). Additionally, when questioned about how she saw an image when it first appeared, Ann said that she saw the image "like a flash, the whole thing" (Task-based interview 1, 10/16/2014) all at once.

Ann did not choose to redraw this figure because she felt that her original drawing was similar to the one in the folder. It should be noted that in comparison to the original figure (see Appendix J), Ann's figure was not proportionally correct; the inner square should have been larger, taking up almost 80% of the interior space.

Task 2. Upon beginning the second task-based interview, Ann viewed the image (see Appendix J) for three seconds, and exclaimed, "Yeah! Oh, ok" (Task-based interview 2, 10/29/2014). As the folder closed, she said that she saw "a three-dimensional square, but it kind of looked a little sideways" (Task-based interview 2, 10/29/2014). She began by drawing a rectangular shape slightly angled up toward the right. She then drew an isosceles-shaped triangle with an altitude of about $\frac{1}{2}$ inch attached to the top of her original rectangle. The right leg of the isosceles triangle was attached to the far upper right corner of her original rectangle, and the vertex of the triangle was directly over the left side of her original rectangle. The other leg of the triangle extended to the left so that the midpoint of the base of the triangle was the left side of the original rectangle. She then finished by drawing another rectangle to form the base of the isosceles triangle and attached to the left of the original rectangle (see Figure 7).

Figure 7. Ann's first attempt at drawing *Quick Draw* Task 2.

Ann realized that her attempt was not like the original drawing because as she finished her drawing, she said, with a laugh, "It looks like a house" (Task-based interview 2, 10/29/2014). Ann appeared tense, likely because her first attempt was not correct. She said, "I was thinking of the 3D [shape] and then when I drew it, it ended up looking like a house" (Task-based interview 2, 10/29/2014).

On her second attempt at drawing Task 2, she again viewed the image for the full three seconds. She started by drawing a rhombus, choosing not to verbalize her thoughts at first. When asked what she was drawing, she responded by saying that she was starting again by drawing "a square" (Task-based interview 2, 10/29/2014). However, Ann's image resembled a rhombus instead of a square, as the angles were not 90 degrees. She then attached another rhombus on the left bottom side of the original rhombus similar in size and dimension, which she referred to as a "square" (Task-based interview 2, 10/29/2014) but angled down, as if forming the side of the cube. Finally, she finished her sketch by drawing an angled trapezoidal shape on the bottom right side of the original rhombus shape to form the right side of her cube (see Figure 8).

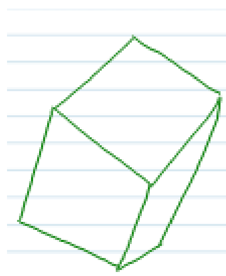


Figure 8. Ann's second attempt at drawing *Quick Draw* Task 2.

Ann's angles and sense of proportion were not accurate; the right side was much narrower than the left side, when in reality all three rhombi should have been the same shape. She said and wrote that she saw it as a "3D cube" (Task-based interview 2, 10/29/2014) but she did not feel that she had drawn it correctly. When the folder was first opened, she said that she saw "almost the whole image" (Task-based interview 2, 10/29/2014) at one time. In describing the shape she said, "It's not a flat square, it's a cube . . . popping up off the page" (Task-based interview 2, 10/29/2014). From her description and drawings, it was clear that Ann had an understanding of what shape she wanted to draw (i.e., a three-dimensional cube), though she was unable to draw the image so that it appeared to look three-dimensional. Neither of the figures looked like the original image (see Appendix J), although her second attempt was better.

Task 3. At the start of the third task-based interview, Ann viewed the image (see Appendix J) for the full three seconds and began by drawing an upside-down V, which she described as “part of a triangle” (Task-based interview 3, 11/11/2014). She then attached a vertical line to the left of the V drawing upward about two inches. She then drew another V attached to the top of the vertical line, moving from left to right. This V was approximately the same size and width as the one she drew for the bottom. She finished the image by drawing another vertical line down the page connecting the two V shapes. She expressed uncertainty, however, as she finished that portion of the drawing by saying, “Don’t know if it is like all the way. (pause) I’m not sure anymore” (Task-based interview 3, 11/11/2014). After a short pause to study her image, she drew a similar image in the same manner as the first, attached to the right side of the original figure. Again, she expressed disgust with her ability to draw the image by saying, “I’m not sure any more . . . ugh!” (Task-based interview 3, 11/11/2014). Last, she repeated a similar image to create the third section of the figure, saying “I think it is like that . . . yeah” (Task-based interview 3, 11/11/2014), as she sat back to view her work (see Figure 9).

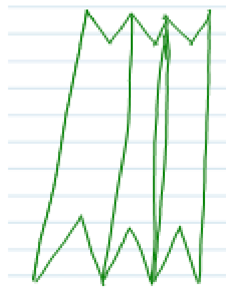


Figure 9. Ann's first attempt at drawing *Quick Draw* Task 3.

In this initial drawing of the figure, Ann started with the bottom left hand corner and drew clockwise around the figure. Additionally, she drew each portion of the shape separately.

Ann wanted to see and draw the image a second time and said, "I can do it this time . . . maybe" (Task-based interview 3, 11/11/2014), as the folder closed. Once again, she studied the image intently for three seconds. This time, she began by drawing two attached A-shapes, which looked like a large M. She described these as "triangles, kind of" (Task-based interview 3, 11/11/2014). She started by drawing the A-shapes from left to right across the page, which formed the top of the figure. She then drew vertical lines down the page by lifting her pen, starting with the left side of the A's making the side approximately two inches long, and moving to the far right side of the connected A's, completing $\frac{3}{4}$ of the outline of the image. Ann then drew a vertical line segment in the middle of the figure separating the two A's she had originally drawn. All three of these vertical lines were approximately the same length. Ann proceeded to draw two more vertical lines in the interior of the image. She drew these two vertical lines down from the apex of the A's toward the bottom. She expressed some uncertainty this time, however, about the length of these two interior lines; she could not recall if they went all the way down or stopped short of the bottom. Ann stated, “I don’t know if it [the interior lines] is like all the way down, I’m not sure so I’m going to go all the way” (Task-based interview 3, 11/11/2014). She mulled over the dilemma for a moment and then chose to draw the lines the same length as the two original outer vertical lines. Thus, all five vertical lines ended at the same horizontal line. Finally, she attached her A-shapes to the bottom of the figure, but instead of drawing a series of two A’s similar to the top, she drew a series of four A’s, one in each of the sections of the image (see Figure 10). She did not realize that the bottom should have been identical to the top of the image.

Figure 10. Ann’s second attempt at drawing *Quick Draw* Task 3.

When asked, she said that the image reminded her of “folded paper” (Task-based interview 3, 11/11/2014) and upon further reflection that it also reminded her of “arrows” (Task-based interview 3, 11/11/2014). In addition, Ann intentionally rotated her drawings both times 90 degrees from the image she was shown. When asked why she turned it, she said, “I was thinking maybe it was supposed to be that way or either you might have had it upside down or something than the way it was supposed to be” (Task-based interview 3, 11/11/2014). When we compared her drawing to the original, Ann redrew the bottom so that it matched the figure in the folder; it was then that she realized the top and the bottom were identical.

Task 4. In starting the last task-based interview, Ann viewed the image (see Appendix J) for a full three seconds. As the folder closed, she started to draw and describe what she saw, quickly drawing a long rectangle slightly angled downward across the page, starting with the upper left corner. She started by drawing a short left side about $\frac{1}{4}$ inch long and proceeded to draw a line about two inches long, angled downward to form the front or bottom leg of the rectangle. She then lifted her pen and drew the side parallel to the long side, and she extended it slightly longer than the front line to form the backside of the rectangle. She finished it by drawing the short parallel side on the right. Afterwards, she attached a rectangle similar in dimension to the original rectangle to the bottom of the original rectangle by drawing the two short ends angled slightly downward, and finished it by connecting the short legs with the longer side. Finally, she said as she finished her figure, "I'm drawing here like a square" (Task-based interview 4, 11/19/2014), which appeared more like that of a rhombus, on the right side of the image that connected the two rectangles (see Figure 11).

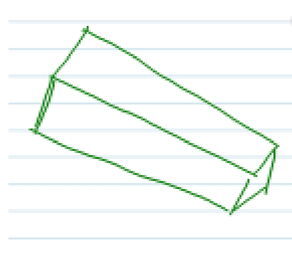


Figure 11. Ann's first attempt at drawing *Quick Draw* Task 4.

Ann adjusted the angles slightly throughout the drawing of the figure attempting to make the image look three-dimensional. When asked, she said that the original image "reminded me of a 3D rectangle" (Task-based interview 4, 11/19/2014); however, she had difficulty making her drawing appear so. Additionally, Ann appeared not to be satisfied with her original attempt for when asked if she wanted to redraw the image she nodded her head, indicating yes (Task-based interview protocol 4, 11/19/2014).

Unlike the first time, Ann only glanced at the drawing for a brief moment, and then started drawing, as if she had confirmed her opinion of the corrections she needed to make to her original drawing. She started by drawing a small square about $\frac{1}{4}$ inch in size. She started with the upper left corner of the square and proceeded to draw counterclockwise to complete the image of a square. Without lifting her pen she then drew a line extending backwards at an angle from the top left corner of her square, up and toward the left about two inches, making the square face look as if it were closer in projection. She then added parallel lines to the drawing to form the top and left side of the rectangular prism. She finished by adding the two short lines that formed the back edge of her drawing (see Figure 12).

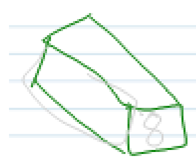


Figure 12. Ann's second attempt at drawing *Quick Draw* Task 4.

When asked, Ann said, "I saw it [the image] slightly different this time" (Task-based interview 4, 11/19/2014), realizing that the smaller side was closer to her. At first, she said that the object did not remind her of anything except a "three-dimensional rectangular shape" (Task-based interview 4, 11/19/2014). However, during the follow-up discussion she mentioned that it "might look like a stick of butter" (Task-based interview 4, 11/19/2014). When further questioned about what she first saw when the folder was opened, she said, "I simply saw a 3D rectangle" (Task-based interview 4, 11/19/2014), and indicated by pointing that the smaller face of the rectangle was closer to her. Ann appeared to be satisfied with her attempt at drawing the figure by saying with confidence, "The second one [drawing] is good!" (Task-based interview 4, 11/19/2014). Upon comparing her drawing to the original image, she pointed out the difference in the two. "This one part [tracing over the long left rectangular side] needs to be [a] little taller" (Task-based interview 4, 11/19/2014). In addition, she identified additional differences, such as she needed to draw a "rectangle rather than a square" (Task-based interview 4, 11/19/2014), making hers wider in addition to angling the lines on the front square a little more.

When asked how she first saw a new figure, she responded, "I just . . . pay attention to what the outside shape is" (Task-based interview 4, 11/19/2014) on which she usually focused and remembered the general overall shape. Then, "I . . . pay attention to the lines inside" (Task-based interview 4, 11/19/2014) to determine what the lines in the interior of the figure looked like. Throughout these experiences, she felt that she saw most of the entire figure "from the outside to the inside" (Task-based interview 4, 11/19/2014) all at one time, even though she often gathered more details upon a second observation. In retrospect, Ann believed that her ability to see and gather details about visual images had improved over the course of the intervention. She said, "When I used to draw them [the figures], I didn't think about it, I just looked at it" (Task-based interview 4, 11/19/2014).

Summary of Ann's four task-based interviews. In a typical interview, based on a thorough review of Ann's task-based interview protocols, Ann took the full time to study the figure intently before beginning to draw the figure displayed. Occasionally, she would trace the figure in the air while looking at the figure (Task-based interview 1, 10/16/2014), as if trying to make a memory of the image. Ann would typically start by drawing the outline or overall exterior shape and then add in the interior details. When asked to describe how she saw the image, Ann felt that she saw “like a flash, the whole thing” (Task-based interview 1, 10/16/2014), but would continue to study it to gather additional information (Task-based interview 1, 10/16/2014; Task-based interview 4, 11/19/2014). In a review of her task-based interviews, it appeared that her method of viewing and drawing remained consistent throughout the process.

Ann had confidence in her ability to look at the figure and then draw it, although during the interviews she usually chose to redraw the figure. She used the second look at the figure to ensure that she had the correct details. Ann also tended to relate the image to a real world object, such as a “music note” (Task-based interview 2, 10/29/2014) or a “stick of butter” (Task-based interview 4, 11/19/2014) in order to remember what to draw. As the figures increased in difficulty over the course of the interviews, she continued to say she saw the images “like a flash, the whole thing” (Task-based interview 1, 10/16/2014; Task-based interview 4, 11/19/2014), all at once. In review, confidence in her ability remained consistent, as indicated when Ann was asked to rate herself: on a scale from one to ten, she replied “a nine” (Task-based interview 2, 10/29/2014; Task-based interview 4, 11/19/2014). Additionally, her method of drawing (i.e., she studied the figure, drew the exterior, and then added interior details) remained consistent (Task-based interview 1, 10/16/2014, Task-based interview 4, 11/19/2014). However, some figures, such as a pentagonal shape (Task-based interview 3, 11/11/2014) and a three-dimensional cube (Task-based interview 2, 10/29/2014) were more tedious for her to draw, even though she could describe both the figure and how she saw it. Throughout the interview process, she continued to intently study the object as it appeared, and would draw or describe the exterior shape first, and then add in the details.

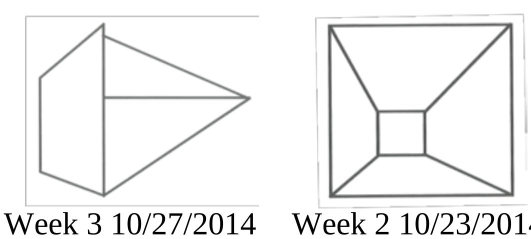
There was one anomaly observed. On a figure that looked like what she called "folded paper" (Task-based interview 3, 11/11/2014), she intentionally turned the figure 90 degrees when she drew it, even though she had not been asked by the interviewer to do so. When questioned, Ann said she thought that "it was supposed to be turned," and that the "original was upside down" (Task-based interview 3, 11/11/2014).

Although her ability to see the figure was strong, Ann did not provide evidence that she saw symmetry in shapes. On one occasion where noticing symmetry would have been helpful in drawing the object, she chose to draw it as three identical, repeated sections (Task-based interview 3, 11/11/2014).

Other data sources. During the classroom activities, Ann was extremely attentive to the activities and reliably waited with anticipation for the figures to be displayed (Classroom observation protocol, 11/10/2014). Ann rarely had to redraw the displayed figure; out of 26 images, she redrew the displayed figure four times. Of these four redrawn figures, three were correct, and the remaining drawing had only minor errors (Classroom *Quick Draw* written responses, 10/29/2014, 11/7/2014, 11/14/2014, 11/19/2014). Based on classroom observations of Ann, she demonstrated an ability to see and gather the details about the whole figure rather consistently throughout the entire process (e.g., Classroom observation protocols, 10/20/2014, 10/29/2014, 11/6/2014, 11/13/2014). A thorough analysis of the classroom *Quick Draw* written responses, classroom observation protocols, and interview protocols revealed that Ann was often able to draw and/or describe the whole image in detail, with minor errors.

Much like the task-based interviews, the classroom observations revealed that Ann was observed studying each figure intently as it was displayed. She often nodded her head while viewing the object as if to indicate that she possessed a clear understanding of what she was to draw (Classroom observation protocol, 11/16/2014). A thorough analysis of the classroom observation protocols and interview protocols revealed that throughout the six-week period there was no evidence that Ann ever tried to draw the image while it was displayed on the screen or during the classroom discussion.

Of the 26 images that were used in the classroom, a majority of them (73%) were not three-dimensional or isometric projections (i.e., visually representing three-dimensional objects in two dimensions). A thorough analysis of Ann's observed classroom *Quick Draw* written responses, classroom observation protocols, and interview protocols revealed that Ann often referred, both verbally and in writing, to the images as a real world three-dimensional object, such as a sailboat or as a long hallway (see Figure 13).



Week 3 10/27/2014 Week 2 10/23/2014

Figure 13. *Quick Draw* classroom observation figures.

Ann demonstrated difficulty in drawing a three-dimensional cube, both in the classroom and in the individual interviews; she did not recognize that the exterior shape was a hexagon (Classroom observation protocol, 11/3/2014, 11/14/2014). Additionally, Ann was not able to draw freehand a regular pentagon (Classroom observation protocol, 11/7/2014, 11/17/2014); however, she had no difficulty in identifying the shape. She often correctly identified geometric shapes within the figures such as a rectangle (Classroom observation protocol, 10/17/2014), triangles (Classroom observation protocol, 10/22/2014), circles (Classroom observation protocol, 10/21/2014), and pentagons (Classroom observation protocol, 11/7/2014).

Upon the completion of the intervention, Ann's overall Post-test score was found to have increased and remained one standard deviation above the experimental group's average (see Table 17).

Table 17

Ann's Individual Subtest and Total Post-test Instruments Scores Compared to the Class Average

	Ann's scores	Experimental (*n*=43)		
		M	*SD*	*Mdn*
Post PSVT:R	5	4.00	2.33	4.00
Post MCT	5	3.16	1.57	3.00
Post DAT:SR	9	4.02	2.41	4.00
Post LAPP	8	3.23	1.86	3.00
Post WSAT	9.40	5.77	2.61	5.80
Post Test Total	7.28	4.04	1.53	3.94

Ann's overall summary. Ann was quiet and reserved in class; she did not normally volunteer answers (Teacher recommendation, 10/3/2014). When called upon in the classroom, however, she would answer, often in a soft voice (Classroom observation protocol, 10/20/2014, 10/29/2014, 11/18/2014). She tended to be shy when she did not feel confident, which was apparent in some of the interviews. Based on an analysis of the classroom protocols, Ann was observed speaking softly or mumbling her words. When asked to repeat a response, she would frequently portray a look that seemed to indicate a hesitation on her part. Despite her apparent shyness, Ann displayed the ability to articulate clearly both verbally and in writing her processes for re-creating the figures.

When asked during an interview how she saw a new figure, Ann stated that she typically saw the image “like a flash, the whole thing” (Task-based interview 1, 10/16/2014), indicating that she initially viewed the entire object as a whole. By examining Ann’s classroom *Quick Draw* written response booklet as well as her task-based interview protocols, it appeared that her self-analysis was correct. In general, Ann was able to draw the entire shape with minor errors with only one look.

Ann felt that of all the varied aspects of the intervention, she enjoyed rotating the objects 90 degrees the most, even though it was only a small part of the overall process. She stated that this forced her to “think a little bit more to turn it” (Task-based interview 4, 11/19/2014). Additionally, Ann said she enjoyed answering the written questions because she said “it helped me to think about what I had drawn” (Task-based interview 4, 11/19/2014), in both what she had seen and how she had drawn it. Based on a review of Ann’s interviews, there was evidence to suggest that she possessed a good understanding of what was involved in the *Quick Draw* activities and appeared to delight in being part of the interview process (Task-based interview 3, 11/11/2014; Task-based interview 4, 11/19/2014).

Overall, Ann appeared to enjoy all of the activities and said that she would miss them when the six-week period was over (Task-based interview 4, 11/19/2014). She believed that her spatial visualization ability was getting better because of the activities and that they were helping her in other classes, although she did not specify which classes (Task-based interview 4, 11/19/2014). Originally, Ann rated her spatial visualization ability at a nine because she enjoyed drawing (Task-based interview 2, 10/29/2014). Throughout the process, her personal assessment of her spatial visualization ability did not change (Task-based interview 4, 11/19/2014). She said that she was starting to think about what she was seeing instead of just looking at it and reactively drawing it (Task-based interview 4, 11/19/2014).

Al's Case

At the time of the study, Al was a 12-year-old Latino boy who enjoyed playing with stuffed animals as a younger child. He had fond memories of taking a particular stuffed dog with him everywhere he went (Demographic survey, 9/8/2014; Task-based interview 1, 10/16/2014). On his demographic survey, Al indicated that he found pleasure in playing baseball, basketball, and cross-country running, although his favorite sport was baseball (Task-based interview 1, 10/16/2014). In addition, he delighted in playing video games such as *Call of Duty,* a three-dimensional warfare interactive role-playing online game (Demographic survey, 9/8/2014; Task-based interview 1, 10/16/2014). He also indicated on his survey that he found satisfaction in playing *Marble Blast* and *Zombies* on the computer.

In thinking about his drawing experiences, Al said that he did not like drawing, having felt that he was not good at it (Task-based interview 1, 10/16/2014); however, he had taken private art lessons in the past (Demographic survey, 9/8/2014; Task-based interview 1, 10/16/2014). He stated that as a younger child, he "used to draw pictures all the time for [his] mom and they used to be good." As he got older, though, his ability to draw had diminished, and "they [the pictures] were horrible" (Task-based interview 1, 10/16/2014), to the point that he did not enjoy drawing.

Al was a conscientious student who was rarely off task, polite, and well-mannered with a good sense of humor (Teacher recommendation, 10/3/2014). Al was able to articulate clearly what he was thinking, both in writing and verbally. Academically, Al's favorite subject was social studies because he liked hearing about the history of things that "were real and actually happened" (Task-based interview 1, 10/16/2014). In contrast, in elementary school he said that he "did not like science because he got low grades" (Task-based interview 1, 10/16/2014). Furthermore, he said that if grades were not an issue he would have liked science because he would have been reading. Additionally, he said mathematics was his least favorite subject because, to him, it was "always the same" (Demographic Survey 9/8/2014; Task-based interview 1, 10/16/2014).

As previously stated, Al's overall Pre-test score was found to be one standard deviation above the mean indicating that he possessed high spatial visualization ability (see Table 18).

Table 18

Al's Individual Subtest and Total Pre-test Instruments Scores Compared to the Class Average

	Al's scores	Experimental (n=43)		
		M	*SD*	*Mdn*
Pre PSVT:R	3	3.14	2.01	3.00
Pre MCT	3	3.05	1.85	3.00
Pre DAT:SR	4	3.53	1.75	3.00
Pre LAPP	7	2.67	1.90	3.00
Pre WSAT	9.10	4.15	2.32	3.85
Pre Test Total	5.22	3.31	1.36	3.40

The subsequent sections relating to Al will be a thorough description of Al's approach to each of the four tasks featured in the task-based interviews along with a summary of the relevant themes found within the interviews. Next will be a description of Al's classroom observations and other data sources, followed by an overall summary of the related overarching themes found in both Al's task-based interview and classroom observations.

Task 1. As the folder opened, Al studied the image (see Appendix J) but began by expressing what he saw almost immediately. He described the figure as a "corner of a room" or "a box" (Task-based interview 1, 10/16/2014). As the folder closed, he started drawing what he called "a box" (i.e., a square) by drawing a vertical and horizontal line about two inches long. He then drew the top of the square and the right side, which enclosed the square. Al referred to this square as the "back wall" (Task-based interview 1, 10/16/2014) of the room. Al then drew a diagonal line from the upper right corner at an acute angle of the square, downward about 1 $\frac{1}{2}$ inches in length, which he described as the “sidewall of the room” (Task-based interview 1, 10/16/2014). He then drew a shorter (about $\frac{3}{4}$ inch) diagonal line from the bottom right corner, parallel to the original diagonal. He enclosed the figure by connecting the two ends of the diagonals, thus giving the shape the appearance of a trapezoid. This, in his words, formed “the corner of the room” (Task-based interview 1, 10/16/2014). Al then drew what he referred to as the “floor of the room” (Task-based interview 1, 10/16/2014) by attaching a rectangle (1 $\frac{1}{2}$ inches tall by 2 inches long) to the bottom of the original square. However, Al did not attach the bottom rectangle to the right side (wall). When he finished, he realized that his angles were off because he could not connect the floor with the sidewall (see Figure 14). He stated, “I probably should have drawn the wall, then the floor . . . because now it is messed up” (Task-based interview 1, 10/16/2014).

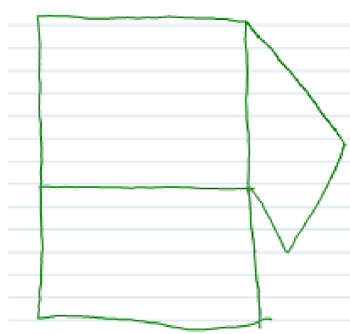


Figure 14. Al’s first drawing of *Quick Draw* Task 1.

Al had no reservations about making a second attempt at drawing the image, having felt that the figure he had drawn did not match what he remembered seeing. In his opinion, he felt that the drawing he made was “messed up” (Task-based interview 1, 10/16/2014). As previously indicated, he even vocalized a plan for drawing the image a second time by saying that he probably should have started with the floor, then the walls, so that they would have connected.

As the folder opened the second time, Al took the entire three seconds to intently study the image before speaking or drawing. Al decided to continue with his new plan by drawing the floor first, which was a narrow rectangle about $\frac{1}{2}$ inch tall and two inches wide. He started with the left vertical side, drawing down the page. Without lifting the pen, he made a 90-degree turn to draw the two-inch horizontal line to form the bottom of the rectangle. He then lifted his pen and extended the original vertical line upward by approximately two inches. He proceeded to draw a horizontal line similar in length to the bottom line, as well as the vertical parallel side enclosing the square. He said that he "started with the floor this time instead of starting with the wall" (Task-based interview 1, 10/16/2014), hoping the final drawing would be more accurate. As he finished the square shape, he drew the interior horizontal line separating the floor with the back wall. As he moved to draw the right side wall, he drew a diagonal line from the top right corner of the square, creating what appeared to be a right triangle attached to the entire length of the square. However, he immediately realized his mistake and declared, "I messed up" (Task-based interview 1, 10/16/2014), to indicate that this drawing was also not correct, because his figure reminded him more of a "lunch bag" (Task-based interview 1, 10/16/2014) than the corner of a room (see Figure 15).

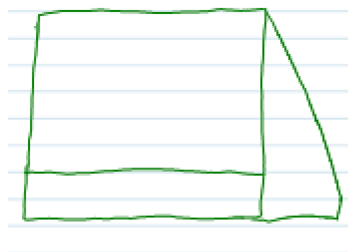


Figure 15. Al's second drawing of *Quick Draw* Task 1.

Al's mental picture of the walls that formed the corner of a room likely helped him to remember the image. However, Al was not successful in producing what he remembered on paper. He knew that the images he had created were not correct. Al was able to remember the individual parts, and that it was divided into three sections; however, he did not realize that the bottom (floor) and sidewall were actually right trapezoids. Al was certain that his figures were not accurate and articulated the errors he knew were present. For example, in the first image, he noted that the sidewall and floor should have been connected, and the second image was a "totally different shape" (Task-based interview 1, 10/16/2014).

Al drew and described his images in terms of individual parts; he did not indicate that he gave attention to the overall shape. Only with a longer look, at the end of the interview, did he realize that the overall shape was a square much like the "corner of a picture frame" (Task-based interview 1, 10/16/2014), and the upper left square was "the picture inside it" (Task-based interview 1, 10/16/2014). In reflecting on this image, Al recalled drawing a similar image in class, but this experience did not appear to help him to draw this image. It was obvious by Al's comments that he vividly recalled what the figure should look like, yet he was unable to recreate it.

Task 2. As the folder opened, Al whispered, “Oh no, the boxes” (Task-based interview 2, 10/29/2014). This statement was made in reference to the image that appeared as a three-dimensional cube tilted so that the top face appeared to be facing the upper left. He looked at the image (see Appendix J) intently and began to draw as the folder closed. Al also articulated what he was going to draw as he began to draw the figure. He began by drawing what he described as the “top of the box” (Task-based interview 2, 10/29/2014), a one-inch by one-inch square. He started by drawing the left vertical side, continuing in a counter-clockwise motion enclosing the square. He then drew a diagonal line from the lower left corner downward about one inch long. Next, he added two sides (left side and top side) enclosing the figure in a shape similar to a square, angled slightly downward and attached to the left of the original square. Al then attached a diagonal line to the bottom left corner of the second enclosed figure going down and to the right about one inch at a shallow angle. He referred to this section as the “end of the box” (Task-based interview 2, 10/29/2014). Finally, Al connected the end of the diagonal line he had drawn to the far right corner of the original square. When this “end of the box” (Task-based interview 2, 10/29/2014) section was completed, it had the appearance of a right trapezoid rather than a square. He sat back with a disgusted look and stated, “Ugh (pause) that does not look like a box” (Task-based interview 2, 10/29/2014). Al knew that the image he had drawn did not match what he had seen. He knew he wanted to draw a three-dimensional cube but he was not successful in doing so (see Figure 16).

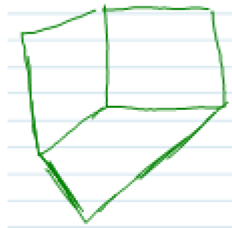


Figure 16. Al's first drawing of *Quick Draw* Task 2.

On his second attempt, Al took the time to study the image intently. As the folder closed, he started the new drawing much like his first attempt. He drew a one-inch square, starting with the left vertical side and drawing counterclockwise to enclose the figure. After a moment of drawing, Al said, "I am drawing the top right now, then the side" (Task-based interview 2, 10/29/2014). However, the side was a congruent square attached to the bottom horizontal line of the original square. Again, he started on the left side and drew in a counterclockwise motion to enclose the figure. Al completed his second drawing by adding on the left of the two squares a figure similar to a scalene right triangle. He started from the top left corner of the two congruent squares and drew the hypotenuse of the triangle, almost the entire length of the two squares. He finished by drawing a horizontal line attached to the bottom right corner of the two squares. As Al completed his drawing, he said, "It looks nothing like a box (pause) again" (Task-based interview 2, 10/29/2014) (see Figure 17).

Figure 17. Al's second attempt at drawing *Quick Draw* Task 2.

When asked to consider what he was doing wrong and why his image did not look like the three-dimensional cube in the folder, he thoughtfully replied, “I do not know” (Task-based interview 2, 10/29/2014). Al knew that the image was supposed to be a cube and could mentally picture the individual square surfaces of the figure but he was not able to draw them. He stated that even though he could mentally picture the squares in his mind, that that this did not help him to draw it. He simply said his image “did not work for me” (Task-based interview 2, 10/29/2014). He said that the figure reminded him of a “cube or dice” (Task-based interview 2, 10/29/2014) when the folder was first opened, even though he had originally described it as a “box” (Task-based interview 2, 10/29/2014). Al did not observe that the outline of the image was a hexagon with three interior axes. He said that even though he had taken drawing lessons, he was “never taught how to draw a cube” (Task-based interview 2, 10/29/2014) and did not know how to draw one.

Task 3. Al viewed the image (see Appendix J) for the full three seconds and began by drawing, from left to right across the page, three upside-down V’s, which he referred to as “mountains, to form the bottom of the figure” (Task-based interview 3, 11/11/2014). He then attached a vertical line going upward on the left side of the V’s about three inches long. At the top of the vertical line, he then attached a horizontal line, about $\frac{1}{2}$ inch long across the page, and drew a vertical line down the page so that it intersected with the apex of the upside-down V. He repeated this same process (i.e., drawing a horizontal line across the top, followed by a vertical line connected to the apex of the upside-down V’s) two more times to create three individual sections. He then drew one more horizontal line, followed by a vertical line, which he attached to the bottom of the rightmost V to form the fourth section of the figure, which he referred to throughout the drawing process as a "wall" (Task-based interview 3, 11/11/2014). As he finished, he said, "That is not what I pictured (pause) it's like a curtain that someone would get dressed behind, but that (pointing to his drawing) doesn't look right" (Task-based interview 3, 11/11/2014). Again, Al had no doubt that he wanted to redraw the image, for he knew that what he had drawn did not match the image he had seen (see Figure 18).

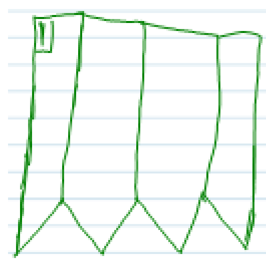


Figure 18. Al's first attempt at drawing *Quick Draw* Task 3.

In developing this image, Al turned his drawing of the image 90 degrees from the way it was displayed (Task-based interview protocol 3, 11/11/2014). When questioned, Al indicated that he had turned it 90 degrees because in his mind he had a mental picture of a "wall" (Task-based interview 3, 11/11/2014). Further, he said that he was trying to draw the image how he was picturing it in his mind rather than how it had appeared on paper. For him, the term "wall" (Task-based interview 3, 11/11/2014) created a vertical image rather than the horizontal image displayed.

In his second attempt, Al took time to study the image before beginning to draw. As he started to draw, he said, "I'm going to draw it sideways this time" (Task-based interview 3, 11/11/2014), which to Al meant drawing it as it appeared in the folder. He began by making a short diagonal line about $\frac{3}{4}$ inch long from left to right across the page.

He then attached a horizontal line extending to the right, about two inches long at the right end of the diagonal. Next, he lifted his pen and drew a line parallel to the horizontal line, connected to the top of the diagonal. Finally, he finished by enclosing the figure with a vertical line connecting the two horizontal lines. He drew the next section of what he referred to as "the second wall" (Task-based interview 3, 11/11/2014) by attaching a diagonal line, about $\frac{3}{4}$ inch long, going from right to left and attached to the bottom of the previous diagonal line. Al then attached a horizontal line, which was parallel to the first two and the same length, to the end of this second diagonal. He completed his drawing by enclosing the figure with a vertical line attached to the right side of the figure. He repeated this process to create what he referred to as the "third wall" (Task-based interview 3, 11/11/2014). This time, however, the diagonal went from left to right and was slightly longer than the previous two. Again, he enclosed the figure by drawing a horizontal and vertical line attaching these sections to the previous two. Al chose to repeat this process one more time creating four sections of the "wall" (Task-based interview 3, 11/11/2014) with the only difference being the direction of the diagonal, which went from right to left this time. As he completed attaching the fourth section of his "wall" (Task-based interview 3, 11/11/2014) to the previous three, he said with confidence, "I'm pretty sure the bottom is right, I don't know about the top" of the figure (Task-based interview 3, 11/11/2014). He also indicated in writing what he considered the bottom of the figure on his drawing (see Figure 19).

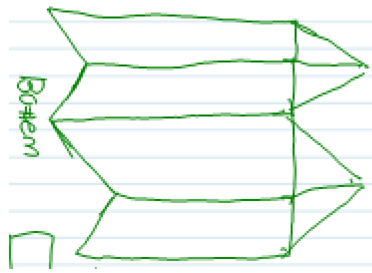


Figure 19. Al’s second attempt at drawing *Quick Draw* Task 3.

As he was discussing what he thought was wrong with his drawing, Al believed that the top was like the bottom in that he thought “it is more of a triangle sort of like the bottom” (Task-based interview 3, 11/11/2014). He indicated that he could not remember with confidence how they looked. It appeared to bother him that he knew there was an error in his figure and he could not recall how to fix it.

When asked to describe what he saw first as the folder opened, Al said that he saw “four rectangles and then I realized there were triangles on the end” (Task-based interview 3, 11/11/2014). It appeared that Al tended to see the drawing as its individual parts rather than as a whole image. When questioned, Al stated that he had not noticed that the left and right sides of the image were identical. He also said that in his second attempt he drew it the way he had seen it because “I thought it might be easier if I just drew it like that (pointing to the picture) instead” (Task-based interview 3, 11/11/2014) of trying to turn it 90 degrees.

Task 4. Before the folder opened, Al said with a laugh that it was going to be “a box” (Task-based interview 4, 11/19/2014). Coincidentally, the image was similar to a rectangular prism (see Appendix J). As the folder opened, Al laughed again, looked at the image, and began to draw silently for a moment. Then he said, “I’m drawing the front of the box” (Task-based interview 4, 11/19/2014). He drew a rectangle silently; a slanted line down and to the left about one inch tall and three inches long. He then attached to this almost vertical line a slightly slanted horizontal line, forming the bottom of the rectangle. He then attached a line parallel to the vertical line on the right end of the rectangle followed by a parallel line to the horizontal bottom completing the front face of the rectangle. Next, Al drew a slanted line from the upper left, backward at a slight angle, to draw what he described as the "top of the box" (Task-based interview 4, 11/19/2014). Again, Al drew a line parallel to the previous horizontal lines to form the back edge of the box, and a line on the right, connecting the back edge of the top of the box with the front of the box. Lastly, Al drew what he referred to as the "side of the box" (Task-based interview 4, 11/19/2014), drawing in the back vertical edge and the bottom completing the left side of the box. He sat back for a moment and said, "I think that is the best box I have ever drawn" (Task-based interview 4, 11/19/2014). Despite this statement, Al thought he needed a second look because he lacked confidence that the image he drew was entirely similar to the image in the folder (see Figure 20).

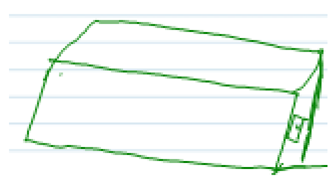


Figure 20. Al's first attempt at drawing *Quick Draw* Task 4.

After viewing the image for the entire three seconds, Al started this time by drawing a square about one inch by one inch, which he referred to as the "bottom edge" (Task-based interview 4, 11/19/2014). He then attached to the upper left corner a horizontal line about two inches long, which he referred to as "the side" (Task-based interview 4, 11/19/2014). Without lifting his pen, he continued to draw the leftmost vertical and bottom horizontal edges to enclose a rectangle attached to his original square. Next, he drew what he referred to as the "top part" (Task-based interview 4, 11/19/2014), which was a rectangle. He started by drawing a one-inch line slightly slanted to the right, to form the left side of the rectangular "top" (Task-based interview 4, 11/19/2014) of the rectangular prism. He then drew a horizontal line the length of the front edge. However, he paused to study the length of the line as if deciding whether or not to encompass the shapes that formed the front, or just one. He completed his "top part" (Task-based interview 4, 11/19/2014) of the rectangular prism by drawing a line to attach the back of the rectangular prism to the front with a vertical line. As he finished, he muttered, "No" (Task-based interview 4, 11/19/2014), as he knew his image was not drawn correctly (see Figure 21).

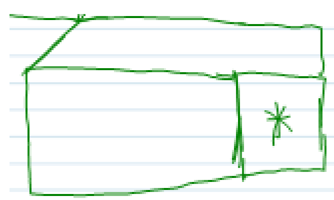


Figure 21. Al's second attempt at drawing *Quick Draw* Task 4.

When asked why this figure was not right he said, "I know exactly what it looks like [but] I just can't draw it" (Task-based interview 4, 11/19/2014). Al felt that he did not possess the skills to draw a rectangular prism and shapes that utilize this skill set were difficult for him. He placed an asterisk on the square and said, "This is supposed to be in the back, not the side" (Task-based interview 4, 11/19/2014), but one could see still see the whole square. He said that when the image was first revealed, he saw "a box falling down" (Task-based interview 4, 11/19/2014).

Summary of Al's four task-based interviews. In a typical interview, based on a review of Al's task-based interview protocols, Al would take the full three seconds to study the image intently before beginning to draw the image displayed. He was extremely articulate about how he was going to draw the figure by describing what he saw in terms of a real-world object, such as the "corner of a room" (Task-based interview 1, 10/16/2014) or "wall" (Task-based interview 3, 10/29/2014). There was only one occasion, during his first attempt at drawing Task 4, in which Al did not start describing his drawing as he drew it. However, when prompted by the researcher, he had no difficulty explaining his drawing (Task-based interview 4, 11/19/2014).

Al displayed a lack of confidence with his drawings when determining whether the image he drew was correct. Based on an analysis of Al's task-based interviews, it was apparent that he often felt that he knew what the image looked like, but he was not able to make his drawing match the image. He frequently pointed out errors in his drawing even before he compared it to the original figure. Specifically, Al was not confident in his ability to draw a "box" (Task-based interview 2, 10/29/2014; Task-based interview 4, 11/19/2014). Despite this lack of confidence, he felt that overall his ability to see and draw objects had improved through the *Quick Draw* activities. When asked to rate himself on a scale from one to ten, he replied anywhere from "an eight" (Task-based interview 3, 11/11/2014) to a "six" (Task-based interview 4, 11/19/2014).

Upon further reflection, Al felt that he was able to "see things faster and write them down more accurately" (Task-based interview 4, 11/19/2014) because of his experiences with the activities. He felt that this ability had been most helpful to him in his science class; during bell work, he had noticed that he could "see things faster" (Task-based interview 4, 11/19/2014). He also said he had experienced this “while watching TV and playing video games” (Task-based interview 4, 11/19/2014). He believed he could see and “read things faster” (Task-based interview 4, 11/19/2014).

Other data sources. Throughout the entire six weeks of classroom observations, Al took the time to study the image intently as it was being displayed before he began to draw. On occasion, he was observed looking at his tablemate’s drawings to compare answers. However, a thorough analysis of the classroom observation protocols revealed that throughout the six-week period there was no evidence that Al ever made corrections to his drawing based on what he saw his classmates drawing (Classroom observation, 10/23/2014). Additionally, he was not observed redrawing the image while it was displayed during the discussion; however, Al did have a tendency to decorate his *Quick Draw* response booklet with additional decorative drawings.

In addition to intently studying the object in the classroom, Al was animated in his reactions to first seeing the displayed images (Classroom observations, 11/12/2014, 11/14/2014) or when comparing his figure to the actual image (Classroom observation, 10/31/2014). When called upon by the teacher, Al would frequently say, “I picture[d] it in my mind” (Classroom observations, 10/27/2014, 10/30/2014, 11/3/2014, 11/5/2014, 11/16/2014, 11/21/2014) when describing how he was able to remember what to draw. For example, when asked how he remembered having drawn Figure 22, Al stated, “When I pictured what to draw, I pictured a staircase in my mind, because I have staircases at my house" (Classroom observation, 11/5/2014).

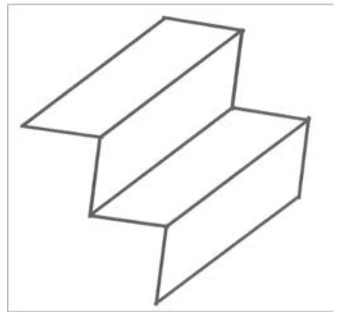
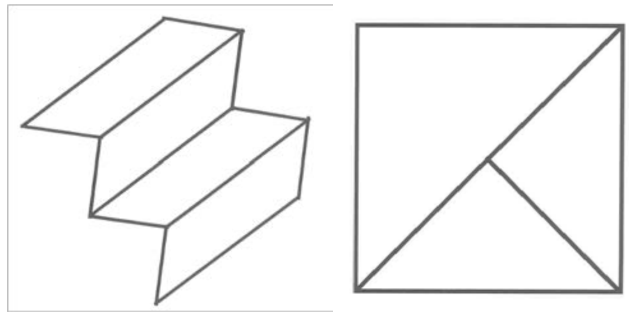


Figure 22. *Quick Draw* classroom observation figure, 11/5/2014.

On a regular basis, Al chose to redraw the displayed image. Out of 26 images, he redrew it 16 times and of those he chose to redraw, a majority (63%) still had errors in them. Al's classroom observations indicated that he was able to get a general idea regarding the displayed image but often was not able to gather the detailed information about the image. A thorough analysis of the classroom *Quick Draw* written responses, classroom observation protocols, and interview protocols revealed that Al was frequently not able to draw the whole image in immense detail; however, he could verbally describe the image in detail. During the personal interviews and the classroom observations, Al did not exude confidence in his ability to draw the *Quick Draw* figures and spoke of his inability to draw the image that he pictured in his mind.

A thorough analysis of Al's observed classroom *Quick Draw* written responses, classroom observation protocol, and interview protocols revealed that Al regularly referred, both verbally and in writing, to two-dimensional images as real-world three-dimensional objects. For example, the images Al referred to in Figure 23 were described as a staircase (Classroom observation, 11/12/2014) and a peanut butter and jelly sandwich (Classroom observation, 11/18/2014).



Week 4, 11/12/2014 Week 6, 11/18/2014

Figure 23. Quick Draw classroom observation figures.

Al had difficulty drawing three-dimensional objects such as a cube, both in the classroom and in the individual interviews (Classroom observations, 11/13/2014, 11/14/2014; Task-based interview 4, 11/19/2014). Furthermore, Al could not draw a regular pentagon (Classroom observations, 11/7/2014, 11/17/2014), although he had little difficulty in identifying the shape. A thorough analysis of Al's classroom *Quick Draw* written responses, classroom observation protocols, and interview protocols revealed that he often correctly used and identified the geometric shapes within the image. In examining Al's *Quick Draw* written responses, at the beginning he had a tendency to give terse answers to the questions; however, during the course of the intervention, he became more expressive with his written responses.

Upon the completion of the intervention, Al's overall Post-test score was found to have decreased, but was similar to the experimental group's average (see Table 19).

Table 19

Al's Individual Subtest and Total Post-test Instruments Scores Compared to the Class Average

	Al's scores	Experimental (*n*=43)		
		M	*SD*	*Mdn*
Post PSVT:R	4	4.00	2.33	4.00
Post MCT	2	3.16	1.57	3.00
Post DAT:SR	3	4.02	2.41	4.00
Post LAPP	2	3.23	1.86	3.00
Post WSAT	8.50	5.77	2.61	5.80
Post Test Total	3.90	4.04	1.53	3.94

Al's overall summary. When asked during an interview about how he saw a new image, Al stated that he typically saw the exterior outline of the image first, then the details of the interior. Al said that if he did not look fast enough he would often miss the interior details of the drawing. By examining Al's classroom *Quick Draw* written response booklet, focusing on his original attempts at drawing the figures, it appeared that his self-analysis was correct. The examination of his Quick Draw written responses first attempts revealed that, in general, Al was able to draw the basic exterior shape but the interior details eluded him. However, in some cases such as Task-based interview 3, Al drew the image as a set of parts pieced together rather than as a whole shape.

For the most part, Al stated that he had enjoyed the experiences and that he would miss it when it ended. When asked in Task-based interview 4 what part of the intervention had been the most helpful, Al said that of all the interventions components (i.e. drawing, written response questions, class discussion), the drawings had been the most helpful for him.

Al demonstrated that he was fun-loving and engaged in class. He volunteered to answer questions and spoke with great confidence when answering the questions, even if his drawing was not correct. He did not shy away from answering the questions. However, because of his lack of confidence in his ability to draw, he was often observed comparing his drawing to his classmates, after he finished drawing, to determine if he had drawn it correctly (classroom observation protocol). If the images were the same, he would express glee with a smile or "oh yes!" gesture with his hand. Additionally, if he drew it correctly the first time, he would often look toward the researcher with an expression of confidence on his face. Rarely did he look at the researcher with a befuddled look.

Overall, Al believed that the experience had helped him in other academic subjects such as science. He thought that he could see things in more detail faster and could write it down more accurately than he could at the beginning of the intervention. Over the course of the intervention, he felt that his spatial visualization ability had improved. Originally, he rated his ability at a four, but by the end of the six weeks, his personal rating had grown to a nine. He was never overly confident in his ability to draw the figures and often expressed disappointment in how his drawings turned out.

Carl's Case

At the time of the study, Carl was an 11-year-old Caucasian male who enjoyed playing basketball and played with a *Buzz Lightyear* helicopter as a younger child (Demographic survey, 9/8/2014). On his demographic survey, Carl indicated that he played video games such as *Mario Kart*, partly related to his love of racing (Task-based interview 1, 10/17/2014). In addition, he indicated that he had played several sports such as basketball, football, archery, and baseball, but he preferred basketball (Demographic survey, 9/8/2014; Task-based interview 1, 10/17/2014). In thinking about his drawing experiences, Carl said that he did not like drawing or art because he felt “it was boring” (Demographic survey, 9/8/2014; Task-based interview 1, 10/17/2014). He had never had any private art lessons. Academically, Carl’s favorite subject was social studies because he said, “It is fun to study about things that happened years ago” (Demographic survey, 9/8/2014). Additionally, he said that mathematics was his least favorite subject because “all the numbers gave [him] a headache” (Demographic survey, 9/8/2014; Task-based interview 1, 10/17/2014). Carl had a rather notably disruptive classroom behavior consisting of speaking out of turn, being off task, and being out of his seat, thus the teacher had him sit next to her desk, semi-isolated from the majority of the class (Teacher recommendation, 10/3/2014; Classroom observation protocol, 10/17/2014, 10/27/2014, 11/13/2014). As previously stated, Carl’s overall Pre-test score was found to be one standard deviation below the experimental group average, indicating that he possessed low spatial visualization ability (see Table 20).

Table 20

Carl's Individual Subtest and Total Pre-test Instruments Scores Compared to the Class Average

	Carl's scores	Experimental (n=43)		
		M	*SD*	*Mdn*
Pre PSVT:R	0	3.14	2.01	3.00
Pre MCT	3	3.05	1.85	3.00
Pre DAT:SR	3	3.53	1.75	3.00
Pre LAPP	1	2.67	1.90	3.00
Pre WSAT	1.00	4.15	2.32	3.85
Pre Test Total	1.60	3.31	1.36	3.40

The subsequent sections regarding Carl are a thorough description of Carl's approach to each of the four tasks featured in the task-based interviews with a summary of the relevant themes found in these interviews. This section will be followed by a description of Carl's classroom observations and other data sources, followed by an overall summary of the relevant overarching themes found in Carl's task-based interviews and classroom observations.

Task 1. As the folder opened to reveal the first interview image, Carl appeared to take three seconds to view the image (see Appendix J) before he began to draw. Carl chose not to talk or describe what he saw while drawing, even though he was prompted to do so. He quickly drew a square-shaped figure about three inches by three inches. He started with the left vertical side and continued counterclockwise to complete the outer shape of the square. He then paused for about 30 seconds, as if contemplating what to draw next (Task-based interview 1, 10/17/2014). He drew a square inside the outer shape in the upper right corner of his original square (i.e., opposite corner from the one in the folder). Carl made the vertical line about $\frac{1}{3}$ inch to the left of his original vertical line, and placed the bottom about $\frac{3}{4}$ inch from the original horizontal line of the outer square. Again, Carl paused for approximately 30 seconds as if contemplating what to draw next (Task-based interview 1, 10/17/2014). He then drew a diagonal line, which he attached to the horizontal line of the inner square about an inch from the right side and connected it to the bottom right corner of the outer square (see Figure 24).

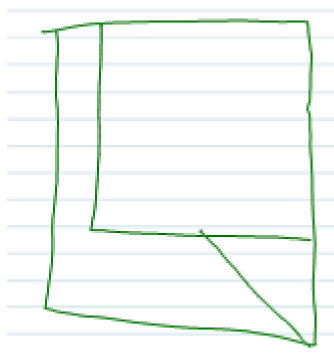


Figure 24. Carl's first attempt at drawing *Quick Draw* Task 1.

When asked if he needed a second look at the image, Carl replied, "Yes" (Task-based interview 1, 10/17/2014); however, after three seconds he quickly wrote "same" to indicate that his original drawing was correct.

Carl was asked to describe what he saw, and hesitantly he said, "I saw a square with another small square inside of it, on the right side" (Task-based interview 1, 10/17/2014). He also said he "saw a diagonal line connecting to it" (Task-based interview 1, 10/17/2014), but he did not expand on where or to what the diagonal line was connecting. He said that the word and image of a square was helpful to him because he "usually observed and drew the outer shape of the figure first" (Task-based interview

1, 10/17/2014). He stated that he had to "guess on the placement of the diagonal" (Task-based interview 1, 10/17/2014), but he "knew there was a square with a smaller square inside of it" (Task-based interview 1, 10/17/2014).

Additionally, Carl implied that he used the second viewing to simply confirm the placement of his guess for the alignment of the diagonal (Task-based interview 1, 10/17/2014). Carl said that the image "did not remind him of any other object" (Task-based interview 1, 10/17/2014); however, he did recall "doing a similar one in class" (Task-based interview 1, 10/17/2014). When questioned, Carl was "100% confident" (Task-based interview 1, 10/17/2014) that his drawing was identical to the one that he had been shown. Even after viewing the two images together, he did not indicate that he recognized the fact that he had placed the smaller inner square in the opposite corner of the image. He had all of the elements of the original image in his drawing but not in the correct location.

Task 2. To begin his second task-based interview, Carl immediately started to draw as the folder opened; he did not take time to study the image (see Appendix J), nor did he indicate that he related it to a known image or object (Task-based interview 2, 10/30/2014). He stared at the folder, and without looking down at the page, began to draw the outer shape of the image. He was able to complete about $\frac{3}{4}$ of the outer shape before the folder closed (Task-based interview 2, 10/30/2014).

Carl started by drawing a horizontal line across the page, about three inches long. He continued to view and draw the object during the entire three seconds the folder was open. Additionally, Carl did not explain what he saw or what he attempted to draw. While the folder was open, he attached a diagonal line about one inch long angled to the lower right. Without lifting his pen or looking down at the page, Carl then attached a three-inch diagonal line to the previous one; however, he turned the angle of the line toward the left of the page. At the end of that diagonal, he attempted to draw a one-inch horizontal line. He was not looking at what he had drawn because he was staring at the image while drawing, thus the line was not perfectly horizontal. At the end of this line, he attempted to draw a diagonal line upward and to the left, but as the folder closed he made a mistake and uttered something under his breath, likely indicating that he knew he had made an error (Task-based interview 2, 10/30/2014).

Carl then attempted to redraw the diagonal line, and while looking at his paper, drew it the same length as the one on the right. He completed the outer shape by drawing a one-inch diagonal line similar to the one on the right to enclose the figure, which was an irregularly shaped hexagon. Still without explanation, Carl then drew the interior of the figure by drawing a diagonal line from the upper left corner of the first horizontal line, down across the entire figure, to connect it to the bottom right corner. Finally, Carl attached a horizontal line about one inch down the last diagonal line that he drew, to the right, to an intersection with the right side at the apex of the two diagonal lines (see Figure 25).

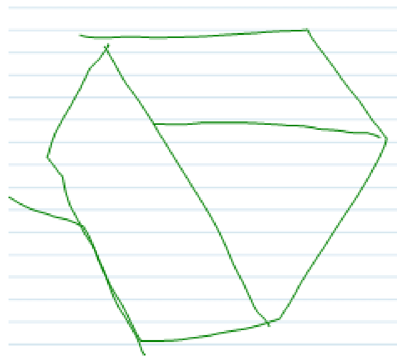


Figure 25. Carl's first attempt at drawing *Quick Draw* Task 2.

Carl seemed very uncertain about what the interior of the image looked like and what he had drawn. When asked, he said, "I saw that thing (i.e., pointing to the outside of the figure) but I really didn't get a good look at the inside [of the image]. I just saw two lines" (Task-based interview 2, 10/30/2014). He stated that when he looked and concentrated on the outline of the drawing, he did not see the whole image. When asked by the interviewer what the image reminded him of when he first saw it, Carl appeared to have difficulty in responding. He said "in class last year [he] had [seen] a shape like that" but he did not identify the shape or relate it to another object.

As the folder opened for his second viewing of the image, Carl immediately started drawing. As before, he did not take time to study the image. Rather, he stared at the folder, and without looking down at the page, began to draw the outer shape of the image. This time, he began with an attempt to draw the horizontal line across the top of the page about one inch long. However, because he looked up at the folder and not down at what he drew, his lines were incorrectly angled. He quickly proceeded to draw the right downward diagonal, also about an inch long, followed by the left downward diagonal, also about an inch long. Carl attempted to draw the bottom horizontal line of the shape. As the folder closed, Carl began looking at his drawing, and his lines became straighter. This time he was able to draw about $\frac{2}{3}$ of the image before the folder closed. He finished by drawing a diagonal from the lower left upward and to the left, about one inch long, followed by another diagonal about $1\frac{1}{2}$ inches long upward and to the right, to complete the hexagonal shape of the exterior. With little hesitation, Carl once again drew a diagonal line from the upper left corner across the entire figure to the lower right corner. Much like his first attempt, Carl completed the figure by adding a short horizontal line from about the center of his last diagonal to the right side of the outer shape (see Figure 26).

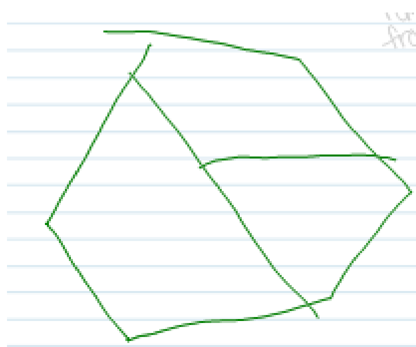


Figure 26. Carl's second attempt at drawing *Quick Draw* Task 2.

Once again, Carl was not able to recreate the image that he had been shown. In addition, he provided no evidence that he could relate it to any other object, such as a cube or die. He said he thought he "had seen a shape like that before in elementary school" but the only shape that he said it reminded him of was a "rhombus" (Task-based interview 2, 10/30/2014). It is noteworthy that if he had drawn the image correctly (see Appendix J), one would be able to see that the shape could be formed by connecting three rhombi. However, in neither of his attempts did he incorporate a rhombus into the figure.

When asked, he felt that the exterior of the shape was correct but he expressed no confidence that the interior was drawn correctly. All he could recall about the interior was "I saw two lines" (Task-based interview 2, 10/30/2014) but could provide no further description of the interior. Carl spent his viewing time attempting to draw the exterior of the image while looking at the image, rather than studying the image. Therefore, it appeared that he had difficulty recalling details, such as the interior of the shape. There was also no evidence that Carl took the time to relate the image to a known image that could have possibly helped him to have drawn what he saw.

Task 3. Carl continued to utilize his method of drawing the image (see Appendix J) while it was being displayed, even when prompted not to. Carl once again was able to complete about $\frac{3}{4}$ of the outline of the shape before the folder closed. Because Carl did not look at what he drew or reflect on what he saw, his outline was misshapen.

Carl began by attempting to draw a horizontal line about three inches long, to which he attached a diagonal about $1\frac{1}{4}$ inch long. The diagonal was angled down and to the right, to which he attached another diagonal line about one inch long, at a sharp angle down and to the left of the page. He continued to draw another diagonal about $1\frac{1}{2}$ inches long, facing down and to the right at a shallow angle. At the end of this diagonal, Carl attempted to draw a horizontal line about three inches long across the page and to the left, but because he was not looking at his drawing, it angled slightly downward. Carl then drew the left side of his figure by again drawing a diagonal about $1\frac{1}{2}$ inch long upward to the right. He attached a diagonal going upward and to the left, and was able to complete about $1\frac{1}{2}$ inches before the folder was closed.

As the folder closed, Carl paused to look down and study what he had drawn, and he decided to extend the current line another inch upward and to the left. Finally, he attached a vertical line about $\frac{1}{2}$ inch long to the original horizontal line to enclose the exterior of the figure. Carl seemed to realize he had an error in his exterior figure so he attached what appeared to be an isosceles triangle to the right of the vertical line he had just drawn, using the vertical line as the base of the triangle. When asked to vocalize his thoughts, Carl stated he "did not know what the inside was" (Task-based interview 3, 11/12/2014) or how the lines were configured which formed the interior of the figure. He could only recall seeing lines inside the figure, but not how many or where they were attached. Thus, he drew three randomly placed horizontal lines connecting the left to the right side of the figure. This divided the figure into four non-congruent figures. When questioned, he said that he saw the "left side of the image first" (Task-based interview 3, 11/12/2014), the zigzag shape. He also said that the image did not remind him of anything and that he "had not really seen a shape like that before" (Task-based interview 3, 11/12/2014). Carl's indication that he had not seen a similar figure was noteworthy as it was made without regard that this same figure, turned at a 45-degree angle, had been previously used in the classroom setting (see Figure 27).

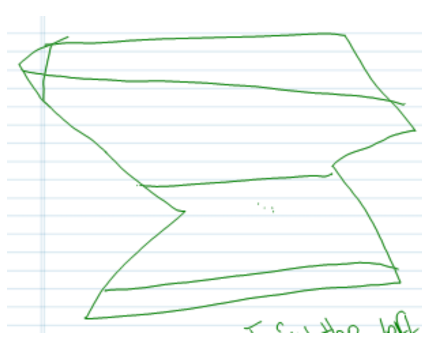


Figure 27. Carl's first attempt at drawing *Quick Draw* Task 3.

When questioned as to whether his drawing matched the original, he paused for a long time and said, “No,” that it did not (Task-based interview 3, 11/12/2014).

During Carl’s second attempt, the researcher requested that he not start drawing the figure until the folder had closed. This was done in the hope of helping Carl to create a mental picture of the displayed image. This time, Carl viewed the image for the full three seconds before beginning to draw. As the folder closed, he began by drawing a series of two sideways V’s opening to the left, which created a zigzag down the left side of the page. Each V was approximately the same height; however, the last V was slightly wider than the first. When prompted while drawing, he said he still saw the “left side of the image first” (i.e., the zigzag) (Task-based interview 3, 11/12/2014). Carl then attached to the bottom of his zigzag a horizontal line across the page about three inches long, angled slightly downward. As he began to draw the right side of the figure, Carl drew a vertical line about $\frac{1}{3}$ inch long upward before beginning to attach a zigzag to the right side of the figure. He drew a sideways V opened to the left, followed by a diagonal, or $\frac{1}{2}$ of a V. He then drew a curved line that attached the diagonal to the right side of the original left zigzag. Carl then paused to look at his drawing, and, once again, he could not recall what the interior of the figure looked like. He said, “It’s, I don’t know” (Task-based interview 3, 11/12/2014). He was urged by the researcher to make an attempt to complete the figure. Much like his first attempt, he placed three horizontal lines (each sloped downward) inside the drawing creating four non-congruent sections (see Figure 28).

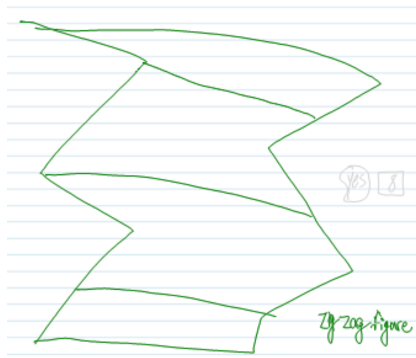


Figure 28. Carl's second attempt at drawing *Quick Draw* Task 3.

When asked, he said he knew that the figure had "lines in the interior and that the sides were zigzagged" (Task-based interview 3, 11/12/2014), but he could not recall where the lines were placed. He also said that his second attempt was "pretty much the same as the first" (Task-based interview 3, 11/12/2014), meaning that his two attempts resembled each other rather than the figure in the folder.

Initially, Carl was not able to relate the image to an object or anything he had seen before. Only when the folder was opened during the follow-up discussion did he realize that he had seen this object before, although rotated 45 degrees, in class. He then recalled someone saying that it looked like two rockets. Even with urging Carl to observe the image for the full three seconds, it appeared he was not able to create a more detailed mental picture of the image. Carl also did not realize that the left side and right side were congruent zigzags, which might explain why he was not able to place the interior lines correctly. Carl continued to say that he usually observed the overall "exterior shape but [did] not have enough time to see the interior" details of the figure (Task-based interview 3, 11/12/2014). This appeared to be a true statement, for he was observed to be quite hesitant in drawing the interior of the shape.

Task 4. As the final interview began, the interviewer reminded Carl of the instructions to view the image (see Appendix J) for three seconds and to begin drawing when the folder closed, as well as to explain what he saw and how he was drawing the figure. However, Carl started drawing the moment the folder was opened and did not verbalize what he saw or drew. His method was to draw, in three seconds, as much of the image as he could while the folder was open. He hastily began by drawing a horizontal line across the page about three inches long. Again, he was intent on looking at the image in front of him; therefore, he did not explain what he saw or was attempting to draw. He then attached a vertical line down the page about three inches to the right side of the horizontal line. Next, Carl made a 90-degree turn to the left and drew a one-inch horizontal line across the page from left to right. He followed that by making a 90-degree turn and drew a vertical line upward until it intersected with the top horizontal line.

As the folder closed, he hurriedly tried to finish his drawing. When asked why he was not explaining his actions, he simply responded, “I’m not good at that” (Task-based interview 4, 11/20/2014), indicating that he could not draw and talk at the same time. Carl proceeded to attach a one-inch vertical line to the left side of his top horizontal line, and after having made a 90-degree turn, drew a horizontal line across the page. This line did not intersect the right side of his drawing because he tried to finish quickly. He made a 90-degree turn and finished that section by drawing a short vertical line upward to intersect with his original horizontal line. Carl rapidly finished his drawing by lifting his pen and attaching what was intended to be a vertical line to the left corner of his drawing, followed by a horizontal line. Because of his rapid attempt to finish, however, he drew a curved line and decided to repeat the lines, which made the lower left of his drawing appear more like a right angle (see Figure 29).

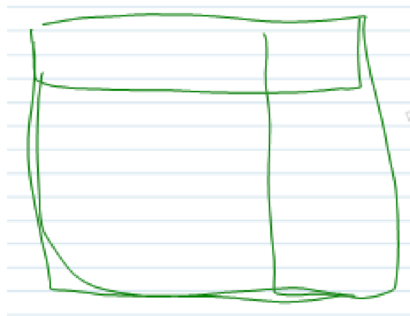


Figure 29. Carl's first attempt at drawing *Quick Draw* Task 4.

As he finished, Carl was asked to explain what he saw when the image first appeared. Carl said he saw a "rectangle was going back and it was like slanting [backwards] like 3D" (Task-based interview 4, 11/20/2014). When questioned, Carl said that the figure he drew did not appear to be three-dimensional; he felt he was "not good at [drawing] 3D" figures (Task-based interview 4, 11/20/2014). He stated he did not "know how to do it" (Task-based interview 4, 11/20/2014), indicating his belief that he was not capable of drawing such a figure.

On his second attempt, Carl paused for about one second to look at the image before starting to draw. As before, though, he started to draw before the folder closed, resulting in his lines being slightly wavy. He rapidly made 90-degree turns so that they appeared as curves rather than corners. He attempted to draw a vertical line approximately two inches long on the right side of the page. While lifting his pen, he made a sharp turn to the left and attempted to draw a three-inch horizontal line across the page. However, instead of a 90-degree corner at the end, he made the line curve upward about $2\frac{1}{3}$ inches. He then completed his rectangular outline of the image by attaching a line from the upper left to the upper right side of the figure. At this point, he mumbled, "I can't do this" (Task-based interview 4, 11/20/2014). He quickly drew a horizontal line from left to right across the page about $\frac{1}{2}$ inch from the top and stopped (see Figure 30).

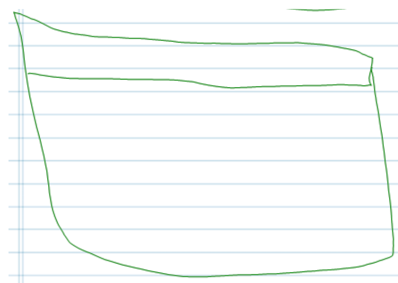


Figure 30. Carl's second attempt at drawing *Quick Draw* Task 4.

When questioned, Carl said that he knew the figure was "supposed to be another line" in the drawing so that it made the image appear to be "going back," but he "did not know how to draw it" (Task-based interview 4, 11/20/2014). He also could not tell the interviewer whether the figure he drew was the interior or exterior of the shape he had seen.

Carl explained that when the folder was opened, he saw a "3D rectangle" because it appeared to be "popping out of the page" (Task-based interview 4, 11/20/2014). When asked to identify any other shapes in the drawing, he did not realize that the outer shape was an irregular hexagon, nor could he identify various rectangles in the interior of the figure. Carl's impression of the image seemed to be limited to a "3D rectangular object" (Task-based interview 4, 11/20/2014). He was initially not able to relate the image to another object; only when pressed for an answer did he finally decide it "could look like a couch" (Task-based interview 4, 11/20/2014).

In reflecting over his participation in the *Quick Draw* activities, Carl thought that perhaps he had "gotten better at looking at [the images]" (Task-based interview 4, 11/20/2014) and his ability to see and draw had improved. He did not think, however, that it had helped him in any other class. He also confirmed that it was "hard for [him] to remember the interior" details of an image (Task-based interview 4, 11/20/2014), and that as the image was more "complicated, it was harder for [him] to draw" (Task-based interview 4, 11/20/2014). Further, Carl confirmed that responding to the written question concerning *how would you explain your drawing* was difficult for him to answer (Task-based interview 4, 11/20/2014). However, Carl stated that he liked the intervention, especially the "classroom conversations" (Task-based interview 4, 11/20/2014), although he did not like answering the written questions. Based on the conversation in Task-based interview 4, it appeared that he never truly understood the intent of this question; he would make judgment statements about his drawings rather than explain the steps of what he drew.

Summary of Carl's four task-based interviews. In a typical interview, Carl would not study the image before beginning to draw, even though he was reminded each time to do so (Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014). Additionally, he would begin to draw without talking about or describing the figure (Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014; Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014). Rather, he would begin drawing within a moment of the image being displayed. During the course of Task-based interview 4 (11/20/2014), Carl indicated that he had difficulty drawing and talking about his drawing at the same time. He used the three seconds that the folder was open to draw as much of the exterior shape as he could. In his words, he would "make a guess" as to the appearance of the interior of the figure (Task-based interview 1, 10/17/2014). Carl had a tendency not to describe the figures in geometric terms. When he did, though, he often used incorrect terminology (Task-based interview 2, 10/30/2014).

For the duration of the interview process, Carl complained about not having enough time to view the drawing (Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014; Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014). In his opinion, he could not get a "good look" (Task-based interview 4, 11/20/2014) at the displayed image; he could only get an idea of the basic exterior shape but could not gather details about the whole image. Furthermore, Carl had difficulty describing what he saw or explaining how he drew the figure (Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014; Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014). It appeared that Carl often rushed through the activities in order to be done quickly. In his opinion, Carl felt he could get the drawing done "faster" (Task-based interview 4, 11/20/2014) if he began to draw when the image was displayed and that when he "tried before doing it the other way it was kind of hard" (Task-based interview 4, 11/20/2014) for him to draw what he saw. Throughout the interview process, Carl expressed frustration with his inability to replicate the displayed images but attributed this inability to the short amount of viewing time (Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014; Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014).

Carl rarely related the figure to any other object or past experiences. When questioned, he would reply with simple answers such as, "I've seen a shape like that before" (Task-based interview 2, 10/30/2014) or "a rectangle" (Task-based interview 4, 11/20/2014). This is not to imply that Carl did not possess the ability to relate the image to another object or prior experiences. For example, after attempting to draw the *Quick Draw* image in Task-based interview 3 (see appendix J), during the discussion Carl recalled that it was similar to one completed in class (see Figure 31) that a classmate had referred to as two rockets (Task-based interview 3, 11/12/2014). However, he did not appear to realize that the interview image was angled horizontally.

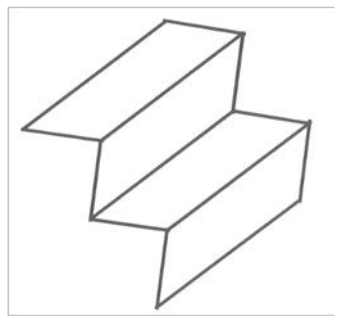


Figure 31. Quick Draw classroom observation figure, 11/5/2014.

Overall, Carl felt that his spatial visualization ability had gotten better over the course of the activities (Task-based interview 4, 11/20/2014). When the interviews began, he rated his ability at a “five” (Task-based interview 2, 10/30/2014), and by the end of the six weeks, he rated his ability to be a “nine” (Task-based interview 4, 11/20/2014) out of ten. While he tended to rate his personal ability high, he admitted that the simple images, “those without interior lines” (Task-based interview 4, 11/20/2014), were easier for him to draw. He thought that he would miss doing the activities (Task-based interview 4, 11/20/2014) and that the consistency of doing them every day was what had helped him to improve. He acknowledged that he enjoyed the classroom conversations but he did not like trying to explain how he drew the image. Carl also stated that he “did not like turning the figure” 90 degrees before drawing it (Task-based interview 4, 11/20/2014). He stated that this was because “I don’t really get a good look at the inside all the time so I don’t know what the inside of the figure looks like so it is hard to [draw] turn[ed]” (Task-based interview 4, 11/20/2014).

Additionally, Carl did not identify any benefit of the activities for himself in any of his other academic classes (Task-based interview 4, 11/20/2014). Upon the completion of the intervention, Carl’s overall Post-test score was found to have increased; however, his score remained one standard deviation below the experimental group average (see Table 21).

Table 21

Carl’s Individual Subtest and Total Post-test Instruments Scores Compared to the Class Average

	Carl’s scores	Experimental (*n*=43)		
		M	*SD*	*Mdn*
Post PSVT:R	1	4.00	2.33	4.00
Post MCT	2	3.16	1.57	3.00
Post DAT:SR	1	4.02	2.41	4.00
Post LAPP	5	3.23	1.86	3.00
Post WSAT	2.15	5.77	2.61	5.80
Post Test Total	2.23	4.04	1.53	3.94

Other data sources. During the six weeks of classroom observations, the classroom observation protocols revealed that Carl did not follow the *Quick Draw* directions; that is, he did not take the time to study the image as it was being displayed before he began to draw. As previously described, Carl tried to draw as much of the image as he could while it was being displayed, instead of studying the image and making a mental picture, and for this reason many of his drawings had major errors. By rushing to draw the figure, it appeared that Carl did not give himself time to relate the images to another familiar object, which could have helped him to draw the figure. During the first two weeks of the classroom activities, Carl chose not to redraw the figures. Instead, prior to the image being shown a second time he simply wrote the word "same" in the redraw space, even when his drawings were incorrect. This issue was later addressed in one of the interviews with the researcher (Task-based interview 1, 10/17/2014).

In class, Carl often volunteered to answer questions or make comments about his drawing even if his responses were incorrect or off topic (Classroom observation protocol, 10/31/1014, 11/11/2014, 11/13/2014). When questioned by the interviewer about some of his responses to the teacher's questions, Carl appeared to truly misunderstand the intent of the teacher's questions. For example, when asked to explain how he drew a figure, he made a judgment response about his drawing, stating, "I didn't draw it so good" (Task-based interview 1, 10/17/2014), rather than trying to explain how he drew it. Other times, for example, he exhibited immature behavior when describing what he saw by altering his voice to respond to the teacher's question (i.e., Carl what did you see?) as "a rectangular figure" (Classroom observation protocol, 11/13/2014). Carl's task-based interviews revealed that he frequently complained he did not have enough time to see the image; therefore he could not draw the figure correctly. It appeared that Carl became uninterested in answering the interview questions and gave impertinent responses, especially during the last interview (Task-based interview 4, 11/20/2014). Overall, Carl did not take the time to study the displayed image. He appeared to be motivated to complete the drawing quickly.

Much like the task-based interviews, the classroom observations revealed that Carl rarely related the image to a known object or prior experience. Additionally, when called upon by the teacher Carl would frequently give short, impertinent answers such as, "I remember seeing triangles a lot" (Classroom observation, 10/27/2014) or "I've seen a rectangle before" (Classroom observation, 11/3/2014). A thorough analysis of the classroom *Quick Draw* written responses, classroom observation protocols, and interview protocols revealed that Carl was frequently not able to draw the whole figure in great detail, nor was he able to verbally describe the image with any detail. Further analysis also revealed that Carl expressed frustration with his ability to replicate the displayed images and tended to blame this inability on the short amount of viewing time.

In addition, there was evidence to indicate that Carl had difficulty both drawing and identifying various geometric shapes. Based on a review of Carl's *Quick Draw* written response booklet, there also appeared to be some evidence that he may have redrawn some of the figures during the open classroom discussion. In examining Carl's *Quick Draw* written responses, it is apparent that he had a difficult time answering the written response questions as previously stated. For example, Carl often made judgment statements, such as bad or horrible, rather than explaining *how* he drew the image (Classroom observation, 11/5/2014). His written responses, as well as many of his classroom responses, were curt and remained so throughout the entire process.

Carl's overall summary. When questioned during the interviews about how Carl saw an image, he stated that he typically got an impression of the exterior (Task-based interview 4, 11/20/2014) and that he "[did not] get a good look at the inside" (Task-based interview 4, 11/20/2014) of the details of the interior of the image. He tended to concentrate on drawing as much of the exterior of the image as he could and then "make a guess" (Task-based interview 1, 10/17/2014) as to what he recalled about the interior. By examining the evidence in Carl's *Quick Draw* written response booklet, classroom observation protocols, and interview protocols, it was obvious that Carl's self-analysis was correct. For each drawing, he made a valid attempt to draw the exterior first. However, this attempt was greatly flawed because he chose to draw while looking at the image. In general, Carl simply was not able to master the activity; however, he stated that he had enjoyed the experience (Task-based interview 4, 11/20/2014). He stated that while he would not change anything, he "did not like answering the written response questions" but he liked the classroom discussions (Task-based interview 4, 11/20/2014).

Overall, Carl did not believe that the experience had helped him in any other academic subject (Task-based interview 4, 11/20/2014). However, he believed that over the course of the intervention, his spatial visualization ability had improved. When asked to rate himself on a scale from one to ten, he gave himself a "five" (Task-based interview 2, 10/30/2014) at the beginning of the intervention and a "nine" (Task-based interview 4, 11/20/2014) at the end. Carl often expressed frustration in his ability to draw the figure and answer the questions. Occasionally he appeared bored. However, when questioned, he attributed his frustration or apparent boredom to the lack of viewing time (Task-based interview 4, 11/20/2014). Carl truly believed that if he was able to see an image for a longer time he would be able to draw it better. There was evidence in both the interview and classroom observation protocols to support that Carl never possessed a thorough understanding of the intent of the intervention. However, Carl stated that he liked the intervention, especially the "classroom conversations" (Task-based interview 4, 11/20/2014), but he did not like answering the written questions.

Opal's Case

At the time of the study, Opal was an 11-year-old African-American female who found enjoyment in playing with Lego blocks and dolls as a younger child (Demographic survey, 9/8/2014). During the first task-based interview (10/17/2014), she said she "just love[d] to play with [Legos] because they connect[ed] together." She liked building and taking them apart and that she "mostly made flowers [out of them] because [she] love[d] flowers" (Task-based interview 1, 10/17/2014). On her demographic survey, Opal indicated that her favorite sport was golf and that she enjoyed dancing. In addition, she liked playing video games such as *Diner Dash* and *Pet Rescue* and often played *Cool Math* and *Papa's Pizzeria* on the computer (Demographic survey, 9/8/2014; Task-based interview 1, 10/17/2014).

In thinking about her drawing experiences, Opal said during the first task-based interview (10/17/2014) that she did not like to draw because, in her opinion, "it did not focus her like writing." Consequently, she had not taken any private art lessons; however, Opal's elective course during the timeframe of this study was art (Demographic survey, 9/8/2014). Academically, Opal's favorite subject, as indicated on her demographic survey (9/8/2014), was mathematics. Opal explained that a member of her extended family was good at mathematics and she thought her love of mathematics came from this family member (Task-based interview 1, 10/17/2014). She also stated that she enjoyed working with numbers and "[her] favorite [was] division" (Task-based interview 1, 10/17/2014). In addition, Opal expressed a "love for writing in her spare time;" she would write stories rather than draw pictures. She indicated on her demographic survey (9/8/2014) that her least favorite subject was social studies. Opal was an outgoing person with a bright and bubbly personality. Additionally, Opal was friendly, inquisitive, and helpful (Teacher recommendation field notes, 10/3/2014). For example, she assisted a classmate who did not speak English well to understand and interpret the intervention as well as what was happening in the classroom. As previously stated, Opal's overall Pre-test score was found to be one standard deviation below the class average, indicating that she possessed low spatial visualization ability (see Table 22).

Table 22

Opal's Individual Subtest and Total Pre-test Instruments Scores Compared to the Class Average

	Opal's scores	Experimental (*n*=43)		
		M	*SD*	*Mdn*
Pre PSVT:R	1	3.14	2.01	3.00
Pre MCT	1	3.05	1.85	3.00
Pre DAT:SR	3	3.53	1.75	3.00
Pre LAPP	0	2.67	1.90	3.00
Pre WSAT	4.10	4.15	2.32	3.85
Pre Test Total	1.82	3.31	1.36	3.40

The subsequent sections are a thorough description of Opal's approach to each of the tasks featured in the four task-based interviews and a summary of the important themes identified in these interviews. The next sections will be a description of Opal's classroom observations and other data sources, followed by an overall summary of the overarching themes identified in Opal's task-based interviews and classroom observations.

Task 1. Opal viewed the image (see Appendix J) for the full three seconds, said, "Okay" (Task-based interview 1, 10/17/2014) as the folder closed, and then quickly started drawing. She began by drawing a complete rectangular object about two inches tall and three inches wide. She continued by drawing the left side of her rectangle and in a counterclockwise motion completed the exterior of her drawing without lifting her pen. She did not talk, however, about what she was doing as she drew. When prompted to describe what she saw as she drew, she responded by saying she saw a "rectangular square divided into an L" (Task-based interview 1, 10/17/2014). As she said this, she drew a similar rectangle inside her original, decreasing its height and width by about $\frac{1}{4}$ inch. She drew in the rectangle forming the L-shape in the interior. She started by attaching a vertical line on the upper right side about $\frac{1}{4}$ inch from the exterior line downward. She then made a 90-degree turn to the left, about $\frac{1}{4}$ inch from the bottom horizontal line, and connected it to the left side of her original rectangle. Finally, she connected the lower right corner of the interior rectangle to the lower right corner of the exterior rectangle, forming a diagonal (see Figure 32).

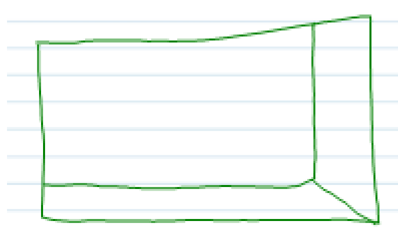


Figure 32. Opal's first attempt at drawing *Quick Draw* Task 1.

While she was drawing, she said that the figure reminded her of "half of the square, like a TV kind of on the side" (Task-based interview 1, 10/17/2014), in addition to seeing the L-shape in the figure. Although Opal chose to view the image a second time, she did not redraw or adjust her original drawing. After viewing it a second time, she appeared confident that her drawing was the same and wrote “same” (Task-based interview 1, 10/17/2014) to indicate that her figure matched the original image in the folder.

When questioned to describe what she saw, Opal repeated that the figure reminded her of a “TV box,” or perhaps the “volume button, the channel button, or the on and off buttons on a flat screen TV” (Task-based interview 1, 10/17/2014). Further, she continued to see an “L” in the figure (Task-based interview 1, 10/17/2014). Opal stated, “If you look at it like this [turning her head sideways] you can see the inside of a box” (Task-based interview 1, 10/17/2014). She said that the first impression she got as the folder opened was that there was an “L” shape inside the rectangle, and then she “looked around [to gather] other details” (Task-based interview 1, 10/17/2014) about the image. While she said she saw the L-shape, she originally drew the exterior rectangle first. Opal said she was “100 percent confident” (Task-based interview 1, 10/17/2014) that her drawing was correct; however, when she compared her drawing to the original, she realized that she had drawn a “rectangle and this one [pointing to the image in the folder] had actual[ly] literally been a square” (Task-based interview 1, 10/17/2014). Throughout the discussion of this task, Opal often interchanged the words rectangle and square, or referred to the image as a “rectangular square” (Task-based interview 1, 10/17/2014). However, Opal had all of the elements of the original image and correct proportions with respect to her drawing. The only issue with her drawing was that she drew a rectangle, whereas the original image was square. When asked if this difference mattered, she said, “Yes, because rectangles are different from squares” (Task-based interview 1, 10/17/2014), although she did not elaborate on the perceived differences. Additionally, when asked if this image was familiar to her, Opal said, “No, not at all” (Task-based interview 1, 10/17/2014). She did not recall having drawn a similar figure in class the week before.

Task 2. Upon beginning the second task-based interview, Opal viewed the image (see Appendix J) for the full three seconds and paused for a brief moment shutting her eyes before starting to draw the figure. As Opal started to draw, she said, “I saw a 3D square which is kind of slanted” (Task-based interview 2, 10/30/2014). Although she said square, Opal drew a rectangle about two inches tall and three inches long. She drew two parallel lines about an inch long at an angle upwards and to the right, on each side of the top of the rectangle she had drawn and one on the bottom right side. All three lines were parallel and approximately the same length. Opal then added the back vertical and horizontal lines that completed her cube, which in her words “makes that a 3D shape” (see Figure 33) (Task-based interview 2, 10/30/2014).

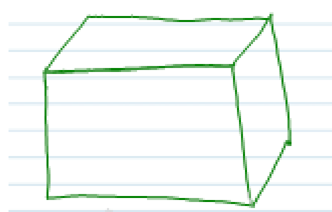


Figure 33. Opal’s first attempt at drawing *Quick Draw* Task 2.

She said that the image she saw when the folder was open was a “3D square” (Task-based interview 2, 10/30/2014), yet she drew it as a three-dimensional rectangle. While Opal appeared confident that her drawing was similar to the original image; she chose to make a second attempt at drawing the figure.

After having looked at the image a second time for the entire three seconds, Opal said as she began to draw that she "noticed that [the original shape] had more of a rhombus shape to it" (Task-based interview 2, 10/30/2014). She made a diagonal line about $1\frac{1}{2}$ inches long, angled upward and to the left of the page. She then attached two lines about an inch long on each of the ends of the original line, both at an obtuse angle to the original line. She then completed the shape by closing in the figure with a line connecting the two lines she had drawn last. In her words, she "attempted to draw a rhombus" (Task-based interview 2, 10/30/2014); however, the shape was more of a trapezoid rather than a rhombus. She did not become deterred from her attempt. She then proceeded to make the figure appear three-dimensional by drawing two parallel lines at each end of the trapezoid angled back and to the upper right. Finally, she connected the two parallel lines to form a rectangle (see Figure 34).

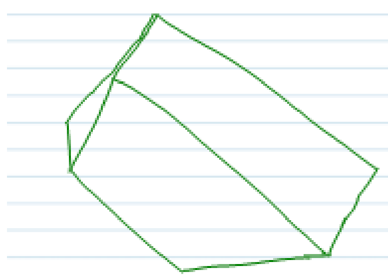


Figure 34. Opal's second attempt at drawing *Quick Draw* Task 2.

By recalling that "it was a slanted 3D rectangle" (Task-based interview 2, 10/30/2014), Opal added on the left side of the drawing a shape similar to a small triangle, again in an effort to make the shape appear more three-dimensional. After viewing her work, she said that she felt the "first attempt" looked more like the original image; however, she realized that she "did not tilt it" (Task-based interview 2, 10/30/2014) at an angle like the original. Throughout her description of the image as she drew, she referred to the object as a "3D rectangle" (Task-based interview 2, 10/30/2014). It was not until the comparison of her attempts with the original shape that she realized the image was a three-dimensional cube.

When the folder was first opened, Opal said that she noticed the "rhombus inside the figure first" (Task-based interview 2, 10/30/2014), but thought the overall shape was rectangular rather than square. Even though Opal knew she needed to draw a rhombus, she was not successful in incorporating a rhombus into her drawing in either attempt. Opal exuded confidence in her ability to draw the figure she had seen. When asked on a scale of one to ten how confident she felt that her drawing matched the image, she said an "eight, not perfect but pretty close" (Task-based interview 2, 10/30/2014). However, upon comparing hers to the original, she realized that the interior shape reminded her of the interior of a "peace symbol" (Task-based interview 2, 10/30/2014). Additionally when asked, Opal said that she felt the *Quick Draw* activities had helped her to increase her ability to draw what she saw from a "five to a nine" on a scale of one to 10 (Task-based interview 2, 10/30/2014), and that she was getting better at the ability. She stated, "Once I make the mental picture I can visualize it and then use it in what I am drawing" (Task-based interview 2, 10/30/2014); however, she still had some difficulty making her drawing look like what she remembered seeing.

Task 3. Opal took time to study the image (see Appendix J) for the full three seconds and began by drawing a horizontal line across the page approximately two inches long, from right to left across the page. On the left side of her horizontal line, without lifting her pen, she made a series of what she called "zigzags" (Task-based interview 3, 11/12/2014) down the page, completing three V's turned sideways so that the apex of the

V faced the right. Each of her V's were similar in size, both in terms of width and height. As Opal drew the zigzag shape, she said, "My line, my zigzag, my line, my zigzag" (Task-based interview 3, 11/12/2014), as if reminding herself where the interior horizontal lines were to be placed. At the bottom of the third zigzag V, she attached a horizontal line going from left to right across the page about three inches long, protruding about an inch longer to the right more than her top horizontal line. Next, Opal drew a series of zigzags up the right side; however, they did not mirror the ones she had drawn on the left side. On the left side, Opal had drawn three complete V shapes, but on the right side, she only drew two V's with the apex pointing to the right. The V's on the right were rather malformed and not symmetrical. After completing the exterior shape, she then drew a series of three horizontal lines in the interior, starting from the apex of each V on the left, across the page until the horizontal line intersected with the right side of the figure (see Figure 35).

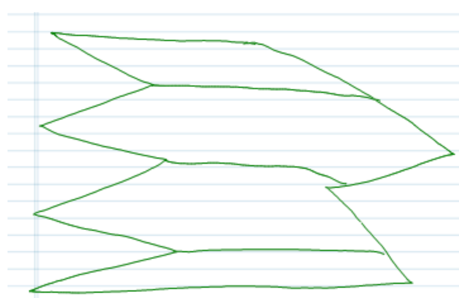


Figure 35. Opal's first attempt at drawing *Quick Draw* Task 3.

Opal felt that she needed a second look and chose to redraw her figure. As the folder closed and without speaking, she began to draw a series of narrow zigzags. She started by drawing zigzags from right to left down the left side of the page so that the apex of the V pointed outward, which when completed formed three $\frac{1}{2}$-V's turned sideways. Opal chose to concentrate on her second attempt at drawing the figure rather than speak. After completing the series of zigzags without lifting her pen, she drew a horizontal line across the page about two inches long. She then drew upward on the right side of the page by drawing only one extremely wide sideways-V pointing inward from the bottom to the top of her drawing. She then lifted her pen and drew a horizontal line across the top of her drawing from left to right connecting the zigzags with the large V on the right. Again, without speaking, she drew a series of three horizontal lines in the interior of the figure starting from the interior apex of each zigzag on the left to the right side (see Figure 36).

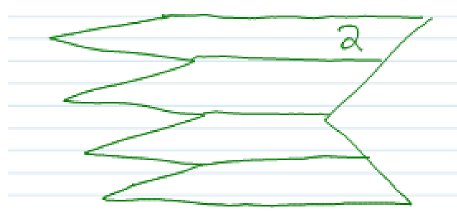


Figure 36. Opal's second attempt at drawing *Quick Draw* Task 3.

When asked, Opal indicated by pointing that her second attempt to draw the figure was closer to the original (Task-based interview 3, 11/12/2014). She described the figure as a "folded up piece of paper that had been folded several times" (Task-based interview 3, 11/12/2014), like a paper fan. In addition to folded paper, Opal also said that it reminded her of a "rocket" and "fire" (Task-based interview 3, 11/12/2014).

During the discussion of her drawing, she recalled that it had "zigzags down the sides" (Task-based interview 3, 11/12/2014) but that the series of zigzags were "not the same" (Task-based interview 3, 11/12/2014) on both sides. She appeared to be surprised to realize that the left and right side of the figure were, in fact, the same image. Furthermore, when asked if the image looked familiar, she said, "Yes, we did it in class"

(Task-based interview 3, 11/12/2014). Upon further discussion, she said with conviction that "we did the exact same one" (Task-based interview 3, 2014) in class. When shown that they were angled differently, she said the one used in class looked like "staircases" and the one in the interview "looked flat, like folded paper" (Task-based interview 3, 11/12/2014). Once again, Opal said that she felt that the *Quick Draw* activities had helped her to increase her ability to draw what she saw and rated her own ability at an eight on a scale of one to 10.

Task 4. Opal took time to study the image (see Appendix J) for the full three seconds; she also traced the image in the air with her finger (Task-based interview protocol 4, 11/20/2014). Opal began by drawing a vertical line down the page about one inch long. Then, at an obtuse angle, she drew a line toward the right of the page about four inches long. Next, she paused to say she saw the image as a "3D rectangle" (Task-based interview 4, 11/20/2014). Opal then completed the rectangular shape by drawing parallel sides on the right and top of the page similar in length to the left and bottom line she had drawn, thus completing the front face of the image. Opal drew a series of three lines approximately the same length (about an inch) angled up and to the right of the page, attaching each line to one of the three corners of her original rectangle, thus making the first rectangle look closer to the viewer. She then drew a vertical line, attaching the two right corners of the three-dimensional shape, forming the right side of the rectangle. Opal finished her three-dimensional rendering by drawing a parallel line connecting the top left corner to the top right corner of her figure, and exclaimed with pride, "There you go!" (Task-based interview 4, 11/20/2014) (see Figure 37).

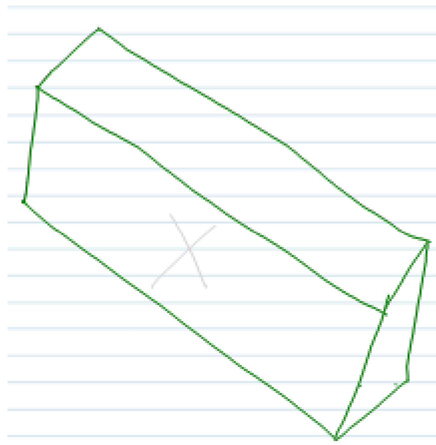


Figure 37. Opal's first attempt at drawing *Quick Draw* Task 4.

When questioned, she believed that her original attempt was satisfactory, but she thoughtfully considered the possibility of redrawing the image. She took a long pause, closed her eyes for a moment. When asked by the interviewer why she had paused and closed her eyes, she said, "I was trying to decide if I should redraw it or not" (Task-based interview 4, 11/20/2014). During the discussion, Opal admitted that she was comparing what she had drawn with what she remembered (Task-based interview 4, 11/20/2014). After a moment, she said that she did not believe she would redraw the figure. However, upon a second look at the image, she chose to make a second attempt at drawing the figure.

Upon viewing the image a second time, Opal attempted to draw the image; however, this time she did not trace the image in the air with her finger. As the folder closed, she stated that she wanted to "redraw the figure" (Task-based interview 4, 11/20/2014). She started by drawing the left face of the three-dimensional rectangle following the same procedure as before. She drew the back left vertical line about an inch long, attached to a line drawn at an obtuse angle toward the right of the page about four inches long, forming the bottom of the slanted rectangle. She added the vertical line drawing upward forming the front right corner of the rectangle followed by the long parallel line to the bottom to enclose the rectangle. As before, she drew a series of three lines approximately the same length (about an inch) angled slightly upward and to the right of the page, attaching each line to one of the three corners of her original rectangle, thus making the first rectangle look closer to the viewer. However, this time the angle of the line on the bottom front right face looked almost horizontal. She proceeded to enclose the front right face by drawing in the vertical right side of the rectangle and followed it by enclosing the top of her rectangle (see Figure 38).

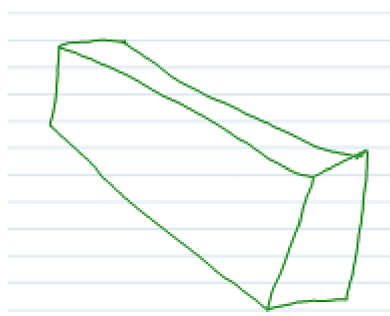


Figure 38. Opal's second attempt at drawing *Quick Draw* Task 4.

When questioned about what she saw when the folder first opened, Opal replied "a 3D rectangle" similar to a "stick of butter" (Task-based interview 4, 11/20/2014) with a long rectangular side. She further explained that she could "remember drawing a slanted 3D rectangle before," and that "the first step [was] to draw the front" rectangular face (Task-based interview 4, 11/20/2014). When her figure was compared to the original image, Opal exclaimed gleefully, "Yes!" (Task-based interview 4, 11/20/2014), for she knew that her figure was similar to what she had seen.

Overall, Opal felt that the *Quick Draw* activities had helped her visualize the individual parts as well as the whole object and she rated her current ability at a “10” (Task-based interview 4, 11/20/2014). In general, Opal did not like to draw and she felt that these activities had been a “challenge for [her]” (Task-based interview 4, 11/20/2014). Upon reflection, she did not think that these activities had been helpful in other classes. Because Opal enjoyed writing, she said that she enjoyed answering the written questions. She indicated, however, that answering the question about what she first saw was difficult, because, in her words, the image just “pops up and I can see everything [the entire image all at once], . . . all the stuff, all the parts, and all the lines” (Task-based interview 4, 11/20/2014).

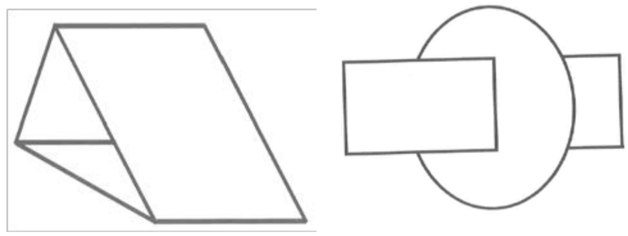
Summary of Opal’s four task-based interviews. In a typical interview, Opal utilized the full three seconds to study the image intently before beginning to draw the image displayed (Task-based interview protocols). During the last of the four interviews, Opal traced the figure in the air while looking at the image (Task-based interview 4, 11/20/2014). On other occasions, she paused for a brief moment, often shutting her eyes, before starting to draw as if recalling the details of the image she had seen (Task-based interview 2, 10/30/ 2014; Task-based interview 4, 11/20/2014). Additionally, when deciding if she would like to redraw the image, she closed her eyes for a moment before answering. When questioned, she said “I was trying to decide if I should redraw [the image] or not” (Task-based interview 4, 11/20/2014). On most occasions, Opal was articulate about describing how she was drawing the figure and what she had seen, and was comfortable sharing her thoughts. She often compared the image to familiar objects such as a television (Task-based interview 1, 10/17/2014), a toy box (Task-based interview 2, 10/30/2014), or a stick of butter (Task-based interview 4, 11/20/2014).

Opal's method of viewing and drawing changed during the intervention activities. At the beginning of the interview process, Opal stated that she typically saw the "interior first" such as the "L" shape in the first interview; then, she looked around for more details about the drawing (Task-based interview 1, 10/17/2014). This appeared to be true; however, she normally began by drawing the exterior of the displayed figure. Over time, her opinion changed and she began to see "everything . . . all the stuff" (Task-based interview 4, 11/20/2014), the entire displayed image all at one time. Because her way of viewing the image had changed, in the last interview she admitted that it was "hard for her to answer the written question concerning what she saw first" as a new image was displayed because she had begun to visualize it as a whole image (Task-based interview 4, 11/20/2014).

Opal's confidence in her ability to look at the image and draw it also changed over time. At the beginning of the intervention, she rated her spatial visualization ability at a five out of 10 because, in her words, she "did not enjoy drawing" (Task-based interview 4, 11/20/2014). For her, the various intervention activities were a challenge. She believed her spatial visualization ability had increased each week to a "10" (Task-based interview 4, 11/20/2014) as the images had increased in difficulty. Another challenge for Opal, in her opinion, was "turning the image" (Task-based interview 4, 11/20/2014); however, she enjoyed the challenge. As previously mentioned, Opal had a tendency to relate many of the images to various real-world objects (Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014; Task-based interview 4, 11/20/2014). However, Opal displayed difficulty in drawing some shapes such as a regular pentagon (Task-based interview 3, 11/12/2014) and correctly identifying geometric shapes (Task-based interview 4, 11/20/2014). Additionally, she did not notice symmetry in some of the images displayed (Task-based interview 3, 11/12/2014). When questioned, Opal could not recognize any benefits for herself in any other academic classes (Task-based interview 4, 11/20/2014). However, Opal expressed some sadness that the intervention and interviews were ending because she had enjoyed participating in the research.

Other data sources. For the duration of the classroom observations, Opal utilized the initial time to study the images intently as it was being displayed before she began to draw. As the images increased in difficulty, a thorough analysis of the classroom observation protocols revealed that Opal redrew her figure to make corrections or add details to the figure. On one occasion, Opal attempted to redraw a figure while it was displayed during classroom discussion time (Classroom observation, 10/30/2014); however, a thorough analysis of her *Quick Draw* written response booklet revealed there was little evidence that this was a customary habit. When questioned by the researcher during an interview to determine if perhaps she had done this before, she said she had not and gave no reason or excuse as to why she had done this. Opal simply stated, “I just thought that [we] could draw the figure once the discussion started” (Task-based interview 3, 11/12/2014).

A thorough analysis of the observation protocols and *Quick Draw* written response booklet revealed that Opal often related the images to real-world objects or experiences. For example, she described Figure 39 (week 3) as a pyramid and a tent, and she related to a swimming experience when she saw a life preserver on a pole at the swimming pool (week 5).



Week 3 Week 5

Figure 39. *Quick Draw* classroom observation figures.

Opal was articulate at describing both verbally and in writing what she had seen or drawn, but on occasions used incorrect geometric terminology when describing the image (Classroom observation protocol, 11/13/2014 & 11/19/2014; Task-based interview 1, 10/17/2014; Task-based interview 2, 10/30/2014). Additionally, Opal was extremely animated when describing her drawing for the class and often gestured toward the overhead (Classroom observation protocol). Opal was also attentive to what her other classmates had to say and would often complement or comment on what they had expressed (Classroom observation protocol, 10/29/2014, 11/5/2014, 11/14/2014). When possible, if not called on by the teacher, Opal would raise her hand to participate in the classroom discussion (Classroom observation protocol 11/11/2014, 11/12/2014). Although she often described images as having three-dimensional characteristics, analysis of her *Quick Draw* response booklets and interview protocols revealed that Opal had some difficulty in drawing three-dimensional images.

Out of the 26 images displayed in the classroom, an analysis of Opal's *Quick Draw* written response booklet revealed that she redrew the image 10 times, and of those that she chose to redraw, half of the images still had errors. In addition, of the 16 images she did not choose to redraw, 75% of them had errors in them. These errors ranged from disproportional sections to arbitrarily placed lines. Opal's classroom observations provided evidence that her ability to see and gather the details about the whole figure changed over time. Although she was able to gain a good impression of the image, she often had to add or correct details about her drawing with her second look (Classroom *Quick Draw* written responses, Task-based interviews). Further, a thorough examination of Opal's classroom observation protocols and *Quick Draw* written response booklet revealed that throughout the intervention observations, she consistently did her best to describe in detail, both in writing and verbally, what she saw, of what it reminded her, and how she drew it.

Upon the completion of the intervention Opal's overall Post-test score was found to have increased and was no longer one standard deviation below the experimental group average, but rather was within one standard deviation of the average (see Table 23).

Table 23

Opal's Individual Subtest and Total Post-test Instruments Scores Compared to the Class Average

	Opal's scores	Experimental (n=43)		
		M	*SD*	*Mdn*
Post PSVT:R	1	4.00	2.33	4.00
Post MCT	2	3.16	1.57	3.00
Post DAT:SR	1	4.02	2.41	4.00
Post LAPP	3	3.23	1.86	3.00
Post WSAT	7.75	5.77	2.61	5.80
Post Test Total	2.95	4.04	1.53	3.94

Opal's overall summary. When asked during the interviews about how she saw a new image, Opal originally stated that she saw the interior of the figure first then would gather details about the whole drawing (Task-based interview 1, 10/17/2014). However, over time she began to see the total image (Task-based interview 4, 11/20/2014). Classroom observations and task-based interviews provided evidence that her ability to see and visualize the image appeared to change over time. Although Opal originally stated that she saw the interior details first, she typically began by drawing the exterior of the image. Although Opal appeared to enjoy the various intervention activities, she indicated that because she did not enjoy drawing, the activities had been a challenge (Task-based interview 4, 11/20/2014). She believed that her spatial visualization ability had increased because the images had increased in difficulty over the six-week period. However, Opal expressed a belief that the experience had not aided her in any other academic subject (Task-based interview 4, 11/20/2014). She expressed the opinion that she enjoyed the activities even if they were challenging, and would miss them when the six weeks were over.

It is apparent based on the classroom observation protocols that Opal enjoyed participating in the classroom discussions. She expressed a genuine interest in what her fellow classmates had to say, and she was articulate and animated in describing both verbally and in writing what she visualized. Although Opal originally rated her spatial visualization ability at a "five" (Task-based interview 2, 10/30/2014), by the end of the intervention, she possessed the belief that it had increased to a "10" out of 10 (Task-based interview 4, 11/20/2014). Opal said she enjoyed the entire process; however, answering the written questions concerning what she saw first was difficult because she began to feel that she could see the entire image at one time.

High Spatial Visualization Skills Case Study Participants

The current study investigated the usefulness of *Quick Draw* intervention for helping sixth grade students improve their spatial visualization skills and to better understand how they approached and interacted with spatial visualizations tasks. This section will compare and contrast the methods by which the case study participants with high spatial visualization skills approached and interacted with spatial visualization tasks based on the overarching themes identified in their task-based interviews, classroom observations, and *Quick Draw* written response booklets.

Overall similarities. In comparing Ann and Al, there were seven key similarities evidenced when interacting with spatial visualization tasks. First, both were conscientious students who displayed a thorough understanding of the *Quick Draw* and task-based interview activities. Second, it appeared that they were fully capable of replication of a majority of the *Quick Draw* images displayed, except for regular pentagons and the more isometric images of a cube or a rectangular prism. Third, based on a thorough analysis of their individual task-based interviews, classroom observations, and *Quick Draw* written response booklets, there was sufficient evidence to support that both participants took the time to study each of the images displayed for the full three seconds prior to beginning to draw the figure. For example, Ann traced images in the air with her finger, or nodded her head to indicate that she had a good idea of what to draw (Classroom observation protocol, 10/16/2014, 10/20/2014). Al often said, “I pictured it in my mind” (Classroom observation protocol, 10/27/2014, 10/31/2014, 10/31/2014, 11/3/2014, 11/5/2014). Of the 26 *Quick Draw* images that were used in the classroom, a majority of them (73%) were not three-dimensional, isometric projections. However, Ann and Al had a tendency to relate the displayed image, whether two- or three-dimensional, to familiar real-world objects, such as a sailboat, music note, staircase, or skateboard ramp. Each said in their interview that those mental notes would help them recall details about what and how to draw displayed images (Task-based interview protocols). Fourth, overall both case study participants correctly used geometric terms to describe sections of displayed images. Although both students appeared to use correct geometric terminology, there was no evidence to suggest that they were able to identify symmetry or repeated patterns (Task-based interview 3, 11/11/2014; Classroom observation protocol, 11/3/2014). Fifth, both participants demonstrated a consciousness of when a *Quick Draw* image had the appearance of a three-dimensional representation (Task-based interview 2, 10/30/2014, Task-based interview 4, 10/19/2014). Sixth, neither participant stated that they particularly enjoyed mathematics (Task-based interview 1, 10/16/2014); however, both expressed that they had enjoyed the *Quick Draw* activities (Task-based interview 4, 10/19/2014). Neither Ann nor Al ever appeared to dislike the intervention process, or expressed any dislike or specific lack of enthusiasm, but rather genuinely appeared to anticipate the start of each new activity (classroom observation protocol, 11/10/2014). Last, they were both extremely articulate and could describe their drawings for the researcher.

Overall differences. In addition to these similarities, there were three differences in their overall behaviors. First, for example, while both Ann and Al might describe a figure as a whole image, such as the letter K (classroom observation, 10/31/2014), their approach in drawing differed. Evidence appeared to indicate that Ann would see the image all at once, while Al observed the general outline of the exterior. Depending on the image, Ann could start by drawing either interior or exterior details of an image whereas Al tended to start with the exterior shape and then add the interior details. During the interview process, it was obvious that Al thought of and drew the displayed image in sections. For example, in Task-based interview 1 (10/16/2014), Al referred to the various sections of the image by names such as “back wall,” “sidewall of the room,” and “floor of the room.” In contrast, Ann said that she saw the same image as “two boxes with a line connecting them” (Task-based interview 1, 10/16/2014).

Second, Ann always exuded confidence in her drawing ability while Al seldom showed confidence in his ability, often pointing out his mistakes prior to seeing the image a second time. Based on an examination of the participants’ *Quick Draw* written response booklets, Ann’s confidence in her drawing ability became evident; she rarely elected to redraw the displayed image whereas Al found it necessary to redraw many of the displayed images.

Third, overall, each of the participants had different classroom behaviors. Both would fully participate in the classroom discussion and answer questions when called upon. Ann, however, rarely volunteered a response, whereas Al often raised his hand.

Changes in thinking. In analyzing the data, there was evidence that suggested their thinking changed as a result of the classroom intervention and, therefore, their spatial skills were impacted by the *Quick Draw* activities. Although Ann’s method of viewing and drawing remained consistent throughout the six weeks, she appeared to get faster at gathering the details about the image. Similarly, at the beginning, Al was only able to get a general impression of the overall exterior of the shape but had trouble with the details. By examining Al's *Quick Draw* written response booklet and Task-based interview 4 (11/20/2014), there was evidence to suggest that over time, he also saw the images faster, with more detail then he had at the beginning of the intervention. Additionally, both participants expressed the belief that this experience had helped them in their other academic classes (Task-based interview 4, 11/20/2014), and that they had enjoyed being part of the research.

Low Spatial Visualization Skills Case Study Participants

In keeping with the purpose of this study, this section will examine how the low spatial visualization skill participants interacted with spatial visualization tasks. This section will compare and contrast the methods by which the case study participants with low spatial visualization skills approached and interacted with spatial visualization tasks based on the overarching themes identified in their task-based interviews, classroom observations, and *Quick Draw* written response booklets.

Overall similarities. In comparing Carl and Opal, while both scored one standard deviation below the class average, it was apparent that they possessed different styles of interacting with the spatial visualization tasks with limited similarities. Yet, there were four key similarities. First, neither of them liked to draw. Carl felt drawing was boring, and Opal said she would rather be writing. Second, both participants had difficulty in drawing regular pentagons and three-dimensional figures such as a cube or a rectangular prism. However, Opal's three-dimensional drawing was more accurate. Third, both participants demonstrated a consciousness of when a *Quick Draw* image had the appearance of a three-dimensional representation (Task-based interview 2, 10/31/2014, Task-based interview 4, 10/20/2014). Fourth, both liked to participate in class and would volunteer answers to questions whenever possible. Based on the classroom observation protocols, it was evident that Opal truly enjoyed sharing her thoughts and ideas about the images as well as listening to her classmates. In contrast, Carl's responses did not seem to align with the expectations of the teacher. For example when asked what he saw in the following figure (see Figure 40) (Classroom observation, 11/14/2014), Carl responded in an immature voice, "A rectangular figure," which invoked laughter amongst his classmates.

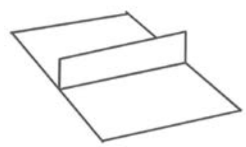


Figure 40. Classroom observation figure, 11/14/2014.

Overall Differences. Despite these similarities, Opal and Carl had different styles of interacting with the spatial tasks. First, Opal consistently studied each image as it was displayed, making a mental image of the object to aid her while drawing the image. She was observed both pausing for a moment before beginning to draw, as well as closing her eyes as if to recall mentally what the image looked like (Task-based interview 3, 11/12/2014; Task-based interview 4, 11/20/2014). She stated, "Once I make the mental picture, I can visualize it and then use it in what I am drawing" (Task-based interview 2, 10/30/2014). It was a common practice of Opal to relate the images to familiar objects or an experience. In contrast, Carl's method of drawing focused on attempting to draw as much of the figure as he could in the three seconds the image was displayed. His rush to draw the image likely prevented him from forming an accurate mental picture. In a thorough analysis of the task-based interviews and classroom observations, there was evidence to support that Carl did not relate images to familiar figures.

Second, throughout the intervention process, it was apparent that Opal possessed a good understanding of the intervention activities, with one exception. On a single occasion, she was observed trying to redraw an image during the class discussion time (Classroom observation, 10/30/2014). An analysis of her *Quick Draw* written response booklet, however, revealed that there was little evidence to support that this was a customary habit or that the images had exceeded her ability to replicate them. Opal was articulate, both verbally and in writing, when describing what she had seen, how to draw it, or how to relate it to a familiar object. During the task-based interviews, Opal had no difficulty describing for the researcher the image that she saw and how she drew it. There were occasions where she would misuse or interchange geometric terminologies, but for the most part, her use of geometric terms was correct.

Alternatively, Carl never appeared to fully comprehend the intervention instructions, even thought they were repeated throughout the six weeks. On occasion, he was asked to explain to the researcher the intervention instructions or what the questions meant to him, and it was clear by his responses that he did not possess a comprehensive understanding (Classroom observation, 11/5/2014; Task-based interview 3, 11/12/2014). Within the first two weeks, Carl was observed not following the intervention instructions as he tried to draw the image during observation time and would not redraw the image but simply wrote “same” in his booklet prior to the image being shown a second time (classroom observation, 10/21/2014). Based on a thorough analysis of Carl’s *Quick Draw* written response booklet, there was some evidence that he may have redrawn some figures during open discussion time. In the last task-based interview, Carl indicated that the images were beyond his drawing capabilities. He said that the more detailed the image was, the harder it was for him to draw (Task-based interview 4, 11/20/2014). Rather than clearly articulating his ideas related to the drawings, Carl gave terse, often impertinent answers to both verbal and written questions. He rarely described what he saw or how he drew an image. Additionally, he rarely related images to a familiar object or experience. Carl stated during the final task-based interview that he could not describe or explain how to draw the image. In addition, Carl often used incorrect geometric terms when describing images.

Drawing style. In analyzing how Opal and Carl saw and drew images, it became obvious that they had different styles. Opal originally saw the interior of the image first then looked around to gather details about the exterior and image as a whole (Task-based interview 1, 10/17/2014). However, over the course of the intervention there was evidence to suggest that Opal had begun to see the image as a whole (Task-based interview 4, 11/20/2014). Alternatively, throughout the intervention Carl consistently concentrated on determining and drawing the exterior shape. Although Carl said that he saw the exterior of the image, there was evidence to suggest that his ability to replicate the exterior image was limited in capacity. For example, he was only able to recall that the image (see Figure 41) used in the third interview had zigzags down the left side, when in fact they were on both sides.

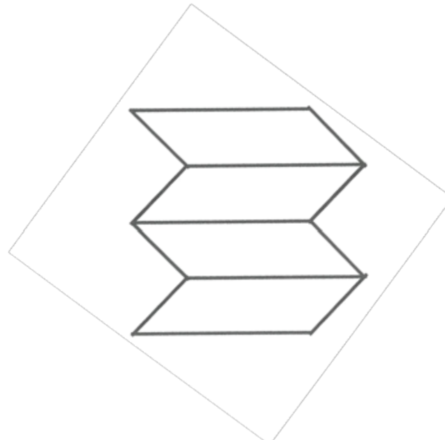


Figure 41. Task-based interview 3, 11/11/2014.

Based on an analysis of the task-based interviews for both participants, there was evidence to suggest that by the end of the intervention both participants knew when their drawings were correct or incorrect. For example, in Task-based interview 2 (10/30/2014), Opal knew that her second attempt was not accurate prior to comparing it to the original, and Carl knew he had made a mistake as he was drawing the image (Task-based interview 2, 10/30/2014). Early in the study, however, this was not the case. Specifically, in Task-based interview 1 (10/17/2014) after Carl compared the image to his drawing, he did not appear to recognize that he had drawn it incorrectly, while Opal immediately saw she had drawn a rectangle instead of a square. There was also evidence to suggest that neither participant was able to identify symmetry or repeated patterns in images (Task-based interview 3, 11/11/2014; classroom observation, 11/3/2014).

Changes in thinking. In analyzing the data to determine if their thinking changed as a result of the classroom intervention and what impact the *Quick Draw* activities had on their spatial skills, the evidence suggested that in Opal's case the intervention had made an impact. As previously stated, Opal began by seeing and describing the interior of a figure, but by the end of the six weeks, she had begun to view the image as a whole (Task-based interview 1, 10/17/2014; Task-based interview 4, 11/20/2014). Opal was also observed during the course of the final interview tracing the image in the air with her finger (Task-based interview 4, 11/20/2014). In contrast, it was more difficult to determine the impact of the activities on Carl's spatial visualization ability due to his failure to follow the directions. A methodical analysis of Carl's task-based interviews and *Quick Draw* written response booklets revealed little evidence that Carl's spatial visualization skills improved. For example, when Opal redrew a figure, her second attempt would be more accurate and include additional details. In comparison, when Carl chose to redraw an image, it was similar to his first attempt with only minor improvements.

It is sufficient to observe that, in general, Carl and Opal were quite different. Opal expressed confidence in her drawing ability, expressed a positive opinion for mathematics, and appeared to have thoroughly enjoyed the interview and classroom interventions. In contrast, Carl displayed a lack of confidence in his ability to draw the images, expressed a negative opinion of mathematics, and over time appeared to have little enjoyment from the intervention. Additionally, when asked, neither participant expressed an opinion that the experience had been of any benefit to them in their other academic subjects.

Cross-case Comparison

The current study investigated the usefulness of *Quick Draw* intervention to help sixth grade students improve their spatial visualization skills and to better understand how they approach and interact with spatial visualization tasks. This section will explore some of the similarities and differences in the methods by which the case study participants with both high and low spatial visualization skills approached and interacted with spatial visualization tasks in a cross-case comparison based on the overarching themes identified in their task-based interviews, classroom observations, and *Quick Draw* written response booklets.

Cross-case similarities. In a review of all of the data sources, there were five common similarities identified between the two groups. First, there was evidence from their final task-based interview (11/19/2014; 11/20/2014) to suggest that all four of the case study participants favorably reflected upon participating in the study and would miss the activities upon completion. Second, based on a thorough analysis of the individual task-based interviews, there was evidence to support that all of the case study participants knew if the image they drew was correct or not before comparing it to the original images, except for one occasion (e.g., Task-based interview 1, 10/17/2014). Third, there is no evidence based on the individual task-based interviews, classroom observations, and *Quick Draw* written response booklets to support that any of the participants recognized symmetry or repeated patterns in an image. Fourth, the analysis of the aforementioned artifacts revealed that, of all of the images that the participants were asked to draw, they had the most difficulty with regular pentagons, cubes, and rectangular prisms. However, upon review of the classroom observation protocols, *Quick Draw* written response booklets, and task-based interviews, there was evidence to support that all case study participants possessed the ability to recognize when an image appeared to be three-dimensional. Fifth, based on a review of observation protocols, all of the participants were readily willing to share their thoughts and opinions about the images with the class, either if called upon by the teacher or if they volunteered. With one exception, the participants could clearly articulate their thoughts and relate the images they had seen to other real-world objects.

Cross-case differences. In a review of all of the data sources, there were three distinct common differences between the two groups. First, and perhaps the most distinctive of the differences, was in how each group viewed the impact that the *Quick Draw* activities had in other academic areas. Both case study participants with high spatial visualization skills believed that by participating in the intervention they were benefiting in other academic subjects, whereas neither of the case study participants with low spatial visualization skills identified any benefit they had experienced in other classes. Second, based on a thorough analysis of the individual task-based interviews, classroom observations, and *Quick Draw* written response booklets, there was sufficient evidence to indicate the participants with high spatial visualization skills had a tendency to use correct geometric terminology when describing figures, whereas the low spatial visualization skill participants did not. The third difference was that the case study participants with high spatial visualization skills appeared to view images holistically, whereas the case study participants with low spatial visualization skills spoke of the components of the figures. This can be best exemplified by Opal's apparent transformation over the course of the intervention; she went from seeing the image as components at the beginning to viewing it as a whole image at the end.

Chapter Summary

The embedded mixed-methods study gathered both quantitative and qualitative data from a Southeastern suburban middle school sixth grade classroom over a period of six weeks. All data, quantitative and qualitative, was analyzed to provide in-depth answers to the research questions addressed in this study. Specifically how sixth grade students are able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques, as well as to examine the gains, if any, with regard to gender using an embedded mixed-methods design. This chapter included an analysis of the data acquired during the study, including the Pre/Post-testing and thick descriptions of four task-based case study results.

CHAPTER FIVE: SUMMARY AND DISCUSSION

Introduction

Over the last century, the field of mathematics education has experienced tremendous advances in understanding the process of teaching and learning mathematics (NCTM, 1989, 2000, 2014). Educators at all levels seek new ways of using and implementing new information about how students learn to inform and improve best practices in the classroom (Arbaugh et al., 2009). One area of interest is spatial intelligence and how it may be enhanced to help students visualize, represent, and solve increasingly complex problems. Although the study of spatial intelligence is not new, researchers are concerned with the development of spatial visualization skills in students (Clements & Sarama, 2009; NCTM, 1989, 2000; NRC, 2006; Sorby, 1999; Wheatley, 1990, 1991; Wheatley & Reynolds, 1999) because strong spatial visualization skills are considered a vital component of numerous fields and careers. For example, mathematics, physics, chemistry, architecture, geosciences, engineering, computer technology, aeronautical design, architecture, and graphic design (Clements & Battista, 1992; Hegarty & Waller, 2005; Olkun, 2003; Sorby, 1999; Suppiah, 2005) all involve such skills.

The purpose of this study was twofold. First, using an embedded mixed-methods design, the study examined how sixth grade students in a Southeastern, suburban middle school over the course of six weeks in the fall of 2014 were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. Second, the study examined the differences in gains, if any, with regard to gender. The specific research questions addressed were:

1. Is there significant improvement in sixth grade students' overall spatial visualization skills as a result of the *Quick Draw* training? Furthermore, do sixth grade students who receive the *Quick Draw* intervention improve on average more than those who do not?
2. How do students of varying spatial ability approach and interact with spatial visualization tasks?
3. Is there a significant difference in the gains made by students based on gender at this grade level?

Review of Methodology

Design

For the purpose of examining the previously stated research questions, an embedded mixed-methods approach was utilized. According to Creswell and Plano Clark (2011), a mixed-methods research design is applicable to a wide range of disciplines and is effective when a single data set, whether quantitative or qualitative, is not sufficient to answer research questions. By utilizing this design, it allowed the researcher to collect a richer and stronger array of evidence to address the stated research questions (Yin, 2014). Specifically, this design allowed the researcher to combine the collection and analysis of both quantitative and qualitative data to address the different foci of the previously stated research questions addressed (Creswell & Plano Clark, 2011). This design was particularly helpful in examining the reactions of the participants during the intervention process (Creswell & Plano Clark, 2011).

One of the purposes of this study was to examine how students of varying spatial ability approach and interact with spatial visualization tasks; therefore, an explanatory case study method was utilized. According to Yin (2014), the function of an explanatory case study is to explain how or why. As a result, the explanatory case study method was well-suited for this study. The research focused on four case study participants to examine in-depth and obtain detailed data (Patton, 2002) of how students of varying ability approached and interacted with the *Quick Draw* intervention. This method allowed the researcher to probe deeper into explaining how students of varying spatial visualization skills interact with spatial tasks through a series of four task-based interviews. As such, the unit of analysis consisted of four individuals identified through Pre-testing as having varying spatial ability. Two individuals of high (one standard deviation above the class average) spatial visualization skills and two individuals of low (one standard deviation below the class average) spatial visualization skills served as the multiple cases of the study. This design, according to Yin (2014), is more robust and provides relevant information concerning similarities and differences amongst subgroups within the study.

Participants

The participants for this study were a convenience sample of sixth grade students in one Southeastern, suburban public middle school teacher's sixth grade mathematics classes during the fall of 2014. During the 2014-2015 academic year, there were 218 sixth grade students enrolled; 51% male and 49% female. Sixth grade was chosen based on the researcher's experience, for it is a pivotal year for some school systems in that at the end of the academic year students are assessed for placement in advanced honors mathematics classes (e.g., Algebra 1). There were 101 students enrolled in the host teachers' mathematics classes. Only the data of those students who returned the signed parental consent forms were used in the analysis, 77 of which (43 experimental and 34 control) completed both Pre- and Post-tests. The participants were semi-randomly divided into two groups. Three intact classes were randomly selected as the experimental group and the remaining two classes acted as the control group. It should be noted that the chosen school used inclusion for those students requiring special education services. The host teacher had two inclusion classes, for this reason one inclusion class was randomly assigned to each group.

Data Sources

Both quantitative and qualitative data were collected during the course of the study with the expectation that the combination of both sets of data would strengthen the results and create a more rigorous analysis. Spatial visualization is a complicated process which involves rotating, twisting, folding, unfolding, as well as relative changes of position of objects in space or motion of machinery, without references to one's self (Clements & Battista, 1992; Hegarty & Waller, 2005; Linn & Peterson, 1985; McGee, 1979; Sorby, 1999). For this reason, several authors have advocated for the use of multiple spatial exams for testing spatial skills (e.g., Hungwe et al., 2007; Kali & Orion, 1996; Patkin & Dayan, 2013; Samsudin, Rafi, & Hanif, 2011).

Quantitative. The quantitative instruments used in this study consisted of five spatial exams measuring various components of spatial skills. These exams consisted of the modified versions of the PSVT:R (e.g., visualize rotated solids), MCT (e.g., visualize cross-sections of three-dimensional figures), DAT:SR (e.g., fold a two-dimensional pattern into a three-dimensional figure), Lappan Test (e.g., understanding of the basics of isometric sketching and orthographic projection), and the unmodified version of the

WSAT (e.g., mentally rotating and comparing various two-dimensional figures). Participants completed the Pre-tests in September 2014 and Post-tests in December 2014, one week after completing the intervention.

The Total score on the Pre- and Post-test was the average of the scaled and equally weighted spatial visualization subtests. The overall Pre- and Post-test scores were paired for each student, and the difference in these overall scores (subtracted in the order of Post-test minus Pre-test) were coded as to whether the student was in the treatment group or the control group (i.e., having received the intervention or not, respectively). The data were analyzed using non-parametric methods because the control group Pre-test total scores were not representative of a sample from a normal distribution.

In addition, to examine differences by gender, the data were analyzed using a two-sample *t*-test for the experimental group. Both female and male Pre-test Total and Post-test Total scores represented scores sampled from a distribution that was approximately normal.

Qualitative. The researcher transcribed each case study interview in order to write a case record for each case study participant, including the major information that was utilized in the case study analysis (Patton, 2002). Additionally, both classroom observations and various artifacts collected during the course of the study were inserted into the case record in order to develop a broader perspective concerning participants' spatial visualization skills (Yin, 2014). The case records for each individual case study participant were used to construct a final holistic case study narrative of each participant, illuminating the focus of the inquiry regarding the influence on their spatial visualization skills as a result of the *Quick Draw* intervention (Merriam, 2009; Patton, 2002).

Furthermore, the individual case studies were compared and contrasted through content analysis in order to generate within-case themes, patterns, and findings (Patton, 2002). Additionally, a cross-case analysis was utilized to build a general explanation concerning the shared similarities and themes of how sixth grade students of varying spatial ability approached and interacted with the spatial visualization tasks (Creswell, 2013; Merriam, 2009; Yin, 2014). The resulting themes from within- and cross-case analyses were described, interpreted, and presented as findings. The qualitative instruments (i.e., a demographic questionnaire, four task-based interviews, *Quick Draw* written response booklets, and classroom observation protocols) were used to collect and provide documentation, insight, and a broader perspective into how students interacted with the *Quick Draw* activities.

The *Quick Draw* Intervention

The experimental group was engaged in the *Quick Draw* activities for six consecutive weeks in the fall of 2014. These activities occurred at the beginning of each class period, lasting approximately five minutes, and were not necessarily in conjunction with the host teachers' mathematical objective of the day. In a typical *Quick Draw* activity, participants were given two three-second opportunities to look at the image and draw what they saw. The participants were then given the opportunity to discuss the figure, share their strategies and thoughts about how they saw and drew the figure, describe how they conceptualized the shape during the viewing stage, and what word or picture they used to help them during the reconstruction of the image.

Summary of Results

Summary of Quantitative Results

In answering the primary, quantitative research question for the study, nonparametric statistical methods were used because the control group total scores were found to not be representative from a distribution that was approximately normally distributed. A summary of the analysis follows.

Pre-test and Post-test analysis. The Kruskal-Wallis test revealed no significant differences existed between the experimental and control group participants' median Pre-test Total test scores at the beginning of the study. Additionally, no significant differences were found to exist between any of the individual subtests. Furthermore, the Kruskal-Wallis test of the Post-test scores of these groups also revealed no significant differences between the experimental group and the control group median Post-test Total scores. Analysis of the individual post subtests also revealed no significant difference between the experimental and control groups at the end of the intervention.

In order to control for individual participant differences in spatial visualization abilities at the beginning and the end of the intervention, the individual Pre-test and Post-test scores were matched by participant scores for the subtest and total scores. In order to determine if there was significant improvement in sixth grade students' overall spatial visualization skills as a result of the *Quick Draw* intervention, the matched pairs difference (Post-test minus Pre-test) for the experimental group was examined using a Wilcoxon Signed Rank test. The test revealed a statistically significant higher difference in the total median scores in the experimental group following participation in the *Quick Draw* intervention. Additionally, the experimental group was found to have made significant improvement on the modified PSVT:R, Lappan, and WSAT. However, one should note that the Wilcoxon Signed-Rank test also revealed that the control group had a statistically significant higher difference between the Post- and Pre-test total scores and had made significant improvement on the DAT:SR and WSAT tests.

Summary of gender comparison. To examine the difference in gains by gender, the differences between females and males of the experimental group were analyzed. There were 21 females and 22 males within the experimental group. A summary of the analysis follows.

Pre-test. Prior to the *Quick Draw* intervention, the males' Total Pre-test score was slightly lower, though not significant, than the females' based on means (and medians). Additionally, there was variation in the Pre-test subtests scores based on gender. A two-sample *t*-test was performed on the Pre-test totals, since both gender groups were determined to be representative of scores sampled from a distribution that was approximately normal. However, there was no significant difference in the average scores for females and males in the Total Pre-test scores.

Post-test. After the *Quick Draw* intervention was completed, the males' Total Post-test score remained slightly lower, though not significant, than the females' based on means (and medians). Additionally, variation in the Post-test subtest scores based on gender also remained. Once more, a *t*-test was used to analyze the data and no significant difference in the scores for females and males in the Total Post-test scores were found to exist. As a comparison, there were no significant differences found based on gender in the control group as well.

Summary of Case Study

A purposeful sample of four participants, two high (i.e., one standard deviation above the total class mean) and two low (i.e., one standard deviation below the total class mean), were selected from the experimental group based on their Total Pre-test score. These four participants completed a series of four task-based interviews in order to document how students of varying spatial ability approach and interact with spatial visualization tasks, to determine if their thinking changed as a result of the classroom intervention, and to examine what impact the *Quick Draw* activities had on their spatial skills, if any. A summary of these results follows.

Cases with high spatial visualization skills. Among the case study participants with high spatial visualization skills, nine similarities and three distinct differences were identified, as well as a change in their thinking based on their experience with the *Quick Draw* intervention.

Similarities. A total of nine similarities emerged from the case study data. First, both participants displayed a thorough understanding of the *Quick Draw* and task-based interview activities. Second, it appeared both participants were fully capable of replicating a majority of the *Quick Draw* images, except for regular pentagons and the more isometric images (e.g., cube or rectangular prism). Third, both participants took the time to study each of the images displayed for the full three seconds as instructed. Fourth, both participants demonstrated the capacity to know if what they had drawn was correct or incorrect prior to comparing it to the original image. Fifth, neither participant provided evidence of being able to recognize symmetry or repeated patterns in the images. Sixth, both participants correctly used geometric terminology when describing various images. Seventh, both participants demonstrated a consciousness of when a *Quick Draw* image had the appearance of a three-dimensional representation. Eighth, neither participant particularly enjoyed mathematics, but they did like the *Quick Draw* activities. Ninth, both participants were articulate and each could describe their drawings for the researcher.

Differences. When comparing the two participants who began the study with high spatial visualization skills, three distinct differences emerged from the case data. First, the participants' approach to drawing the figures differed: one demonstrated that they could see the entire image all at once, while the other focused on the general outline of the exterior shape and tended to think of the image in sections. Second, the participants' confidence in their drawing ability differed, with one exuding confidence while the other questioned their ability. Third, their classroom discussion interaction differed; one would wait to be called upon by the teacher while the other often volunteered a response.

Change in thinking. In analyzing the data, there was evidence to suggest that their thinking changed as a result of the classroom intervention and therefore, their spatial skills were impacted by the *Quick Draw* activities. While one of the participants appeared to gain speed and accuracy, the other gained the ability to see the image as a whole and to gather details more quickly. Additionally, both participants expressed the belief that this experience had helped them in their other academic classes.

Cases with low spatial visualization skills. Among the case study participants with low spatial visualization skills, seven key similarities were identified. Although they both scored one standard deviation below the mean, it became quickly apparent that they were distinctly different. Four differences were identified, as well as a change in their thinking, based on their experience with the *Quick Draw* intervention.

Similarities. In comparing the participants with low spatial visualization skills, seven key similarities emerged for the case data. First, neither of the participants liked to draw. Second, both had difficulty in drawing some of the *Quick Draw* images, for example, regular pentagons and the more isometric images such as a cube or rectangular prism. Third, both appeared to enjoy participating in the classroom discussions of the *Quick Draw* images. Fourth, both participants demonstrated that they had the capacity to know if what they had drawn was correct or incorrect prior to comparing it to the original image. Fifth, neither participant provided evidence of being able to recognize symmetry or repeated patterns in the images. Sixth, both participants demonstrated a consciousness of when a *Quick Draw* image had the appearance of a three-dimensional representation. Seventh, both participants had a tendency to incorrectly use geometric terminology when describing various images.

Differences. The comparison of these two participants yielded four key differences. First, one of the participants consistently did not follow the *Quick Draw* instructions and provided no evidence of attempting to make a mental picture of the image, while the other followed the instructions and consistently studied each image as it was displayed, appearing to make a mental picture of the image. Second, one gave terse, often impertinent answers to both verbal and written questions, while the other was articulate both verbally and in writing. Third, one participant rarely related the images to real-world objects to help form a mental picture, while the other showed no difficulty relating the image to a real-world object. Fourth, their drawing styles also differed; one tried to draw as much of the figure as they could while simultaneously viewing the image, while the other drew their figure presumably based on the mental image.

Change in thinking. In analyzing the data, there was evidence that suggested the participants' thinking changed differently among the low scoring participants, and, therefore, the impact on their spatial skills was different. While one of the participant's drawing ability did not appear to improve, the other went from seeing the interior of an image to viewing the image as a whole. Additionally, neither participant expressed an opinion that the experience had been a benefit to them in their other academic subjects.

Cross-case comparison. This study also was interested in the relevant themes identified in the task-based interviews, classroom observations, and *Quick Draw* written response booklets, of similarities and differences that were apparent in both the high and low spatial visualization skills case study participants in how they approached and interacted with spatial visualization tasks. What follows is a description of the cross-case similarities and differences.

Similarities. Five common similarities between the two case study groups were identified based on a review of all data. First, there was evidence that all of the case study participants reflected favorably upon their experiences in the study. Second, there was evidence in the task-based interviews to support that all of the participants knew if the image they drew was correct or incorrect prior to comparing it to the original image. Third, there was no evidence based on a review of the task-based interviews, classroom observations, and *Quick Draw* written response booklets that any of the case study participants recognized symmetry or repeated patterns in an image. Fourth, the analysis of the aforementioned artifacts revealed that the participants had the most difficulty in drawing regular pentagons, cubes, and rectangular prisms. However, there was evidence to support that all of the case study participants possessed the ability to recognize when an image appeared three-dimensional. Fifth, the observation protocols revealed that all of the case study participants were willing to share their thoughts and opinions with the class, and with one exception, the participants could clearly articulate their thoughts and relate the images they had seen to other real-world objects.

Differences. Three common differences between the two case study groups were identified based on a review of all data. First, and perhaps the most distinctive of differences, was how each group viewed the impact that the intervention activities had had on other academic areas. Both case study participants with high spatial visualization skills expressed a belief that by participating in the intervention they were able to apply the skills to other academic subjects, whereas neither participant with low spatial visualization skills identified any personal benefit that they had experienced in other academic subjects. Second, there was sufficient evidence to indicate that the high-scoring participants had a tendency to use correct geometric terminology when describing figures, whereas the low-scoring participants did not. Third, and perhaps the most distinctive difference is that the case study participants with high spatial visualization skills appeared to view the image holistically, whereas the participants with low spatial visualization skills spoke of the components of the image.

Interpretation of Findings and Discussion of Results

The current study examined how sixth grade students in a Southeastern, suburban middle school over the course of six weeks in the fall of 2014 were able to benefit, if at all, from spatial visualization intervention *Quick Draw* techniques. The following sections discuss the implications derived from the findings and suggest recommendations for future research.

Improvement

In reviewing the data associated with the first part of research question one, the Wilcoxon Signed Rank test revealed statistically significant higher differences (Post- minus Pre-) in the total median scores from the experimental group following participation in the *Quick Draw* intervention with a medium-to-large effect size (r = 0.47). However, when examining the second part of the research question, the control group also had a statistically significant higher difference between the Post- and Pre-test total scores with a medium effect size (r = 0.39). This leads one to question why both control and experimental groups had significant improvements. One could theorize that the improvement in the control group was due, in part, to the makeup of the students contained within the control group. Due to scheduling and that intact classes were used, all of the students identified as academically gifted were members of the randomly selected control group, although the percentage of students who were classified as gifted was not known. Regardless, this could, in theory, have influenced the results of the control group Post-test scores. Further research in this area is needed to determine how gifted students and students requiring special education services interact with spatial visualization tasks.

Elective Influence

Another hypothesis for the improvement of the control group could be that 15% of the control group, versus 9% of the experimental group, was enrolled in art during the course of the intervention. Although the researcher does not know what type of art instruction students received during this time, there is evidence to suggest that they could have received some instruction regarding how to draw three-dimensional objects. During the course of Opal's last task-based interview, she indicated that one should first draw the front face of a rectangular prism and commented that she "remember[ed] drawing a slanted rectangle, 3D rectangle [and] that is your first step." This is noteworthy because she was the only case study participant enrolled in art during the course of the intervention. Additionally, of the four case study participants, her attempt at drawing a rectangular prism, although not identical to the image shown, was the best attempt. With that said, it is not possible to know how participation in art classes influenced the results of this study.

Testing Effect

One may also argue that the control group increase could have been a result of testing effect; familiarity with a test and items can increase performance on the test (Mulligan & Peterson, 2015). However, in a prior study by Sorby, Signorella, Veurink, and Liben (2013) in which middle school students completed Pre- and Post-tests with many of the same testing instruments (i.e., modified PSVT:R, Lappan, and MCT) as was used in the current research, no testing effect was reported.

Test Alignment

Another area of interest is the amount of variation in the Pre- and Post-test results based on subtest. This causes one to speculate about the alignment of the testing instruments with the chosen intervention. Thus, it is worth attempting to compare the skills tested by the individual subtests and determining which subtest may be more closely aligned with the chosen intervention (see Table 24).

Table 24

*Comparing Skills Tested in Individual Subtest to Participant Results**

Subtest	Measures Visualizing	Grade level	Results based on medians Experimental	Control
PSVT:R	rotated solids	Ages 13 and older (7th grade and higher)	Significant improvement	No significant improvement
MCT	Cross section of a three-dimensional solid	College entrance exam	No significant improvement	No significant improvement
DAT:SR	Folding a two-dimensional pattern into a three-dimensional solid	Academic and Vocational screening (grades 8-12)	No significant improvement	Significant improvement
LAPP	Isometric sketching and orthographic projection	Middle school	Significant improvement	No significant improvement
WSAT	Comparing rotations of two-dimensional figures	Elementary or Middle school	Significant improvement	Significant improvement

* see Chapter Four, Post-test minus Pre-test Paired differences Analysis section for details, all *p*-values less than 0.05

Two of the tests are three-dimensionally related: the LAPP and PSVT:R. These two subtests showed that the experimental group had significant improvement, while the control group did not. By examining the 26 *Quick Draw* images that were used in the classroom, in the researcher's opinion, only 27% were three-dimensional or isometric projections (i.e., visually representing three-dimensional objects in two dimensions). However, in a review of the four case study participants' *Quick Draw* written responses, classroom observation protocols, and task-based interviews, the analysis revealed that, with the exception of Carl, the participants typically related many of the images to three-dimensional or real-world objects (i.e., a sailboat, a stick of butter, a diamond). In fact, all of the case study participants mentioned the term three-dimensional when describing the images they viewed during their interviews. Thus, one might argue that the LAPP and PSVT:R are the most valid subtests of the intervention, and could explain why the experimental group had significant improvement in these subtests while the control group did not. Further study is needed to test this theory. For example, future studies might consider utilizing the LAPP and PSVT:R test and purposefully selecting *Quick Draw* images that appear three-dimensional to see if there is significant improvement in student scores.

Maturity Level

Another point to consider is although Gorska and Sorby (2008) found that their modified versions of the PSVT:R, MCT, DAT:SR, and LAPP were applicable and reliable exams for measuring middle school students' spatial visualization skills, these modified exams have not been widely tested. It is also worth noting that the study by Gorska and Sorby (2008) was not conducted on students below the seventh grade level, which can lead to speculation on another issue: one of the participants' maturity. Again, looking at Table 23, one can see that many of the original exams (i.e., unmodified forms) were developed for more mature students (i.e., college entrance exams, academic and vocational screening). Additionally, Ben-Chaim, Lappan, and Houang (1988) suggested that seventh grade is the optimal age for the teaching of spatial visualization skills based on the results of a study involving fifth through eighth grade students, in which seventh grade students showed the most gains. These facts lead one to question if perhaps the age and maturity level of the students tested may have had an influence on the results.

Gender

With regard to gender and spatial visualization skills, the literature tended to indicate that males are better at spatial visualization tasks than females. In a meta-analysis by Linn and Peterson (1985), the authors stated that their analysis of spatial visualization supported the previous findings of Maccoby and Jacklin (1978) in that males performed better and that “[gender] differences in spatial visualization do not change across the life span” (p. 1490). However, the current study does not support this. In analyzing the data, while no significant differences were found in the average gains in the total test scores based on gender, it was found that for this sample females scored higher than the males on both Pre- and Post- Total test scores. Additionally, in examining the amount of improvement for this sample based on gender by comparing the experimental group females to males, one found that the males improved their combined total score slightly more than half a unit (0.59 or approximately 6%), whereas the females improved almost an entire unit (0.88 or approximately 9%). Thus, one tends to agree with Battista (1990) that the ultimate goal of studying gender differences should not be to determine if such differences exist, but to design an effective intervention strategy to help all students succeed by improving their spatial skills. The results of this study seem to indicate that *Quick Draw* is an effective intervention strategy for all students. Given the identified limitations of the present study, further study is needed in this area to identify additional support for this finding.

Varying Ability

In examining the data related to the methods by which the case study participants with high and low spatial visualization skills approached and interacted with spatial visualization tasks, the cross-case comparison provided evidence to suggest that by helping students to make mental connections between the image and a real-world object, their spatial visualization skills may be enhanced. Additionally, it appears that by enhancing their ability to see images as a whole, rather than its parts, their spatial visualization skills may be enhanced. Future research in this area is needed. In addition, recognizing that these results surfaced through an analysis of participants' *Quick Draw* written response booklets and interviews, future research might also include the development of a metric that could be used to analyze written responses in determining evidence of students' spatial visualization ability and growth.

In addition, further study is needed in this area to determine if educational experiences such as *Quick Draw* can help all students not only improve their spatial visualization skills but also benefit in other academic areas, such as science.

Summary

In this current era of fast-paced, computer-aided technology, one may wonder how students' spatial intelligence may be enhanced to help them visualize, represent, and solve increasingly complex problems, both inside and outside of the mathematics classroom. Spatial visualization is often an underappreciated and underutilized cognitive ability in many of today's classrooms (Arnheim, 1980; NRC, 2006; Sorby, 1999). When one considers that strong spatial visualization skills have been shown to be a vital component of numerous fields and careers such as mathematics, physics, chemistry, architecture, geosciences, engineering, computer technology, aeronautical design, architecture, and graphic design (Clements & Battista, 1992; Hegarty & Waller, 2005; Olkun, 2003; Sorby, 1999; Suppiah, 2005), it becomes apparent that this area should be addressed. By helping students to improve their spatial visualization skills, there are potential benefits both inside and outside the mathematics classroom, as well as to make their skill sets more marketable for their future careers. To this end, this study serves to inform educators regarding the potential that the *Quick Draw* intervention holds for supporting students in this way.

REFERENCES

Ackermann, E. K. (1991). From de-contextualized to situated knowledge: Revisiting Piaget's water-level experiment. In I. Harel & S. Papert (Eds.), *Constructionism: Part 4: Cybernetics and constructionism* (pp. 367-379). Norwood, NJ: Ablex Publishing.

Arbaugh, F., Herbel-Eisenmann, B., Ramirez, N., Knuth, E., Kranendonk, H., & Quander, J. R. (2009). *Linking research and practice: The NCTM Research Agenda Conference report.* Reston, VA: National Council of Teachers of Mathematics.

Arnheim, R. (1980). A plea for visual thinking. *Critical Inquiry, 6*, 489-497.

Assessing Women in Engineering Project (2005). *Visual spatial skills: Research overviews.* Retrieved from http://www.engr.psu.edu/awe/

Baki, A., Kosa, T., & Guven, B. (2011). A comparative study of the effect of using dynamic geometry software and physical manipulatives on the spatial visualisation skills of pre-service mathematics teachers. *British Journal of Educational Technology, 42*, 291-310. doi:10.1111/j.1467-8535.2009.01012.x

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

Battista, M. T. (2007). The development of geometric and spatial thinking. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 843-908). Charlotte, NC: Information Age Publishing.

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

Ben-Chaim, D., Lappan, G., & Houang, R. T. (1988). The effect of instruction on spatial visualization skills of middle school boys and girls. *American Educational Research Journal, 25,* 51-71. doi:10.3102/00028312025001051

Bennett, G., Seashore, H., & Wesman, A. (1973). *Differential aptitude test: Spatial relations, form T* (4th ed.). New York, NY: Psychological Corporation.

Bishop, A. (1980). Spatial ability and mathematics education: A review. *Studies in Mathematics Education, 11*, 257-269.

Boakes, N. J. (2009). Origami instruction in the middle school mathematics classroom: Its impact on spatial visualization and geometry knowledge of students. *Research in Middle Level Education Online, 32*(7), 1-12.

Brown, D. L., & Wheatley, G. H. (1997). Components of imagery and mathematical understanding. *Focus on Learning Problems in Mathematics, 19*(1), 45-70.

Bruner, J. (1959). Learning and thinking. *Harvard Educational Review*, *29*, 184-192.

Carroll, J. B. (1993). Abilities in the domain of visual perception. In J. B. Carroll (Ed.), *Human cognitive abilities: A survey of factor-analytic studies* (pp. 304-363). New York, NY: Cambridge University Press.

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

College Entrance Examination Board. (1939). *Special aptitude test in spatial relations (Mental Cutting Test).* Developed by the College Entrance Examination Board, USA.

Chu, M., & Kita, S. (2011). The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General, 140*(1), 102-116. doi:10.1037/a0021790

Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics* (pp. 420-464). New York, NY: Macmillan.

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

Clements, D. H., & Sarama, J. (2009). *Learning and teaching early math: The learning trajectories approach.* New York, NY: Routledge.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Creswell, J. W. (2013). *Qualitative inquiry & research design: Choosing among five approaches* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage Publications.

Deno, J. A. (1994). The relationship of pre-college experiences to spatial visualization ability of beginning engineering graphics college students (Doctoral dissertation). The Ohio State University, Columbus, OH.

Eliot, J., & Smith, I. M. (1983). *An international directory of spatial tests.* Atlantic Highlands, NJ: Humanities Press Inc.

Erbilgin, E., & Fernandez, M. L. (2004). *Spatial ability, achievement, and use of multiple representations in mathematics*. Paper presented at the Annual Meeting of the North American Chapter of the International Group for the Psychology of Math Education, Toronto, Ontario, Canada.

Goetsch, D. L., Nelson, J. A., & Chalk, W. S. (1994). *Technical drawing.* Albany, NY: Delmar Publishers Inc.

Gorska, R., & Sorby, S. (2008). *Testing instruments for the assessment of 3-D spatial skills.* Paper presented at the meeting of American Society for Engineering Education (ASEE) Annual Conference, Pittsburgh, PA.

Guay, R. B. (1977). *Purdue spatial visualization test* - *visualization of rotations.* West Lafayette, IN: Purdue Research Foundation.

Hamlin, A. J., Veurink, N. L., & Sorby, S. A. (2009). *Enhancing visualization skills* - *improving options and success (EnViSIONS): An overview.* Paper presented at the 63rd Annual ASEE/EDGD Mid-Year Conference, Berkeley, CA.

Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial abilities. In P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 121-169). New York, NY: Cambridge University Press.

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

Hungwe, K. N., Sorby, S., Drummer, T., & Molzon, R. (2007). Preparing K-12 students for engineering studies by improving 3-D spatial skills. *International Journal of Learning, 14*, 127-135.

Jones, M. G., Gardner, G., Taylor, A. R., Wiebe, E., & Forrester, J. (2011). Conceptualizing magnification and scale: The roles of spatial visualization and logical thinking. *Research in Science Education*, *41*, 357-368.

Kali, Y., & Orion, N. (1996). Spatial abilities of high-school students in the perception of geologic structures. *Journal of Research in Science Teaching*, *33*, 369-391.

Kozhevnikov, M., Motes, M. A., & Hegarty, M. (2007). Spatial visualization in physics problem solving. *Cognitive Science*, *31*, 549-579.

Kurtulus, A., & Yolcu, B. (2013). A study on sixth-grade Turkish students' spatial visualization ability. *The Mathematics Educator*, *22,* 82-117.

Lane, D., Seery, N., & Gordon, S. (2009). The understated value of freehand sketching in technology education. *Engineering Design Graphics Journal, 73*(3), 13-22.

Lefrancois, G. R. (2006). *Theories of human learning: What the old woman said* (5th ed.). Belmont, CA: Wadsworth.

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

Lubinski, D. (2010). Spatial ability and STEM: A sleeping giant for talent identification and development. *Personality and Individual Differences*, *49,* 344-351.

Maccoby, E. E., & Jacklin, C. N. (1978). *The psychology of sex differences* (Vol. 1). Stanford, CA: Stanford University Press.

McCoy, A., Barnett, J., & Combs, E. (2013). *High-yield routines for grades K-8*. Reston, VA: National Council of Teachers of Mathematics.

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

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation.* San Francisco, CA: Wiley.

Miller, D. I., & Halpern, D. F. (2012). Can spatial training improve long-term outcomes for gifted STEM undergraduates? *Learning and Individual Differences, 26*, 141-152.

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

Mohler, J. L. (2008b). Examining the spatial ability phenomenon from the student's perspective. *Engineering Design Graphics Journal, 72*(3), 1-15.

Mulligan, N. W., & Peterson, D. J. (2015). Negative and positive testing effects in terms of item-specific and relational information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(3), 859-871.

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

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

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all*. Reston, VA: Author.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum.* Washington, DC: National Academies Press.

Newcombe, N. S. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American Educator, 34,* 29-35,43.

Newcombe, N. S. (2013). Seeing relationships: Using spatial thinking to teach science, mathematics, and social studies. *American Educator, 37,* 26-40.

Newcombe, N. S., & Frick, A. (2010). Early education for spatial intelligence: Why, what and how. *Mind, Brain and Education, 4*, 102-111.

Newcombe, N. S., & Huttenlocher, J. (2000). *Making space.* Cambridge, MA: MIT Press.

Newcombe, N. S., Uttal, D. H., & Sauter, M. (2013). Spatial development. In P. Zelazo (Ed.)*, Oxford handbook of developmental psychology* (pp. 564-590). New York, NY: Oxford University Press.

Olkun, S. (2003). Making connections: Improving spatial abilities with engineering drawing activities. *International Journal of Mathematics Teaching and Learning*. http://www.ex.ac.uk/cimt/ijmtl/ijabout.htm.

Parolini, L., Sorby, S., & Hungwe, K. (2006). Developing 3-D spatial skills for K-12 students. *Engineering Design Graphics Journal, 70*(3), 13-17.

Patkin, D., & Dayan, E. (2013). The intelligence of observation: Improving high school students' spatial ability by means of intervention unit. *International Journal of Mathematical Education in Science and Technology, 44*, 179-195. doi:10.1080/0020739X.2012.703335

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Piaget, J., & Inhelder, B. (1967). *The child's conception of space.* New York, NY: W. W. Norton.

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

Richardson, K., & Stein, C. (2008). Developing spatial sense and communication skills. *Mathematics Teaching in the Middle School, 14*, 101-107.

Risma, D. A., Putri, R. I., & Hartono, Y. (2013). On developing students' spatial visualization ability. *International Education Studies, 6*(9), 1-12.

Salthouse, T. A., Babcock, R. L., Skovronek, E., Mitchell, D. R., & Palmon, R. (1990). Age and experience effects in spatial visualization. *Developmental Psychology, 26*, 128-136.

Samsudin, K., Rafi, A., & Hanif, A. S. (2011). Training in mental rotation and spatial visualization and its impact on orthographic drawing performance. *Educational Technology and Society, 14*, 179-186.

Sanz de Acedo Lizarraga, M. L., & Garcia Ganuza, J. M. (2003). Improvement of mental rotation in girls and boys. *Sex Roles, 49*, 277-286.

Sarama, J., & Clements, D. H. (2009). *Early childhood mathematics education research: Learning trajectories for young children.* New York, NY: Routledge.

Sherman, J. (1980). Mathematics, spatial visualization, and related factors: Changes in girls and boys, grades 8-11. *Journal of Educational Psychology, 72*, 476-482.

Sholl, M. J. (1989). The relation between horizontality and rod-and-frame and vestibular navigational performance. *Journal of Experimental Psychology, 15*, 110-125.

Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal, 63*(2), 21-32.

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education, 31*, 459-480.

Sorby, S. A. Personal communications. (June 3, 2014).

Sorby, S. A., Signorella, M. L., Veurink, N. L., & Liben, L. S. (2013). *Developing spatial skills among middle school students.* Paper presented at the 68th EDGD Midyear Conference , Worchester, MA.

Strong, S., & Smith, R. (2002). Spatial visualization: Fundamentals and trends in engineering graphics. *Journal of Industrial Technology, 18*(1), 2-6.

Suppiah, K. (2005). Improving and identifying the spatial visualisation ability of students. ITE Teachers' Conference, Singapore.

Toptas, V., Celik, S., & Karaca, E. T. (2012). Improving 8th grades spatial thinking abilities through a 3D modeling program. *The Turkish Online Journal of Educational Technology, 11*, 128-134.

Tzuriel, D., & Egozi, G. (2010). Gender differences in spatial ability of young children: The effects of training and processing strategies. *Child Development, 81*, 1417-1430.

Uttal, D. H., & Cohen, C. A. (2012). *Spatial thinking and STEM education: When, why and how?* Northwestern University, Spatial Intelligence and Learning Center. Chicago, IL: Northwestern University.

van Garderen, D. (2006). Spatial visualization, visual imagery, and mathematical problem solving of students with varying abilities. *Journal of Learning Disabilities, 39*, 496-506.

van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. (1994). *The think aloud method: A practical guide to modeling cognitive processes.* London: Academic Press.

Velez, M. C., Silver, D., & Tremaine, M. (2005). *Understanding visualization through spatial ability differences*. Paper presented at the 16th IEEE Visualization Conference, Minneapolis, MN.

Vygotsky, L. (1986). *Thought and language.* Cambridge, MA: Massachusetts Institute of Technology.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its imprtance. *Journal of Educational Psychology, 101*, 817-835. doi:10.1037/a0016127

Wheatley, G. H. (1990). Spatial sense and mathematics learning. *Arithmetic Teacher, 37*(6), 10-11.

Wheatley, G. H. (1991). Enhancing mathematics learning through imagery. *Arithmetic Teacher, 39*(1), 34-36.

Wheatley, G. H. (1992). The role of reflection in mathematics learning. *Educational Studies in Mathematics, 23*, 529-541.

Wheatley, G. H. (1996). *Wheatley spatial ability test (mental rotations): Administration packet.* Tallahassee, FL: Mathematics Learning.

Wheatley, G. H. (2007). *Quick draw: Developing spatial sense in mathematics.* Bethany Beach, DE: Mathematics Learning.

Wheatley, G. H., Brown, D. L., & Solano, A. (1994). Long term relationship between spatial ability and mathematical knowledge. In D. Kirshner (Ed.), *Proceedings of the sixteenth annual meeting of the North American Chapter of the Psychology of Mathematics Education* (Vol. 1, pp. 225-231). Baton Rouge, LA: Louisiana State University.

Wheatley, G. H., & Reynolds, A. M. (1999). "Image Maker": Developing spatial sense. *Teaching Children Mathematics, 5,* 374-378.

Yilmaz, H. B. (2009). On the development and measurement of spatial ability. *International Electronic Journal of Elementary Education, 1*(2), 83-96.

Yin, R. K. (2014). *Case study research: design and methods* (5th ed.). Thousand Oaks, CA: Sage Publications.

Youssef, B. B., & Berry, B. (2012). Learning to think spatially in an undergraduate interdisciplinary computational design context: A case study. *International Journal of Technology and Design Education, 22*, 541-564.

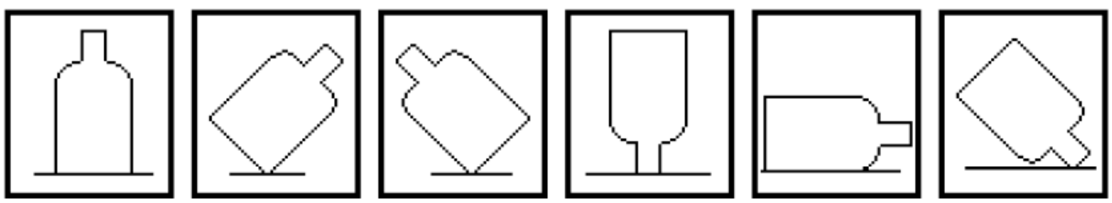
APPENDICES

APPENDIX A

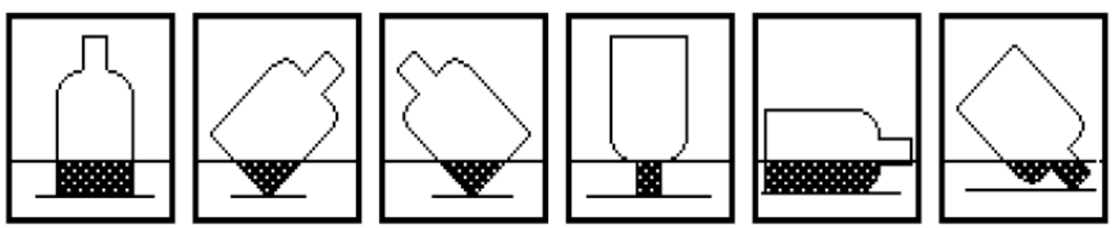
Piaget's Water Level Task for Measuring Spatial Perception

The Water-level task was initially designed by Piaget and Inhelder to study a child's construction of the horizontal and vertical coordinate system (Piaget & Inhelder, 1967). In Piaget's experiment, children were asked to anticipate the water surface orientation when partially filled bottles were tipped and covered with a cloth. Children were then asked to draw the position of the water level based on the orientation of the bottle (Ackermann, 1991; Piaget & Inhelder, 1967; Sholl, 1989) as shown below.

Orientation of covered bottle



Water level surface orientation



APPENDIX B

Demographic Survey

Demographic Information **Pseudonym _____**

Gender: M or F (circle one)

Age: _________________ years

Ethnicity: _____ African-American _____ Asian _____ Caucasian

_____ Latino _____ Native-American

_____ Other (please specify: _____________________________)

What toys did you play with as a child?

What was your favorite toy?

What video games did/do you play?

What is your favorite video game?

What computer games did/do you play?

What is your favorite computer game?

What sports do you play?

What is your favorite sport to play?

Do you like to draw? Why or Why not?

Have you ever taken private art, drawing or sculpting classes?

What is your favorite subject? Why?

What is your least favorite subject? Why?

What elective (art, teen living, health, keyboarding, technology education, band, music/choir, physical education) class are you currently taking?

APPENDIX C

Task-Based Interview Protocols

Initial Task-Based Interview: Quick Draw Activity

Identification Pseudonym: ____________________ Date_____

I saw on your survey that you said that you like to play with __________________, why?

I saw on your survey that you liked to play the _____________ video/computer games.

What about this game do you like?

Why is ______________ your favorite subject?

On your survey you said that you did/did not like to draw, why/why not do you like to draw?

Quick Draw Activity

I want you to look at the following image (**L1-2 bottom**), and as you draw it, I want you to "talk to me as you draw" the image; what you are thinking about as you draw what you saw?

First time: Draw what you saw:

Do you need a second look?

Second time: Draw what you saw; if your drawing matched the image write "SAME"

Write a word that describes what you saw? Why was this word helpful?

What did you see first?

How did this help you to remember what to draw?

What else did you see?

Second Task-based interview: Participant Name________________ Date_____

Specific question to be determined from classroom observations or artifacts:

In class I heard you say _________________; can you expand on what you meant (to be determined from classroom observation): or, one of your class mates said _________________ during the discussion of this _____________ figure, can you _______________ (expand, see, etc., what they were thinking).

Quick Draw Activity

I want you to look at the following image (**L4-3 top),** and as you draw it, I want you to "talk to me as you draw" the image; what you are thinking about as you draw what you saw?

First time: Draw what you saw:

Do you need a second look?

Second time: Draw what you saw, if your drawing matched the image write "SAME"

Write a word that describes what you saw. Why was this word helpful?

What did you see first?

How did this help you to remember what to draw?

What else did you see?

Do you think that your ability to see and move figures in your mind (spatial visualization) is getting better through the Quick Draw activities? Why or why not?

Third Task-based interview: Participant Name________________ Date_____

Specific question be determined from classroom observations or artifacts:

In class I heard you say __________________; can you expand on what you meant (to be determined from classroom observation): or, one of your classmates said _________________ during the discussion of this _____________ figure, can you _______________ (expand, see, etc., what they were thinking).

Quick Draw Activity

I want you to look at the following image (**L4-9 top**), and as you draw it, I want you to "talk to me as you draw" the image; what you are thinking about as you draw what you saw?

First time: Draw what you saw:

Do you need a second look?

Second time: Draw what you saw; if your drawing matched the image write "SAME"

Write a word that describes what you saw? Why was this word helpful?

What did you see first?

How did this help you to remember what to draw?

What else did you see?

Do you think that your ability to see and move figures in your mind (spatial visualization) is getting better through the Quick Draw activities? Why or why not?

Final Task-based interview: Participant Name___________________ Date_____

Specific question to be determined from classroom observations or artifacts:

In class I heard you say __________________; can you expand on what you meant (to be determined from classroom observation): or, one of your classmates said _________________ during the discussion of this _____________ figure, can you _______________ (expand, see, etc.; what they were thinking).

Quick Draw Activity

I want you to look at the following image (**L7-2 top**), and as you draw it, I want you to "talk to me as you draw" the image; what you are thinking about as you draw what you saw?

First time: Draw what you saw:

Do you need a second look?

Second time: Draw what you saw, if your drawing matched the image write "SAME"

Write a word that describes what you saw? Why was this word helpful?

What did you see first?

How did this help you to remember what to draw?

What else did you see?

Final Follow-up Questions

As you think back over the last six weeks how do you think that your ability to see and move figures in your mind (spatial visualization) has changed, if at all, through the Quick Draw activities.

In what way (how is it changed)?

Why do you think this?

What part of what we did was most helpful?

What part of what we did was least helpful?

If I did this with a class of students similar to yourself next year, can you think of any changes that would make to this more beneficial to someone like yourself?

APPENDIX D

Teacher Observation Protocol

Teacher Observation Fidelity of Implementation

Date:

Beginning Time: Ending time:

Number of Students Present:

Quick Draw Figure (used for this data):

Deviations from the classroom Quick Draw activity (if any)

Follow-up questions asked by teacher?

Comments:

APPENDIX E

Whole Class Interaction Protocol

Class Observation Protocol

At the beginning of each class observation and utilizing a seating chart -

Date: Beginning Time: Ending Time:

Number of Students Present:

Quick Draw figure (used for this date):

Which of the four interview participants are in the class (Highlighted on seating chart):

Deviations from the classroom Quick Draw written responses activity protocol (if any)

Notes regarding open class discussions to indicate:

Probing questions asked by teacher

Specific insights by specific students (including the four interviews---noted on seating chart)

Questions asked by class during discussion

Class engagement (body language and interest level):

Student use of gestures during description of image:

Student language during verbal description of image:

Additional comments:

APPENDIX F

Case Student Interaction Protocol

Individual Class Observation Protocol

At the beginning of each class observation and utilizing a seating chart -

Date: Beginning Time: Ending Time:

Number of Students Present:

Quick Draw figure (used for this date):

Which of the four interview participants are in the class (Highlighted on seating chart):

Deviations from the classroom Quick Draw written responses activity protocol (if any)

Notes regarding student participation in open class discussions to indicate:

Probing questions asked by teacher

Specific insights by case study participants

Student engagement (body language and interest level):

Number of comments made by participants

Types of comments made by participants

Student use of gestures during description of image:

Student language during verbal description of image:

Additional comments:

APPENDIX G

IRB Letter of Approval

MIDDLE TENNESSEE STATE UNIVERSITY

8/5/2014

Investigator(s): Teresa A. Schmidt, Dr. Angela Barlow
Department: Mathematics
Investigator(s) Email: Teresa.Schmidt@mtsu.edu, Angela.Barlow@mtsu.edu

Protocol Title: "A Study of the Impact of a Drawing Intervention on the Spatial Visualization Skills of Sixth Grade Students "

Protocol Number: 15-018

Dear Investigator(s),

The MTSU Institutional Review Board, or a representative of the IRB, has reviewed the research proposal identified above. The MTSU IRB or its representative has determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 and 21 CFR 56.110, and you have satisfactorily addressed all of the points brought up during the review.

Approval is granted for one (1) year from the date of this letter for 120 participants.

Please note that any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918. Any change to the protocol must be submitted to the IRB before implementing this change.

You will need to submit an end-of-project form to the Office of Compliance upon completion of your research located on the IRB website. Complete research means that you have finished collecting and analyzing data. **Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date.** Please allow time for review and requested revisions. Failure to submit a Progress Report and request for continuation will automatically result in cancellation of your research study. Therefore, you will not be able to use any data and/or collect any data. Your study expires **8/5/2015**.

According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to complete the required training. **If you add researchers to an approved project, please forward an updated list of researchers to the Office of Compliance before they begin to work on the project.**

All research materials must be retained by the PI or faculty advisor (if the PI is a student) for at least three (3) years after study completion and then destroyed in a manner that maintains confidentiality and anonymity.

Sincerely,
Kellie Hilker
Compliance Officer/ MTSU Institutional Review Board Member

APPENDIX H

Classroom *Quick Draw* Written Responses

Classroom: *Quick Draw* Activity

First time: In the space below, draw what you saw.

Second time: In the space below, draw what you saw; if your drawing matched the image write "SAME"

What did you see?____

____

Write a word that describes what you saw. ____________________________________

What did you see first? ____

____

____

How did you draw it? ____

____

____

How did this help you to remember what to draw?______________________________

____

____

What else did you see? ____

____

____

How would you explain your drawing? ______________________________________

____

____

APPENDIX I

Schedule of Weekly *Quick Draw* Activities

Weekly Classroom *Quick Draw* Activities
Activity selected

Week 1	L1-1 top	L1-2 top*	L1-5 bottom	L1-7 top	L1-9 top
Week 2	L2-2 bottom	L2-4 bottom	L2-7 top	L2-8 bottom	L2-11 top
Week 3	L3-1 top	L3-5 top	L3-7 top	L3-6 top*	L3-9 bottom
Week 4	L4-3 top	L4-4 top	L4-7 bottom	L4-8 bottom*	L4-11 top
Week 5	L5-1 bottom	L5-4 bottom	L5-5 bottom	L5-8 top	L5-12 top
Week 6**	L6-3 top	L6-5 bottom	L7-2 bottom*	L7-4 top	L7-12

* Similar to individual interview questions
** These are optional, may choose some of the previous ones to draw rotated

APPENDIX J

Task-based Interview *Quick Draw* Images

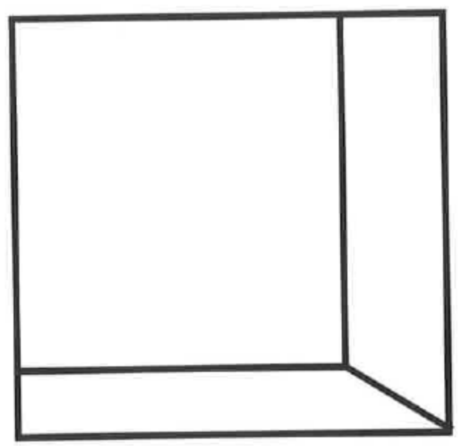


Image for first interview

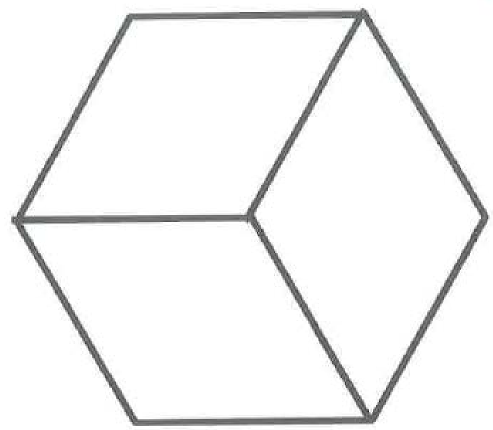


Image for second interview

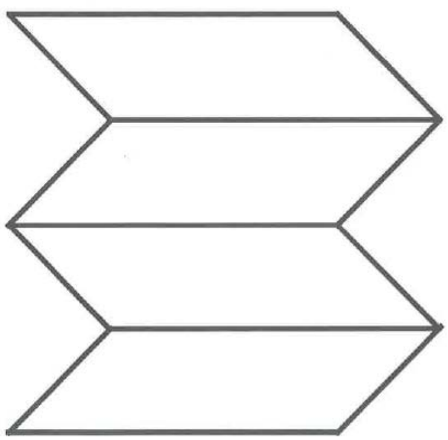


Image for third interview

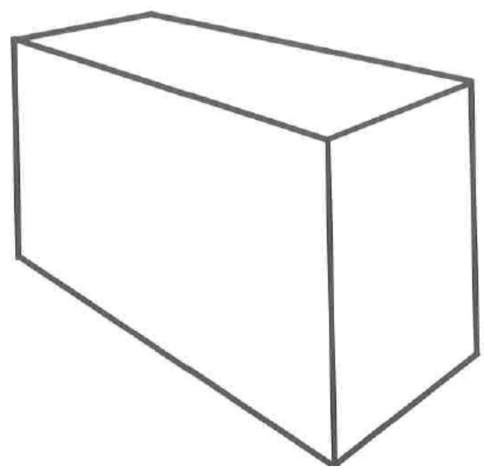


Image for fourth interview