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By Helen W. Kang

Entitled The Effectiveness of Spatial Visualization Training for Children with and without Attention Deficit Hyperactivity Disorder (ADHD)

For the degree of Doctor of Philosophy

Is approved by the final examining committee:

James L. Mohler, Ph.D
Chair

Patrick E. Connolly, Ph.D

Sydney Zentall, Ph.D

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For the degree of Doctor of Philosophy

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THE EFFECTIVENESS OF SPATIAL VISUALIZATION TRAINING FOR CHILDREN WITH AND WITHOUT ATTENTION DEFICIT HYPERACTIVITY DISORDER (ADHD)

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Helen W. Kang

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

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West Lafayette, Indiana

To my special people … you know who you are.

I am lucky to have you all in my life.

(Especially, thank you 엄마, 아빠, 은미언니, 은정이 언니, 케빈, 제이미, 토로, 똥주, 쨍이, 지영이 for listening my endless complaints, being stress relievers and tolerating my grumpiness.)

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ABSTRACT

Kang, Helen W. Ph.D., Purdue University, May 2010. The Effectiveness of Spatial Visualization Training for Children With and Without Attention Deficit Hyperactivity Disorder (ADHD). Major Professors: James L. Mohler and Patrick E. Connolly.

The development of spatial ability in children is crucial to their success in learning geometry. The lack of spatial development could result in students not being able to comprehend embedded figures and conflicting shapes during mathematics instruction. The current study evaluated and compared the use of computer-generated training as a method of assistive instructional technology to enhance spatial ability for students with and without ADHD. The study recruited a total of 50 seventh and eighth grade students with and without ADHD from local schools. The study assessed student responses to two different computer-generated training sessions – static and dynamic conditions. Both conditions included the same text, but the graphics associated with dynamic instruction were animated (moving), whereas the static condition included graphics that were fixed. The findings revealed improvement in the static condition for students with and without ADHD. However, the performance of male students with ADHD was significantly diminished in the dynamic condition.

CHAPTER 1. INTRODUCTION

Chapter one contains an introduction to the current research study. This chapter provides the statement of the problem, purpose, and significance of the current study. Furthermore, associated research questions and hypotheses as well as the assumptions, limitations, delimitations of the study, and definitions of terms are also included in this chapter. Finally, the chapter concludes with an overview of the current study.

1.1. Introduction

Affecting an average of at least one student in every classroom, Attention Deficit Hyperactivity Disorder (ADHD) has been defined as a behavioral disorder (American Psychiatric Association, 2000). The causes of ADHD are unknown and studies have indicated that ADHD may be a combination of both genetic and environmental factors (Zentall, 2006). Regardless of the causes, the symptoms of ADHD impact student learning. Estimating that two million students will be diagnosed with ADHD in the next decade (Gardner, 2007), schools are attempting to accommodate these students by providing them with alternate learning methods to assist their learning and to improve their academic performance.

A student who is diagnosed with ADHD may display characteristics such as the inability to sit still, difficulty with organization, lack of concentration, and impulsiveness.

In addition, one could also suffer from anxiety (American Psychiatric Association, 2000). The characteristics of students with attention problems vary and can range from mild to severe. Often the symptoms caused by the disability interfere with a person's daily life. For those students diagnosed with ADHD, their academic performance can be hindered by the symptoms and their academic success jeopardized because the majority of learning tasks require students to focus on presented information for a significant period of time (Zentall, 2006).

Lack of academic success for students with ADHD has been demonstrated in the area of English and mathematics. Previous studies have acknowledged that performing a mathematical task is more difficult for students with attentional problems. These studies also have indicated that fewer mathematical problems were attempted and calculated by students with ADHD, and students were often diagnosed as having a math disability (Zentall, 1990; Zentall & Ferkis, 1993; Zentall & Smith, 1993; Zentall, Smith, Lee, & Wieczorek, 1994). Geometry, one mathematics subject that has received increased attention as of late, appears to be more difficult for these types of students (Mistretta, 2000). However, there has been little research done in geometry intervention to assist students with learning disabilities, math disabilities, and ADHD, and also students without disabilities. Learning geometry requires one to focus on a variety of math principles. Learning geometry also requires one to analyze embedded figures and shapes, manipulate and mentally transform them, and visualize spatial information. All these activities are difficult for students with ADHD. Yet, these skills are associated with learning geometry and defining the realm of spatial ability. Spatial ability is identified as the ability to mentally "generate, manipulate, and retain abstract information and/or images" (Lohman, 1979, p.188). The definition of spatial ability suggests that one needs adequate spatial skills to learn and solve problems related to geometry. Therefore, spatial ability could predict a student's geometry performance.

The present study hypothesized that one of the contributors to poor performance in geometry by students with ADHD could be due to low spatial ability. Many studies have claimed that spatial ability could be improved with specific intervening methods. Therefore, the current study developed and examined the effectiveness of a spatial ability training tool for students with ADHD. Their performance result was compared with students without ADHD. The study also proposed that integrating substantial movement during instruction (i.e., animation) could perhaps enhance their spatial ability, because previous studies had indicated that graphics and the use of computer technology provided stimulation that students with ADHD needed in order to direct their attentional functions (Kang, Zentall, & Burton, 2007; Zentall, 2006).

The current study measured the performance of seventh and eighth grade students with and without ADHD over a brief period of time. The study then assessed the value of computer-generated spatial ability instructional tools in an attempt to enhance student geometry performance and spatial skills. Two different conditions were used - static and dynamic conditions. Both conditions presented the same textual information to the participants. However, the dynamic condition included graphics that were animated (moving), whereas the static condition included graphics that were fixed (non-animated).

Many studies have acknowledged that spatial skills can be improved with the proper training (Aldahamash, 1995; Alderton, 1989; Anglin, Towers, & Moore, 1997; Baldwin, 1984; Ben-Chaim, Lappan, & Houang, 1988; Carpenter & Just, 1986; Harris, 1978; Lohman, 1989; Lohman, 1993; Rovet, 1983; Vandenberg, 1978). Training that encourages students to recognize visual spatial relationships with a computer could facilitate the understanding of geometry. For students with ADHD, this instructional material could be used as method of stimulation, which students with ADHD constantly require to stay focused and learn effectively. Furthermore, students with ADHD mathematic performance could be improved without drugs or behavioral treatment with this alternative learning method. Therefore, appropriate spatial training may be a solution to assist students with ADHD in learning geometry, and also guide them to be successful in an academic setting.

1.2. Statement of the Problem

Students with Attention Deficit Hyperactivity Disorder (ADHD) have difficulty learning geometry. Student ability to visualize spatial relationships between abstract images is associated with their performance in geometry. Students with ADHD inability to visualize spatial information could be caused by the disability. This study evaluated the effectiveness of spatial visualization training for seventh and eighth grade students with and without ADHD in an attempt to enhance their spatial ability. The training material's effectiveness was assessed by analyzing of student performance before and after the training session.

1.3. Significance of the Study

To this date, there is no known cure for ADHD. Drug therapies have been used as common methods to minimize the symptoms caused by the disability. One may argue that current treatments effectively improve the performance of students with ADHD in a learning environment. However, there have been debates regarding the use of drugs as treatment for children with ADHD because, like many other medications, psycho-stimulant drugs taken by children with ADHD cause numerous side effects. Recently, the U.S. Food and Drug Administration (FDA) indicated that a number of psycho-stimulant drugs for children with ADHD may prompt suicidal thoughts, depression, increased anxiety, and paranoia (Gardner, 2007).

Parents who have children with ADHD and do not wish to place their children on psycho-stimulant medications are most likely to rely on something else (i.e., schools) to help their children. Public schools are bound by public laws such as the Individuals with Disabilities Educational Act (IDEA) to provide any necessary accommodations to meet the needs of students with disabilities. According to IDEA, it is mandatory for public schools to provide alternate learning methods for those students meeting the criteria of IDEA. Computerized instructional training tools have been utilized as an alternate learning method and accommodation provided by the schools for students with disabilities. For parents and students, this tool could be a solution to low academic performance and perhaps strengthen of student on-task behavior while they are engaged in lessons.

Many researchers have supported the ideas of early intervention and treatments for children with disabilities rather than employing the drug therapies. Researchers have claimed that an effective intervention promoting other learning methods for children with ADHD appears promising and shows improvement in their learning (Gardner, 2007; Zentall, 1990; Zentall & Smith, 1993). The current study hypothesized that a spatial ability training tool could provide stimulation for students with ADHD, and might play a significant role in learning geometry. In addition, the study assumed that this instructional tool might allow students with ADHD to gain equal benefits from their education as their peers, and perhaps assist them in their future academic performance.

1.4. Statement of Purpose

The purpose of this study was to assess the effectiveness of dynamic and static spatial visualization training for seventh and eighth grade students with ADHD from local middle schools. Participants of this study were instructed on tasks related to the spatial visualization, which included: (1) The Paper Folding and (2) The Surface Development tests from the Ekstrom, French, and Harman's (1976) the *Kit of Factor Referenced Cognitive Test*.

1.5. Research Questions

Several research questions were addressed throughout the current study, including:

1. Were there initial performance differences on spatial ability (i.e., spatial orientation, relation, and visualization) among seventh and eighth grade students with and without ADHD before instruction on spatial visualization?
2. Would dynamic images improve student spatial performance more than static images?
3. Would spatial performance of seventh and eighth grade students with and without ADHD improve differently with instruction on spatial visualization?

4. Was there a correlation between visual working memory and spatial performance of students with and without ADHD?

1.6. Research Hypotheses

1. *Ho*: There will be no initial performance differences on spatial ability among seventh and eighth grade students with and without ADHD before instruction on spatial visualization.

   Ha: There will be initial performance differences on spatial ability among seventh and eighth grade students with and without ADHD before instruction on spatial visualization.

2. *Ho*: There will be no significantly improvement in all student performance for any conditions.

   Ha: The dynamic condition will significantly improve all student performance versus the static condition.

3. *Ho*: There will be no significant difference in the student performance based on different conditions.

   Ha: There will be a statistically significant difference in the student performance based on different conditions.

4. *Ho*: There will be no correlation between student working memory their spatial performance.

   Ha: Student working memory will be positively correlated with their spatial performance.

1.7. Assumptions

The following assumptions were inherent in the pursuit of this project:

1. The students have had some exposure to a computer-based learning environment.
2. The students have responded to the best of their ability to complete the testing instruments (geometry, visual memory, and spatial ability tests).
3. The students have been properly diagnosed with ADHD and do not have co-occurring disabilities.
4. The participants of the study do not have prior exposure to the instructional material that is presented during the study.
5. Alternate methods of learning may enhance the performance of students with ADHD in mathematics.
6. The dynamic condition will provide additional stimulation that is not represented in static condition.

1.8. Delimitations

The following delimitations were inherent in the pursuit of this project:

1. Some of the students were medicated for their disabilities.
2. The researcher attempted to provide similar experimental settings for the participants, as the implementation of the study occurred within participant schools.
3. For the purpose of the study, both dynamic and static conditions were operationally defined.

4. The purpose of this research was to measure the effectiveness of the spatial training tool; the author did not evaluate the following:
    a. Rendering techniques and/or method for generating images that are used in the instruction.
    b. Instructional methods between local schools.
    c. The capability or functionality graphic software packages.

1.9. Limitations

The following limitations were inherent in the pursuit of this project:

1. The researcher could not control whether students were medicated or not during participation in the study.
2. The test instruments accurately measured participant abilities.
3. The researcher was not able to provide the same experimental settings for all participants.
4. The research study was conducted at participant schools.
5. The researcher could not control the participant behavior before or during the study (e.g., getting sick or not wanting to participate).

1.10. Definition of Terms

The following terms were defined to assist the reader:

ADHD: The Attention Deficit Hyperactivity Disorder (ADHD) is a behavioral disorder. The primary characteristic of ADHD is impairment in school social performance.

Those who are diagnosed with ADHD display characteristics of failure to invest, organize, or sustain attention and response impulsivity (American Psychiatric Association, 2000; Barkley, 1997; Douglas, 1972).

Dynamic images: The visual stimulus that contains moving elements (animation), visual information that changes over time, such as translation, transformation, and progression (Betrancourt, 2005; Hunt, Pellegrino, Frick, Farr, & Alderton, 1988).

Spatial ability: The ability to generate, retain, and manipulate abstract visual information and images (Lohman, 1979).

Spatial orientation: The ability to imagine how a visual stimulus will appear from another location and viewpoint (Lohman & Kyllonen, 1983).

Spatial relation: The ability to solve spatial-related problems quickly (Lohman & Kyllonen, 1983).

Spatial skill: Learned or acquired to visualize spatial relationships through training (Sorby, 1999)

Static images: An illustration without any moving elements (i.e., still graphics) (Hunt, Pellegrino, Frick, Farr, & Alderton, 1988).

Visual working memory: A temporary storage with the capacity to maintain and manipulate visual information (Baddeley & Hitch, 1974; Philips, 1974).

Spatial visualization: The ability to imagine the mental transformation and rotation of objects (Sorby, 1999), and the folding and unfolding of patterns (Lohman & Kyllonen, 1983).

Working memory: The system or systems that involve the temporary maintenance and manipulation of information (Baddeley & Hitch, 1974).

1.11. Overview of Study

The purpose of this chapter is to provide an introduction and overview of the current research study. This chapter also describes the statement of the problem, significance, and purpose of the study. Furthermore, research hypotheses, assumptions, delimitations, limitations, and definitions are discussed. The second chapter of this document provides pertinent literature with regards to Attention Deficit Hyperactivity Disorder, spatial ability, working memory, and the importance of multimedia instruction. Following the review of literature, chapter three provides an overview to the methodology that was used in the study. This chapter includes the description of participants, research designs, procedures, and an explanation of the data analyses that were used in the study. The fourth chapter reports the results from the data analyses. The final chapter provides discussion based on the data results, a conclusion, and recommendations for future research.

CHAPTER 2. REVIEW OF THE LITERATURE

Chapter two discusses relevant literature in order to exhibit the significance of the study. This chapter provides background information concerning Attention Deficit Hyperactivity Disorder (ADHD) and how ADHD affects the performance of students diagnosed with this disability. Various literature has acknowledged the fact that students with ADHD have significant difficulty performing in academic settings due to their disabilities, especially in geometry. Studies also have inferred that one of the reasons for poor performance of students in geometry is due to low spatial ability caused by deficits in visual working memory. Each of these areas of research was outlined as it related to the proposed study. Specifically, there are brief explanations on the importance of constructing spatial ability.

In addition, the chapter further discusses differences in individual performance on spatial related tasks. Studies have claimed that variations in individuals might be due to differences in gender, age, information processing, and strategies used by individuals to complete the spatial tasks. Furthermore, the literature on working memory and one of its specific components, visual working memory, are examined in this chapter.

One of the reasons behind the discussion of visual working memory is because lack of visual working memory capacity could manifest itself as one's difficulty with comprehending spatial relationships. The chapter concludes with an overview of the significance of interactive media instruction that may assist with spatial ability enhancement.

2.1. Attention Deficit Hyperactivity Disorder

The Attention Deficit Hyperactivity Disorder (ADHD) has been labeled as the most common childhood disorder in the United States (National Institutes of Health, 2000). Experts have concluded that approximately two million school-aged students have been diagnosed with ADHD and approximately 44% of these students are receiving special education services (Bloomingdale, Swanson, Barkley, & Satterfield, 1991; Bussling, Zima, Perwien, Belin, & Widawski, 1998; Zentall, 2006). Even though students are receiving assistance from their schools, the symptoms caused by the ADHD disability more often than not interfere with students' daily lives and hinders their academic performance (Gardner, 2007; Zentall, 2006). The following section defines ADHD disability. Followed by the definition, the researcher outlines the reasons for students with ADHD poor academic performance by evaluating the symptoms caused by the disability. Finally, this specific section concludes with an examination of the different types of treatments that could be used to improve academic performance for students with ADHD.

2.1.1. What is ADHD?

Unlike other cognitive disabilities such as dyslexia, dyscalculia, and learning disabilities that affect student academic performance, ADHD diagnosis is made by the physician. The ADHD diagnosis is determined by the *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR).* According to *DSM-IV-TR,* ADHD has three subtypes: the hyperactive-impulsive type (ADHD-H), the inattentive type (ADHD-I), and the combined type (ADHD-C). ADHD-C is defined as showing both signs of hyperactivity-impulsivity and inattentive ADHD symptoms (American Psychiatric Association, 2000). There is only a small chance that an individual will fit precisely within only one subtype of ADHD and a study suggested that approximately 55% of the population that has been diagnosed with ADHD falls into the combined subtype (i.e., ADHD-C) (Kaplan, Dewey, Crawford, & Wilson, 2001). An individual who is diagnosed with ADHD can have characteristics of the inability to sit still, a difficult time organizing, lack of concentration, impulsiveness, and anxiety (American Psychiatric Association, 2000; Zentall, 1985). Due to the nature of its symptoms, the American Psychiatric Association (2000) has identified ADHD as a behavioral syndrome.

The causes of ADHD are unknown and studies have indicated that there may be a combination of both genetic and environmental factors (Zentall, 2006). Because the public still does not fully understand the causes of ADHD, it has received criticism from the public. This criticism usually involves the issue of overdiagnosis and misdiagnosis of ADHD. One could argue that parents, educators, and physicians are too quick to reach a decision on student disability and not on his or her ability. However, there may be a reason why parents desire to obtain a diagnosis earlier. Once a student is diagnosed with a disability by a physician, under the Individuals with Disabilities Educational Act (IDEA), he or she is eligible for special services from the school. Any early actions taken by parents and educators could assist students with disabilities tremendously in their academic careers because IDEA was established to provide financial assistance and it also support appropriate educational methods for students with disabilities. These educational methods are defined as any assistance or accommodations from schools in order to benefit students with disabilities in their learning process equally as their peers. For example, one of the accommodations made by the schools could include integrating computers as instructional tools. If these accommodations from schools are not met, the parents have the choice to turn to the legal system (Zentall, 2006). Schools are legally bound by the public law to assist students in any way possible to enhance their learning experiences.

2.1.2. Academic Performance

A significant number of students who are diagnosed with ADHD fail to perform in the same academic setting when compared with their peers. Studies have indicated that nearly 80% of students with ADHD have difficulty performing in a learning environment and 30% of them fail to perform at their expected IQ levels (Barry, Lynman, & Klinger, 2002; Cantwell & Baker, 1991). Nevertheless, researchers such as Leung, Ho, Luk, Taylor, Bacon-Shone, and Mark (1996) have argued that low IQ scores and academic deficits are the consequences of ADHD symptoms rather than a main reason.

Poor performance in academic achievement tests and/or in IQ could be due to the fact that students with ADHD have difficulty maintaining attention when vital information is presented to them (Zentall, 2006). The inability to pay and maintain attention to important learning materials, such as an answer to a question or learning concept, creates gaps while students construct their knowledge. This might be the real reason that students with ADHD perform below their IQ levels and have low academic performance, rather than having the inability to learn. Due to low IQ scores, students with ADHD are often misdiagnosed as having various types of other learning disabilities (e.g., verbal, reading, and math disabilities). Sometimes it may take a significant time period for students to be properly diagnosed with the accurate disability. Until then, student learning continuously suffers in various school subject matters.

2.1.2.1. General Subjects

In order for proper knowledge to transfer and be constructed by learners, students are expected to stay focused on learning a topic for a significant period of time. Zentall (2006) noted that almost all school activities, as well as social tasks, require student attention. However, students with ADHD have demonstrated difficulty with maintaining focus when tasks are long, rote, repetitive, uninteresting, or nonactive (Zentall, 2006). Zentall's optimal stimulation theory has confirmed that students with ADHD are constantly understimulated, which makes them unable to stay focused on certain or any activities (Zentall, 1975). The characteristics of an inability to stay focused is often shown in students with an inattention diagnosis (i.e., ADHD-I) rather than in those students with the hyperactivity and impulsivity subtypes of ADHD (i.e, ADHD-H) (Wilcut & Pennington, 2000).

Students who are identified as having ADHD-I subtype can have either sustained attention or selective attention problems. One of the main characteristics of students with selective attention problems is that they have difficulty ignoring irrelevant information (Zentall, 1975, 1985, & 2006). These students become distracted when they are presented with competing information. When there are multiple visual stimuli, the students cannot separate important information from the unimportant information (Zentall, 1985). Students with sustained attention problems have a tendency to look around and change their attention focus more than their peers (Zentall, 1985). For these reasons, students with inattention subtypes show more significant academic deficiency in general academic settings than those with any other subtypes of ADHD.

2.1.2.2. Mathematics

For students with ADHD, their low performance in general subjects and mathematics could be linked to the inability to maintain attention, failing to organize, identify and update information in their minds (Passolunghi & Pazzagliab, 2004). Passolunghi and Pazzagliab (2004) have indicated that these abilities are properly demonstrated in children who can solve math problems and perform mathematics computations. Passolunghi and Pazzagliab (2004) supported Zentall's (1990) conclusion by indicating that students with ADHD have shown significant deficits in mathematics, especially in computations. Studies have indicated that fewer problems were attempted and calculated by students with attentional problems in mathematics and these students are often misdiagnosed as having math disabilities (Zentall, 1990; Zentall & Ferkis, 1993; Zentall & Smith, 1993; Zentall, Smith, Lee, & Wieczorek, 1994).

Mistretta (2000) stated that students who have math computation difficulty also have difficulty in learning geometry. Geometry is another mathematical subject that recently has received much attention along with mathematics computation. In order for students to comprehend geometry, they may have to mentally visualize hidden lines and patterns within an object and understand the visual spatial relationship of abstract visual information. One may argue that understanding these concepts is essential for higher mathematics, science, engineering, and other disciplines, and as a result the importance of learning geometry in the mathematics curriculum has increased drastically over the years (Mistretta, 2000). Nevertheless, there are very few studies available that address geometry interventions that could improve the overall academic performance of students with or without disabilities.

2.1.3. Improving Attention

There are claims that the academic performance of students with ADHD can be improved. As stated earlier, students with ADHD require additional optimal stimulation to sustain attention because they are “underaroused” and “understimulated” (Cooley & Morris, 1990; Rosenthal, 1973; Zentall, 1975). Students who are understimulated are more likely to pay attention to what is brighter, bigger, more intense, more colorful, louder, or moving to obtain necessary stimulation (Copeland & Wisniewski, 1981; Radosh & Gittelman, 1981; Zentall, 1986, 1989, & 2006). According to Zentall and Dwyer (1988), student performance errors were reduced when attention getters with bright and intense stimuli were placed directly onto important information. When color was added to highlight important facts, students with ADHD were able to outperform their peers (Zentall, 1989). Kang, Zentall and Burton (2007) supported claims that were made by Zentall’s previous research. They acknowledged that students with characteristics of ADHD (especially ADHD-I subtype) were able to outperform comparison students when they were instructed on geometry with images that contained additional visual stimuli (i.e., images with shadows, reflection, and highlights). For students with ADHD-I, the intense stimuli appear to help students ignore irrelevant information and concentrate on important information. The previous study conducted by Kang, Zentall and Burton (2007) concluded that increasing visual novelties such as color, shadows, and highlights in images through the use of computer technology helped students stay on task and increased their performance scores in geometry.

Computer technology has been identified as another source of stimulation for students with ADHD (Kang, Zentall, & Burton, 2007; Zentall, 2006). Utilizing computers as instructional tools not only provides stimulation for students with attention problems, but it could be an effective tool to display visual novelties. Presenting images on a computer improved academic performance for students with ADHD in the Kang, Zentall, and Burton study. Furthermore, allowing students to have control over the pace of instructions that are developed by the computer also assisted students to be on task.

However, there is the possibility that presenting these types of intense visual stimuli with highly demanding mental tasks in educational settings might not be a solution for some students. Studies conducted by Mayer and Sims (1994) and Vekiri (2002) supported that, if there is a high demand for processing visual information, students with low visual skills show difficulty performing tasks when visuals are introduced to the study. Students with attention problems have difficulty analyzing very complex perceptual tasks. If performance tasks require visual analysis of detailed stimuli, such as manipulating, transforming, and orienting images that are combined with intense visual stimuli, students with attentional problems will probably fail to perform. The inability to manipulate, transform, and orient an abstract image could be caused by their symptoms. Nevertheless other studies also indicated that these problems could be due to the lack of working memory storage capacity in students (Carpenter & Just, 1986; Kosslyn & Pomerantz, 1977; Lohman 1979; Lohman & Kyllonen, 1983; McGee 1979a; Pelligrino & Hunt, 1993; Philips, 1974; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Strong & Smith; 2002; West & Morris, 1985). Studies acknowledged that students with ADHD have significant difficulty with their working memory. One of the core reasons for their deficit in working memory is that students with ADHD cannot hold information "in mind" for a long period of time due to their limited working memory capacity. This topic will be further discussed in a later section of this chapter. Nevertheless, integrating visual stimuli within computer instructions appears to be a solution to minimize student cognitive overload. Researchers indicated that this type of instruction could help students use their working memory to full capacity (Larkin & Simon, 1987; Mayer, 2005; Sweller, 2005; Vekiri, 2002).

One can conclude that the academic performance of students with ADHD could be improved if the tasks are rather short, not repetitive, and do not exceed their working memory capacity. Student performance was especially improved when they were given appropriate stimulation, which also helped students to be on task and stay focused. These methods could be identified as examples of early intervention and treatment for students with disabilities and may be necessary for them to perform successfully in an educational setting.

However, one must consider that the information presented to the students in an instructional setting should be relevant to the learning objectives and learning context. Moreover, if tasks require the analysis of detailed information, one must be careful when applying additional visual stimuli. Visual stimuli should be incorporated in the instructional material to highlight the pertinent information, not to compete with important facts. Finally, one should be aware that these methods could help students to organize information while information is being presented to them. Perhaps providing additional and appropriate amounts of stimulation could ease student working memory load. Furthermore, if working memory overload is the cause of student deficit in spatial ability, then perhaps additional stimulation could be employed to improve the spatial ability performance of students with ADHD.

2.2. Spatial Ability

It was noted earlier in this chapter that students with ADHD have difficulty with learning geometry, and one of the reasons for the low performance in geometry may be due to their inability to mentally transform, manipulate, and visualize spatial information. In other words, if students have low spatial ability, it might influence their performance in geometry. Numerous questions could be raised based on this statement. What is spatial ability? Why is spatial ability important? Why does one person perform better in spatial-related tasks than another person? There are no easy answers to these questions due to the nature of the topic. Spatial researchers have been studied since the 1920s, and many have spent their life's work trying to answer these questions. In the following section, the researcher attempts to clarify these questions and perhaps bring some closure concerning the topic of spatial ability.

2.2.1. What is Spatial Ability?

Numerous studies have shown different definitions with regard to spatial ability, and these variations appear to depend on the context of one's research. Conflicts and complications among the research studies have arisen possibly due to a wide range of meanings of the term "spatial" itself (Kimura, 1996). Some researchers used the phrases "spatial skills" and "spatial intelligence" to describe spatial ability. Sorby (1999) made an attempt to define spatial ability by differentiating the term spatial ability from spatial skills. She stated that, "Spatial ability is defined as the innate ability to visualize that a person has before any formal training has occurred; i.e., a person is born with ability. However, spatial skills are learned or are acquired through training" (p. 21). Conceivably the claim made by Sorby could lead to the conclusion that the current study measured the effective training methods to enhance spatial skills, rather than spatial ability. Nevertheless, the difference between how one defines spatial ability and spatial skills has been argued by numerous researchers. For the purpose of this study, the difference between the phrases spatial ability and spatial skills was not distinguished, but rather spatial skill was considered as within the realm of spatial ability.

Even though there are discrepancies about what exactly spatial ability is, there is a general agreement that spatial ability has to do with one's mental operation. Lohman defined spatial ability as being related to one's ability to mentally "generate, manipulate, and retain abstract information and/or images" (1979, p. 188). Lohman argued that spatial ability is composed of three major factors: spatial visualization, spatial relation, and spatial orientation. He defined spatial relation as the ability to quickly solve a spatial-related problem. He defined spatial orientation as the ability to mentally reorient visual images, and spatial visualization as one's ability to solve complex spatial problems by using multiple spatial and peripheral factors (Lohman, 1979). Countless efforts have been made by Lohman and others to identify the "true" meaning of spatial ability. Their efforts allowed the researchers to establish a general consensus that spatial ability is not unitarily constructed, but it is formed by the collection of these major and minor spatial factors. Discovery of various spatial factors throughout research studies are further discussed in the subsequent paragraphs.

In 1993, Carroll (1993) followed up on Lohman's study, and his analysis was primarily focused on one's cognitive ability and its hierarchical structure. Carroll identified spatial, verbal, and mathematical parameters, as part of the human cognitive system and used visual perception to describe spatial ability. He stated that spatial ability has to do with an individual's ability to "search the visual field, comprehend the forms, shapes, and positions of objects as they are visually perceived, and mentally form and manipulate them" (p. 304). Carroll further acknowledged that spatial ability is as important as verbal and math abilities and that it can influence one's occupational and educational success. If spatial ability is a predictor of occupational and academic success, as suggested by researchers such as Lohman, Carroll, and many others (Carroll, 1993; Lohman, 1979; Maccoby & Jacklin, 1974; McGee, 1979a; Smith, 1964; Sorby, 1999), what about those individuals who have low spatial ability? Are they destined to fail to perform well in some professional and educational fields?

2.2.2. Importance of Spatial Ability

There are common factors among renowned scientists and artists such as Einstein, Galileo, Michelangelo, Leonardo da Vinci, and Mozart (Lord & Clausen-May, 2002). They made significant contributions to society, yet many of them had to endure some form of learning disability during their lifetimes (West, 1998). However, they also shared the significant ability to think and visualize spatially. By examining what those scientists were able to achieve throughout their lives, one would wonder about the importance of spatial ability. Can having low or high spatial ability influence individuals' lives?

Smith (1964) stated that spatial ability is used in approximately 84 careers, which included many academic fields, engineering, architecture, art, design, and even the medical fields. Smith's statement was also supported by Bishop (1978), who noted that many professions such as artists, draftsmen, engineers, and scientists involve a high degree of spatial aptitude. Other careers that require spatial ability include aircraft piloting and occupations that use computers (Deno, 1995; Guilford & Lacy, 1947). For these professionals, spatial ability is an absolute necessity in order to perform their jobs at an adequate level. Approximately half the adult population has difficulty with spatial ability, and these researchers found that a lack of spatial skill has hindered their career paths (Maccoby & Jacklin, 1974; McGee, 1979a).

In addition, general academic success is assumed to be closely correlated with spatial skills. There have been many claims that verbal ability is associated with student performance of in mathematics (Aiken, 1971). Nevertheless, many studies found the contrary (Aiken, 1971; Battista, 1990; Bishop, 1980 & 1989; Brown & Wheatley, 1989; Fennema & Sherma, 1977). They acknowledged that student mathematics achievement is highly correlated with spatial ability. Specifically, student scores on the spatial visualization factor appear to be highly associated with their ability to learn geometry (Aiken, 1971; Battista, 1990; Ben-Chaim, Lappin, & Houang, 1985, 1988, & 1989; Gagnon, 1986). In the broad spectrum, student logical and reasoning skills are also influenced by the ability to think spatially (Battista, 1990; Wheatley & Wheatley, 1979), and even linked to musical and athletic ability (Harris, 1981; Lord & Garrison, 1998; Mason, 1986; Mohler, 2006).

2.2.3. Discovery of Spatial Factors

The spatial research gained its popularity among British and American psychologists and researchers in the early twentieth century. At first, renowned British researchers such as Burt and Vernon sided with Spearman's general intelligence factors (g) (Spearman, 1904), arguing that there is no other group factor in spatial ability. Later these same researchers discovered a verbal and spatial group factor that had occurred during their study, and opposed Spearman's view of (g) factor (Eliot & Smith, 1983). In direct contrast, American researchers Thorndike (1921), Kelley (1928), El Koussy (1935), and Thurstone (1938) advocated from the beginning that spatial ability is composed of multiple factors and argued against the general intelligence theory.

The first serious spatial ability factors emerged and were undertaken by the United States Army Air Forces. Additionally, due to the discoveries of these factors, the Army Air Forces developed several spatial tests (Eliot & Smith, 1983; Guilford & Lacy, 1947). Different spatial factor names and definitions came about when the popularity of spatial research grew in the fields of education, engineering, and science. Even though these factors were developed around the well-established spatial visualization and orientation factors, the variations caused confusion among spatial researchers and research communities (Cooper & Mumaw, 1985; McGee, 1979a).

To ease the confusion, Thurstone introduced the *Multiple Factor Theory*, a theory that intelligence was composed of several major and minor factors (Thurstone, 1950). Similar to other American researchers, Thurstone disagreed with Spearman's (g) factor. Thurstone proposed that there are seven primary mental abilities that are associated with memory, number facility, perceptual speed, reasoning, spatial visualization, verbal comprehension, and word fluency. Thurstone identified the three spatial factors as S1, S2 and S3 abilities that correlate specifically to the spatial ability. Thurstone explained S1 (i.e., mental rotation) as "the ability to recognize the identity of an object when it is seen from different angle" (1950, p. 518); S2 (i.e, spatial visualization) as "the ability to recognize the movement or internal displacement of an object from their position (p

518)"; and finally, S3 (i.e., spatial perception) as "the ability to use their body orientation to solve the spatial orientation tasks (p. 518)."

Countless researchers followed Thurstone's work and made attempts to name and define other spatial factors that emerged from their studies. Carroll (1993) made great effort to reexamine approximately 300 spatial factors that were developed from previous research, and concluded that these factors differ in definitions, names, number of spatial abilities, and tests that were used to measure each factor (D'Oliveira, 2004). As indicated these conflicts between various spatial factors created significant confusion in spatial research communities. The number of factors and definitions that were developed by previous examination is highlighted in Table 2.1. The table is from Mohler (2006), who developed the chart based on Hegarthy and Waller (2004) and Lohman (1984) and McGee (1979a & 1979b)'s work in effort to address the disagreement among researchers with regard to spatial factors.

Table 2.1

Mohler's (2006) Spatial Factors and Definition Chart

Researchers	**Factors**	**Definitions**	**Markers**
Thorndike, 1921	"mechanical" ability	The ability to visualize relationships among objects and understand how the physical world worked	Completion, Arithmetic, Vocabulary, and Directions test (CAVD)
McFarlane, 1925	"practical ability"	Adept at judging concrete spatial relations	Fitting Shapes, Pattern Perception, Completion, Analogies, Form Equations, Cube (non paper and pencil: Construction Test, Healy's Puzzle Box)

Table 2.1 (continued)

Mohler's (2006) Spatial Factors and Definition Chart

Kelley, 1928	Spatial factor	The mental manipulation of shapes	Speed in Reading, Power in Arithmetic; Memory for Meaningful Symbols, Memory for Meaningless Symbols; Manipulation of Geometric Forms
El Koussy, 1935	"K" factor	Ability to obtain and the facility to utilize, spatial imagery	Area Discrimination, Memory for Designs, Form Relations, Fitting Shapes, Form Equations A-C, Overlapping Shapes, Pattern Perception, Spatial Analogies, Classification, Band Completion, Correlate A & B, Mechanical Explanations, Mechanical Completion
Thurstone, 1938	Space (S)	Facility in spatial or visual imagery	Flags, Lozenges A & B, Cubes, Block Counting, Pursuit, Hands, Figure Classification, Surface Development, Form Board, Syllogisms, Verbal Classification, Sound-grouping
Guildford & Lacy, 1947	Spatial Visualization	An ability to imagine the rotation of depicted objects, the folding or unfolding of flat patterns, the relative changes of position of objects in space, the motion of machinery.	Guilford-Zimmerman Spatial Visualization, Pattern Comprehension, Mechanical Movements, Mechanical Principles, Spatial Visualization, Directional Plotting

Table 2.1 (continued)

Mohler's (2006) Spatial Factors and Definition Chart

Thurstone, 1950	S_1	An ability to recognize identity of an object when it is seen from different angles, or an ability to visualize a rigid configuration when it is moved into different positions	Punched Holes, Form Board, Surface Development, Paper Puzzles
	S_2	An ability to visualize a configuration in which there is movement of displacement among the internal parts of the configuration	Cubes; Flags, Figures and Cards; Lozenges
	S_3	An ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem	Cubes; Flags, Figures and Cards; Lozenges
French, 1951	Visualization (V_i)	An ability to comprehend imaginary movements in three-dimensional space or the ability to manipulate objects in the imagination	Form Board, Punched Holes, Surface Development
	S (Space)	An ability to perceive spatial patterns accurately and to compare them with each other	Cards, Figures, and Flags; Cubes; Spatial Orientation of the Guilford-Zimmerman Aptitude Survey;
	Spatial Orientation (SO)	An ability to remain unconfused by the varying orientations in which a spatial pattern may be presented; dimensionally less important to the factor than the rotational position of presentations	

Table 2.1 (continued)

Mohler's (2006) Spatial Factors and Definition Chart

Michael, Guilford, Fruchter, & Zimmerman, 1957	Visualization (V_Z)	Mental manipulation of visual objects involving a specified sequence of movements	Paper Folding, Form Board, Punched Holes
	Spatial Relations and Orientation (SR-O)	Ability to comprehend the nature of the arrangement of elements within a visual stimulus pattern primarily with respect to the examinee's body as a frame of reference	Cube Comparisons Test, Guilford-Zimmerman Spatial Orientation, Card Rotations
	Kinesthetic Imagery (K)	Merely a left-right discrimination with respect to the location of the human body	Hands; Flags; Bolts
Ekstrom, French, & Harman, 1976	VZ	An ability to manipulate or transform the image of spatial patterns into other arrangements, which requires that a figure be mentally restructured into components for manipulation, or the mental rotation of a spatial configuration in short-term memory and the performing of serial operations, perhaps involving analytic strategy	Form Board Test, Paper Folding Test, Surface Development Test
	S	An ability to perceive spatial patterns or to maintain orientation with respect to objects in space; requires that a figure be perceived as a whole	Card Rotations Test, Cube Comparisons Test
McGee, 1979b	Spatial Visualization	Ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object.	Paper Folding

Table 2.1 (continued)

Mohler's (2006) Spatial Factors and Definition Chart

	Spatial Orientation	Comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented	Cube Comparisons, Guildford-Zimmerman Spatial Orientation
Lohman, 1979	Spatial Relations (SR)	Ability to solve such problems (typically mental rotations) quickly, by whatever means.	Cards, Flags, Figures
	Spatial Orientation (SO)	Ability to imagine how a stimulus array will appear from another perspective; there is often a left-right discrimination	None specified.
	Visualization (Vz)	Ability to solve complex spatial-figural content	Paper Folding, Form Board, WAIS Block Design, Hidden Figures, Copying
Carroll, 1993	Spatial Visualization (VZ)	Ability in manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successful, without regard to the speed of task	Paper Folding, Form Board, Cube Comparisons, Guilford-Zimmerman Spatial Orientation
	Spatial Relations (SR)	Speed in manipulating relatively simple visual patterns by whatever means (rotation, transformation, or otherwise).	Card Rotations
	Closure Speed (CS)	Speed in apprehending and identifying a visual pattern without knowing in advance what the pattern is, when the pattern is disguised or obscured in some way.	Snowy Pictures

Table 2.1 (continued)

Mohler's (2006) Spatial Factors and Definition Chart

	Flexibility of Closure (CF)	Speed in finding, apprehending, and identifying a visual pattern, knowing in advance what is to be apprehended, when the pattern is disguised or obscured in some way.	Hidden Pictures
	Perceptual Speed (P)	Speed in finding a known visual pattern, or in accurately comparing one or more patterns, in a visual field such that the patterns are not disguised or obscured.	Identical Pictures

Among these various named factors, studies suggested that the spatial visualization factor is the most important in learning mathematics because learning mathematics requires one to identify a pictorial representation that has spatial components (Aiken, 1971; Battista, 1990; Beh-Chaim, Lappin, & Houang, 1985, 1988, & 1989). According to Guilford-Zimmerman (1948), high spatial visualization skills are shown in occupations specifically related to an aircraft pilot, blueprint reader, dentist, designer, draftsman, electrician, engineer, inventor, machine operator, navigator, and surgeon. As important as it sounds, developing spatial visualization skills is not often integrated within a school's curriculum (Ben-Chaim, Lappan, & Houang, 1988). Michaelides (2002) stated that geometry is still being instructed in a traditional manner and over the years schools have neglected the concept of visualization and the sense of space during geometry instructions. The Ben-Chaim et al. (1989) study noted that, "Geometry is a means of describing the physical world. It is the mathematics of space" (p.50). These studies supported the statement that the development of logical and spatial reasoning skills is essential to learn geometry (Wheatley & Wheatley, 1979). In order to develop mathematical reasoning ability with the hope of learning geometry effectively, one must develop adequate spatial visualization skills.

2.2.4. Individual Differences

Individual differences in spatial skills are widely studied by a number of researchers. Similar to defining the true meaning of spatial ability, researchers have refuted each other studies concerning spatial ability and individual difference. Widely disputed topics include differences in gender, age, information processing, and strategies employed by individuals in order to solve spatial-related tasks. For the purpose of this study, refuted areas of age, information processing, and strategies used by individuals will be discussed in the paragraphs that follow.

2.2.4.1. Development

The age-related differences in spatial ability are perhaps based on the location of one's cognitive development stage. Piaget and Inhelder (Piaget & Inhelder, 1956 & 1971; Piaget, Inhelder, & Szeminska, 1960) worked extensively with children and their spatial perception. The researchers claimed that children undergo a series of stages in order to construct their own spatial ability, and these stages are highly correlated with their cognitive development. They further acknowledged that the perception of space emerges from a child's own actions and internalized actions, that is, a child's understanding of space is based on their own actions. Meaning of space is defined by a child's involvements within their interpretation of space. In addition, Piaget and Inhelder discovered that knowledge of space evolves through four levels: sensorimotor, preoperational, concrete operational, and formal operational. One may consider these levels as the levels of achievement. They are dependent from one another and children construct their own knowledge (schemata) in order to proceed to the next level.

During the sensorimotor stage, a child's first spatial understanding is the topological concept of figures or objects. In this stage, children begin to understand the relationship of proximity, separation, order, enclosure, and continuity of an object. Then at the age of two, children reach the preoperational stage where they are able to start verbalizing their thoughts. In this stage, children are able to distinguish stationary and moving objects. As children reach the preschool and elementary schools, they enter into the concrete operational level of development. Even though students are able to understand topological relationships at this stage, they still cannot clearly represent what they perceive from the surrounding environment. Nevertheless, children gradually comprehend their position in space and the concept of reflected views (e.g., mirror images that their left becomes right when seen from the reflected views). In the later stage of their cognitive growth, the formal operational stage, children achieve a frame of reference, which allows them to orient, locate, and visualize object movement in space (Piaget & Inhelder, 1956 & 1971; Piaget, Inhelder, Szeminska, 1960). Olson (1975) model of spatial development stated that children do not perceive information as adults do. Adults may see circles and lines, but children may perceive information as balloons or lollipops (Elliot, 1987). Olson also argued that children tend to utilize spatial information based on their personal experiences. Therefore, children may not be able to construct or perform correctly on spatial tasks if they have not reached the appropriate level of cognitive development or if they are not familiar with the tasks.

Students with ADHD often fall behind on their cognitive level compared with their peers. However, the targeted population for this study was seventh and eighth graders who were assumed to have reached their full level of cognitive development. The comparisons were made between seventh and eighth graders to evaluate whether their age differences influenced their spatial performance after they were engaged in the training session.

2.2.4.2. Gender

Gender difference is probably the most controversial issue in the spatial ability research communities. Numerous studies have indicated the male's superior performance in spatial-related tasks. Harris (1978, p.405) stated that, "On a number of tests, only 20% to 25% of females exceed the average performance of males." The male superiority is often demonstrated on spatial tests after they reach puberty, and during the stage of puberty males demonstrated better performance in spatial visualization and orientation tasks were demonstrated (Gagnon, 1986; Harris, 1978; Johnson & Meade, 1987; Maccoby & Jacklin, 1974; McGee, 1979a; Slater, 1940).

Maccoby and Jacklin (1974) and many others (Harris, 1978; Linn & Petersen, 1986; Nyborg, 1983; Voyer, Voyer, & Bryden, 1995) attempted to explain the origin of sex differences in spatial ability. They acknowledged that sex differences are due to genetic (i.e., recessive x-linked gene), environmental exposure, neurological, and hormonal factors. Some even suggested that there could be a combination of multiple factors such as environmental and genetic that causes sex differences (Allen, 1974). The reasons for gender differences remain unclear in spatial ability research communities (McGee, 1979b), yet the sex differences are continuously found and measured in numerous spatial research studies.

Caplan, MacPherson, and Tobin (1985) tried to allocate some inconsistencies for those who claim sex differences in their study. Caplan et al. noted that some of these studies do not address how spatial tests were used or constructed. In addition, these researchers have the tendency to overgenralized their results of sex differences even with small effect sizes. Moreover, some of the studies that claimed sex differences do exist have defined spatial ability in their own way to meet the context of their studies, that is, there are still discrepancies among studies in regards to the definition of spatial ability.

Even with these inconsistent claims of male superiority in spatial ability, especially in spatial orientation performance, Linn and Hyde (1989) and others (Caplan, MacPherson, & Tobin, 1985) stated that sex differences are declining. There many studies indicating no sex differences in their studies (Smith, 1964; Harris, 1978; Manger & Eikeland, 1998). This decline could be result of different physical activities that both females and males have approached during childhood or maybe the result of appropriate instruction and training. The current study hypothesized that there will be sex differences between female and male students with and without ADHD. The scores of both female and male students were examined to ascertain any declines and improvements after the training.

2.2.4.3. Information Processing

According to Carpenter and Just, “An information processing analysis should indicate how spatial information is represented, how the transformations are executed, and how individuals differ in the way they solve such problems” (1986, p. 222). The purpose of this section is to do such a task. Many studies have indicated that in order to solve spatial-related problems, one must encode and retain visual information, examine other given external visual stimuli, make comparisons (i.e., between original and other visuals), recall and determine the transformation and orientation of visuals, then match visual stimuli and respond with an answer to a problem (Bishop, 1980 & 1989; Carpenter & Just, 1986; Cooper, 1980; Cooper & Mumaw, 1985; El Koussy, 1935; Gages, 1994; Kyllonen, 1984; Lohman, 1979 & 1984; Lohman & Kyllonen, 1983; Pillay, 1994; Pellegrino, Alderton, & Shute, 1984; Poltrock & Agnoli, 1986). “High spatial ability individuals are better at generating, maintaining and coordinating information during spatial tasks” (Carpenter & Just, 1986, p. 249). However, those students with low spatial ability contributed by the poor working memory may not be able to encode visual information, generate mental images or even retain visual information long enough to rotate, manipulate, and transform. Lohman (1993) suggested that in order to distinguish between high and low spatial ability individuals, one should examine the amount of information that can be stored in working memory rather than concentrate on the rate of information processing. Those students with high spatial skills appear to store more spatial information and retrieve it as necessary. Furthermore, they "chunk" the information to allow efficient encoding and construction of mental images. These types of information processing strategies used by individuals allow researchers to differentiate who has high or low spatial ability (Carpenter & Just, 1986).

2.2.4.4. Strategies

In 1954, Anderson, Fruchter, Manuel, and Worchel made an effort to distinguish spatial ability factors by utilizing various spatial tests. Instead, they discovered that their participants tended to use different strategies as they faced harder spatial problems. Interest in how individuals use different strategies in spatial tasks continuously grew, and those interests are addressed in the following (Cooper, 1980 & 1988; Lohman & Kyllonen, 1983; Mayer & Sims, 1994).

Ben-Chaim, Lappan, and Houang (1985) found that students use and switch up to four different strategies in order to solve spatial-related problems. However, Bodner and Guay (1997) argued that there are two major processing strategies used to solve spatial tasks: analytic processing and Gestalt processing.

> Gestalt processing occurs when an individual forms and transforms visual images as an organized whole in much the same way that one recognizes faces. Analytic processing occurs when the whole is broken into individual parts, whose relationship is mapped in a one-to-one process (p. 7).

Some researchers (Cooper, 1980 & 1988; Gages, 1994; Lohman & Kyllonen, 1983) substitute the terms holistic and serialistic for the strategies that are used in spatial tasks. Those terms appear to coincide with analytic and Gestalt processing. The holists tend to examine the overall problems whereas serialists examine the small pieces of information to develop logical and sequential steps to understand the problems.

In a particular scenario, Cooper (1980) evaluated two visual learning strategies that were used in mental rotation: the constructive and the analytic strategies. Constructive learners have the tendency to use internal representation by tapping into visual memory and analytic learners examine features and make comparisons by using verbal cues. Furthermore, in Cooper's study, the learners used holistic strategies on easy problems and analytic strategies for the difficult problems. In addition, high-spatial ability students have the ability to switch and shift strategies as they solve problems, whereas low-spatial ability students have the tendency to use a single strategy throughout the tasks (Carroll, 1993; Lohman, 1984; Lohman & Kyllonen, 1983). Lohman specified that, "Those who were able to flexibly adapt their performance committed fewer errors on the experimental tasks and on most reference tests than those who followed more rigid routine" (1993, p 132).

Other characteristics of high-spatial ability includes, "High-ability students usually knew the answer before looking at the alternatives, whereas low-ability students spent more time evalinguat and eliminating alternatives" (Lohman & Kyllonen, 1983, p. 118). Lohman and Kyllonen claimed that low-spatial ability students guessed on their answers more frequently and they were uncertain about their choice of answers. Lohman (1993) concluded that the reasons for these differences in solving strategies are mainly due to the capacity of visual memory. It is often difficult to measures strategies used by individuals. Few studies have used talk-loud methods to examine the strategies to understand how subjects solve spatial problems (Mohler, 2006). Lohman and Kyllonen suggested qualitative studies should be used instead of quantitative to investigate the variation in solution strategies because a qualitative approach to a spatial ability study could allow one to understand the alternate solution strategies used by the participants.

It might be beneficial to be acquainted with the list of strategies that are available when solving spatial-related tasks. Some strategies might not work for or fit some individuals. However, individuals may be able to adjust and manipulate these strategies to meet their cognitive and proficiency levels. There are still undiscovered strategies that could be used by others. It may even be impossible to finalize this list of strategies because each individual is likely to apply or develop different strategies as he or she faces different spatial tasks. Nevertheless quantitative and qualitative investigation on spatial ability strategies used by others would be valuable for those students with low-spatial ability (i.e., students with ADHD). These studies could provide students with ADHD a different way to engage in spatial tasks.

2.2.5. Improving Spatial Ability

There are different opinions regarding whether spatial ability is innate or acquired through experience (El Koussy, 1935). Thurstone (1938) and Piaget and Inhelder (1971) strongly agreed that spatial ability is an innate ability. Nevertheless, numerous studies have argued that spatial ability can be obtained and improved through appropriate motivation, training, and activities (Alderton, 1989; Ben-Chaim, Lappan, & Houang, 1988; Harris, 1978; Lohman, 1993; Vandenberg, 1978). Even though there are many inconsistent results and acknowledgements regarding the effects of practice and training on spatial ability, studies acknowledged that the spatial visualization skill has been successfully enhanced by employing conventional classroom techniques that are specifically designed for intervention (Kyllonen, Lohman, & Snow, 1984; Salthouse, 1987; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990). Some of these interventions include using animated visuals, and/or providing physical hands-on activities such as Lincoln Logs, Tinker Toys, and Legos to improve spatial ability (Aldahamash, 1995; Anglin, Towers, & Moore, 1997; Mitchell & Burton, 1984; Pak, 2001; Rovet, 1983). Furthermore, studies concluded that during these interventions the participants' overall performance improved after a period of training and, additionally, there were minimal gender differences during their experiments (Alderton, 1989; Ben-Chaim, Lappan, & Houang, 1988).

Baenninger and Newcombe (1989) noted that the simplest method of training is usually conducted by providing the subjects with repeated exposure to specific spatial tests. This type of training appears to be promising, but it has been criticized by many educators who claim that it causes practice effects (Baldwin, 1984). Researchers have suggested that to avoid practice effects, researchers often use a number of instructional sessions, which sometimes last from a single training session to a yearlong program. However, Rovet (1983) indicated that, "The 12 minutes of instruction were roughly equivalent to three years of untutored development on spatial ability tests" (p. 171). For the purpose of this study, students will be going through a training session for 12 minutes as suggested by Rovet (1983) in an attempt to enhance their spatial ability. Finally, Baenninger and Newcombe (1989, p. 340) stated that "training can be beneficial to the extent that the improvement it provides is permanent..."

2.3. Working Memory

In order for learners to construct meaningful knowledge, the information presented to them has to be processed and transferred into long-term memory. Researchers refer to this step as building schemata in long-term memory. However, some information can be transferred and processed automatically to long-term memory, while some information cannot. Studies argued that not all novel information can be processed automatically due to the limited capacity in the working memory. The following section describes how other studies have defined functionality of working memory and how the limited working memory capacity affects one's ability to construct meaningful schemata in the long-term memory.

2.3.1. What is Working Memory?

All new information goes through working memory before it reaches long-term memory. Even though not all information can be processed at the same time, one can describe working memory as a placeholder for information. Baddeley and Hitch specifically describes working memory as, "The system or systems that involve the temporary maintenance and manipulation of information, and it supports human thought processes by providing a linkage between perception, long-term memory and action" (Baddeley & Hitch, 1974, p. 829). Based on this definition, some researchers questioned the differences between working memory and short-term memory (Hebb, 1948; Miyake, Friedman, Rettinger, Shah, & Hegarthy, 2001). Miyake et al. (2001) acknowledged that short-term memory and working memory are similar to the extent that they both require temporary storage of information. Nevertheless, they differ in the position that working memory requires a lot of controlled attention in order to transfer information to long-term memory. Short-term memory might be able to perform working memory functions, but working memory can be impacted by selective attention during the stages of information processing.

To further examine how information is processed and transferred from the working memory to long-term memory, Baddeley and Hitch introduced three components of the working memory model in 1974. Their working memory model consists of a visuospatial sketchpad, central executive and phonological loop system (see Figure 2.1). Even though Baddeley and Hitch revised their model 20 years later with other subcomponents added onto the existing working memory (see Figure 2.2), their first working memory model is still being used as the fundamental guideline for others who have shown interest in the working memory research. The revised models include information regarding working memory and intelligence, which will be discussed in a subsequent section of chapter two.

The current study has already established through various literature that children with ADHD have significant deficits in visual working memory. Therefore, following sections will mainly focus on the visual and spatial component of Baddeley and Hitch working memory model.

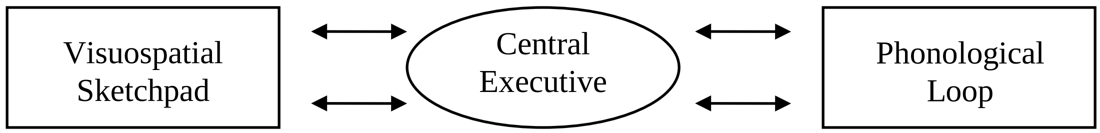

Figure 2.1 The model proposed by Baddeley and Hitch in 1974 (Baddeley, 1974).

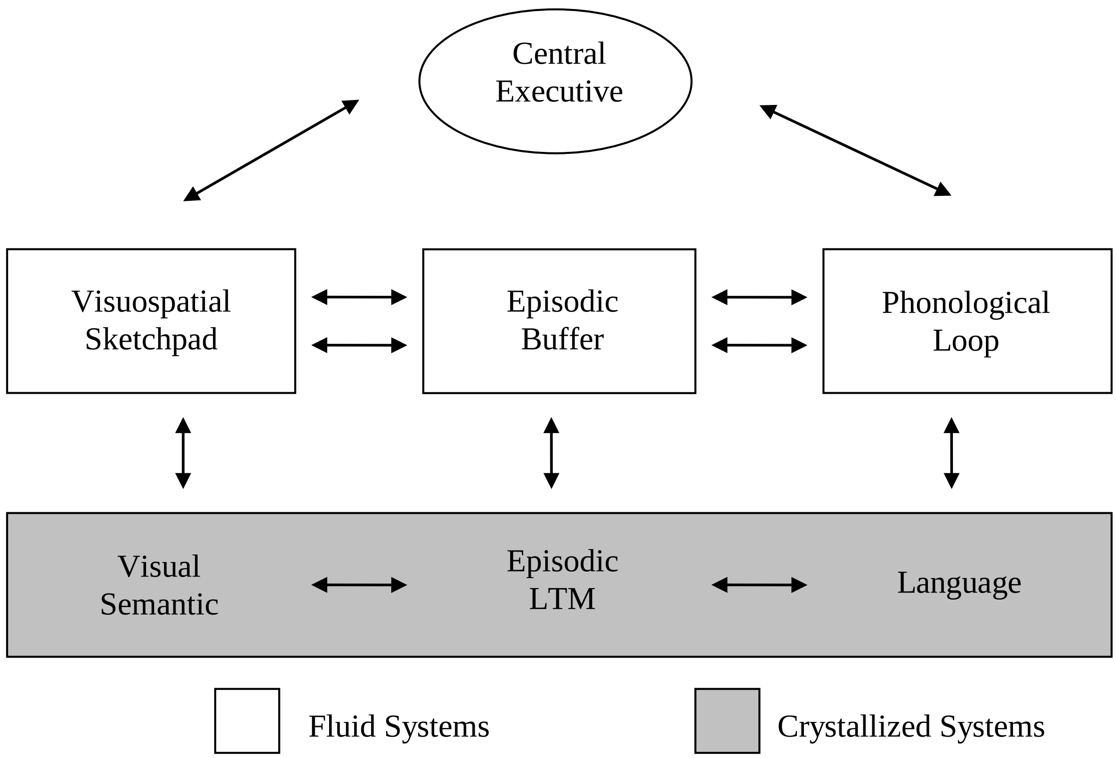

Figure 2.2 The revised model proposed by Baddeley in 2000 (Baddeley, 2001).

2.3.2. Visuo-Spatial Working Memory

Baddeley defined the visuospatial sketchpad from his three-component working memory model as, “Temporary storage with capacity to maintain and manipulate visuospatial information” (Baddeley, 2001, p. 88). Philips (1974) defined visual working memory as a temporary storage for visual imagery and a place where one can hold and manipulate visuals in his or her mind. Both definitions share similarities and researchers such as Logie (1985) proposed that the visuospatial sketchpad should be identified as visuo-spatial working memory. Even though current study is uses Baddeley and Hitch's working model as the fundamental base of working memory structure, the term visuo-spatial working memory will be utilized throughout the study instead of the phrase visuospatial sketchpad to minimize confusion for the readers.

Based on Baddeley and Hitch's model, visuo-spatial working memory could be described as a subcomponent of working memory. Such a subcomponent allows one to solve spatial orientation-related tasks and provide solutions to visuospatial problems (Baddeley, 2001). Visual and spatial information is usually accessed through one's senses (e.g., perception, motor, tactile, and haptic senses). Once information is perceived from an external stimulus, the visuo-spatial working memory goes through a series of stages before transferring the information to long-term memory.

First, the organization of perceptual information is made when an external stimulus occurs. In the second stage, the organized information is moved and stored in a "domain specific short-term buffer." Finally, the central executive processes are initiated. The central executive processes including the maintenance and manipulation of information, react to the content of the incoming information from the short-term buffer (Baddeley, 2001; Leonard, Ibanez, & Giannakopoulos, 2002). However, similar to working memory, the visuo-spatial working memory is severely constrained when the visual information is new and/or too complex. The information could be easily lost when the visuo-spatial working memory tries to interpret these new and complex materials and maximize processing capacity.

2.3.2.1. Visuo-Spatial Working Memory Capacity

There are mixed reviews regarding the causes of working memory deficits for individuals. Nevertheless, many researchers have claimed that the real reason behind working memory deficit could be a lack of working memory storage capacity (Gilhooly, Wynn, Phillips, Logie, & Sala, 2002; Gold, Wilk, McMahon, Buchanan, & Luck, 2003). There are two different meanings for capacity in the context of the working memory system.

> First, the working memory system includes a storage component with a limited *storage capacity,* which determines how much information can be presented in the system at one time. Second, the working memory systems include processing component (the central executive in Baddeley's model), this component may be limited in its *processing capacity,* which refers to the amount of information that can be processed in a given period of time (Gold, et al., 2003, p. 61).

The visuo-spatial working memory capacity can be described in terms of a fixed number of objects that can be stored or by the total amount of visual information that can be stored (Alvarez & Cavangh, 2005; Baddeley, 2003; Luck & Vogel, 1997). Based on this description of visual working memory capacity, the visual working memory deficit could be caused by both limited storage and processing capacity. Studies indicated that there are approximately four visual objects could be stored in visual working memory for each individual. Once the storage and processing capacity is met or exceeded in visual working memory, one's task performance tends to decline (Gilhooly, Wynn, Phillips, Logie, & Sala, 2002).

Because of the symptoms caused by ADHD, students may have a difficult time storing or processing visual information accurately. It also has been recognized that students with ADHD often have difficulty differentiating the important information from unimportant information. Students may be able to store information in their minds; however, it is possible that students with ADHD may have exceeded their visual working memory storage with unimportant information. When unimportant information is processed in their minds, this information will not help them solve the given problems accurately. Studies have claimed that limited visual working memory capacity could be a predictor of poor performance in spatial ability and ultimately cause the poor performance on geometry-related tasks (Purcell & Gero, 1998; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Strong & Smith, 2002; Verstijnen, van Leeuwen, Goldschmidt, Hamel, & Hennessey, 1998; West & Morris, 1985).

Further studies are needed regarding working memory capacity in general because it appears that working memory capacity is highly correlated with various cognitive skills and reasoning ability (Baddeley, 2003; Gathercole, 1999; Hale, Bronik, & Fry, 1997; Klingber, Forssberg, & Westerberg, 2002; Luciana & Nelson, 1998). Cognitive and reasoning skills were demonstrated in those students who have the ability to solve geometry and spatial problems as well. Also, occupations in engineering and architecture require high cognitive, reasoning, and spatial skills, and these occupations rely heavily on the capacity to hold and manipulate visual spatial information (Crottaz-Herbette, Anagonsons, & Menon, 2004). With statements such as this, one could argue that there is a strong correlation between visuo-spatial working memory capacity and spatial ability, but this relationship needs to be further investigated.

2.3.3. Improving Visuo-Spatial Working Memory

Based on the investigation that was conducted for the purpose of this study, it is evident that there is an absolute need to improve visual working memory of students with ADHD in order for them to be successful in geometry. There has been growing evidence that students with ADHD are unable to maintain and manipulate visual spatial information that occurs in visual working memory (Bedard, Martinussen, Ickowicz, & Tannock, 2004; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Various studies have made attempts to improve individual maintenance and manipulation processes in visual working memory by utilizing drug therapy (Bedard, Martinussen, Ickowicz, & Tannock, 2004; Rhodes, Coghill, & Matthews, 2004). In these studies, the researchers compared a number of students with ADHD and a control group and examined the effects of Methylphendiate (MPH) drugs. Students were administered a single dose of MPH and the researchers concluded that MPH did indeed help participant performance on some visual working memory and pattern recognition tasks. The studies concluded that MPH assisted students in retaining visual spatial information and showed significant improvement in their cognitive processes. These conclusions were shared in other studies that suggested MPH is a form of dopamine that provides stimulation and enhances visual spatial working memory (Barnett, Maruff, & Vance, 2001; Bedard, Martinussen, Ickowicz, & Tannock, 2004; Kempton, Vance, Maruff, Luk, Costin, & Pantelis, 1999).

Nevertheless, Gold, Wilk, McMahoon, Buchanan and Luck (2003) suggested that there are other strategies to improve visual working memory rather than employing drug treatment. They claimed that working memory itself depends on the ability to organize information into chunks. The impairment in working memory is due to one's inability to use these chunking strategies in an effective manner (Gold, Wilk, McMahoon, Buchanan, & Luck 2003). In visual working memory, one can retain four visual information features or orientations at one time (Luck & Vogel, 1997; Sweller, 2005). However, an individual can increase visual working memory storage by utilizing methods that are similar to "chunking" strategies commonly used in order to improve verbal working memory. Visual working memory stores information as integrated objects rather than individual features (Luck & Vogel, 1997). When four objects are defined by four separate features (e.g., color, shape, angles, size), the individuals are able to retain this visual information as well as the objects with single features. The study explained that participants were able to retain sixteen individual features of four objects because they perceive the objects as "a whole" rather than analyzing them as having individual features (Luck & Vogel, 1997). Luck and Vogel (1997) concluded in their study that at least four features can be joined with four objects without exceeding visual working memory storage capacity.

Several researchers (Gold, Wilk, McMahoon, Buchanan, & Luck, 2003; Lamme, 2003) have related a person's selective attention span to working memory capacity in order to enhance visual spatial working memory. Their studies indicated that attentional problems cause a reduction in working memory storage capacity. A deficit in attention prohibits those persons from storing information when the information exceeds their working memory capacity, which also makes them unable to use their working memory capacity to its full potential (Gold, Wilk, McMahoon, Buchanan, & Luck, 2003). The solution to the problem is to provide controlled stimulation. Studies suggested that controlled stimulation appears to assist working memory capacity for those individuals with attention problems (Engle, Kane, & Tuholski, 1999; Gold, Wilk, McMahoon, Buchanan, & Luck, 2003). Lamme (2003) stated that "…Cuing relevant items could provide stimulation which may direct the attention to important information" (p.14). Cuing important information creates stimulation according to Lamme (2003), and Lavie and DeFockert (2005) suggested that when providing stimulation such as cuing, one must specify which stimuli are currently task-relevant and which are irrelevant. By doing so, one can allow working memory to actively maintain and organize the information priorities and transfer them to the long term memory.

As discussed earlier, MPH drugs have been used to release dopamine to the body and improve visual working memory. Dopamine is a form of stimulant that directs attention for those with attentional problems. The current study proposed that there are other methods to supply stimulation for those with attentional problems and improve visual working memory. Thus, the study attempted to provide appropriate visual stimulation and display visual information as chunks to enhance visual working memory capacity, rather than employing the drug treatments. As a final note in regard to improving visual working memory, Baddeley made the following assertion: "The visuospatial working memory is an active but poorly integrated area of research" (Baddeley, 2003, p. 835). The visual working memory could have a significant role in student performance in spatial ability and is highly related to student performance in mathematics. Perhaps the integration of these ideas may bring attention to the research communities and expand the realm of visual working memory research.

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2.4. Use of Computer Technology

There has been an effort to reform the public school education system due to the No Child Left Behind Act (*NCLB).* According to the U.S. Department of Education, the *NCLB* Act requires states to implement statewide accountability systems to cover school settings and students. To reinforce these accountability systems, students in grades three through eight are given annual standardized tests to ensure that they reach proficiency levels in English and mathematics. Students with disabilities are not an exception to *NCLB,* which places an increased emphasis on educating students with disabilities. Effective strategies and modification of instructions may allow teachers and parents to assist students with disabilities to achieve their academic goals and meet the *NCLB* standards. Among these strategies, the adaptation of computer technology has been used as one of the effective solutions. Utilizing computer technology could be imperative to promote academic success for this group of students (Bryant & Bryant, 2003).

Studies have claimed that computer technology provides experiences that many students need to perform well in an academic setting. Computer technology can provide students with disabilities with extra practice to promote the mastery of skills, development of writing abilities, problem-solving, and to gain adequate stimulation that is needed for students with attentional problems (Lewis, 1993). According to Bryant and

Bryant (2003), instructional software developed by computer technology usually includes words and graphics (e.g., pictures, animation) features to promote effective learning. This specific learning method is identified as a type of multimedia learning (Atkinsons, 2005; Clark, 2005; Mayer, 2001), which will be further discussed in following paragraphs. Needless to say, the computer appears to be the one of the most effective tools to present texts, graphics, and animations, and it may provide better assistance and additional stimulation to students with ADHD than the conventional teaching methods.

2.4.1. Multimedia Learning

The learning methods that utilize both words and graphics are defined as a multimedia learning (Atkinson, 2005; Clark, 2005; Mayer, 2001). This learning method could be established by either the use of computer-based or traditional pencil and paper instructions. Bertoline (1998) stated that computers give everyone access to represent information visually. In the field of education, numerous studies have concluded that students learn better when text, graphics, and computers are integrated into their curriculum. Computer-based multimedia learning may provide more effective learning for students than the traditional instruction. Furthermore, studies acknowledged that when computer-based multimedia learning was used in mathematics instruction, student performance was drastically increased. Instruction that uses text and graphics (i.e., visuals) and integrates the computer in mathematics may assist students who have difficulty with the conventional approach (Atkinsons, 2005; West, 1998). Providing computer-based multimedia instruction may be able to enrich student mental representations and increase their ability to generate images in their minds, which is necessary when they learn geometry (Clark & Paivio, 1991; Kosslyn, 1988). The potential use of computer technology and multimedia learning may clarify the obscure learning materials and allow learning concepts to be easily communicated.

2.4.1.1. Dynamic (Animation) vs. Static

Lohman (1993) stated that spatial tests often ask subjects to mentally transform and manipulate images, but these images are presented as a static object on the paper and pencil-based exams. He concluded that perhaps providing dynamic visuals to promote the understanding of spatial relationships could increase the spatial ability performance for individuals. Dynamic visuals could be defined as visual representations that demonstrate series changes and sequences of movement (Atkinsons, 2005). Unlike traditional instruction, the computer has the capability of displaying visuals in motion. When dynamic visuals are effectively used (i.e., showing a simple procedure or process) students demonstrated similar or better performance than when they were instructed with static visuals (Mayer, & Moreno, 2002; Mayer & Sims, 1994; McClurg & Chaille, 1987; Park, 1998; Pepin, Beaulieu, Matte, & Leroux, 1985).

Also, various spatial ability researchers acknowledged that dynamic visuals facilitate both high and low spatial ability students (Mayer & Moreno; 2002; McCuistion, 1990; Park, 1998). One of the reasons for this significant improvement is that animations that were used in dynamic visuals attract and direct student attention. When students are given static visuals to solve spatial-related tasks, they have to mentally construct and transform the image on their own. However, a dynamic visual has the capability to assist students to construct a mental image (Lohman, 1993; Park, 1998).

In the study of Mayer and Moreno (2002), high spatial ability students obtained significantly better scores on spatial tests than students with low spatial ability. This particular scenario indicated that students with low spatial ability did not have enough experience utilizing computer technology. Consequently, students struggled to use the technology, which resulted in ineffective learning experiences. There may be another reason that students with low spatial ability were not able to achieve significant performance improvement in Mayer and Moreno's study. Even though studies claimed that the dynamic multimedia learning methods are successful in many cases, students have to process additional information (i.e., movement) in their working memory that is not necessarily required in the traditional or the static learning method. Additional information processing may result in cognitive overload. However, there are methods of managing cognitive overload when using dynamic visuals: (1) provide simple and short animation sequences, (2) allow learners to have control over the animation, (3) "chunk" the visual information and (4) provide visual cues to direct attention to important elements (Clark, 2005). These methods could possibly overcome the problems of computer-based dynamic multimedia learning.

There are still arguments whether computer instruction is better than conventional instruction that is commonly used in the learning environment. Many studies that used computer technology to enhance spatial ability noted that the effect of computer-based instruction could be almost parallel to conventional instruction (Bertoline, 1991;

Clements, Battista, Sarama, & Swaminathan, 1997; Devon, Engel, Foster, Sathianathan, & Turner, 1994; Mackenzie & Jansen, 1998; McCuistion, 1990). Yet, one must consider the students, and the curriculum, as well as the task and learning objectives, prior to the integration of computer technology and computer-based multimedia learning (Bryant & Bryant, 2003). The need for careful instructional planning is an absolute. Instructional planning will allow one to analyze the learning environment, learning outcome, and develop an instrument that will be utilized to enhance not hinder the student learning experiences.

2.5. Conclusion

Success in advanced mathematics requires the mastery of basic facts. Without a proper foundation in basic mathematical facts, students may have difficulty solving complex mathematical problems. Furthermore, the development of spatial ability in children is an essential skill in order to be successful in mathematics, especially in geometry. Studies have indicated that student performance in spatial intelligence tests is associated with being successful in mathematics (Aiken, 1971; Baldwin, 1984; Battista, 1990 & 1999; Gardner, 1993). Therefore, effective interventions should be implemented in order to enhance spatial ability in children with ADHD.

Many studies have agreed that spatial ability could be improved with the right training and intervention (Baldwin, 1984; Carpenter & Just, 1986; Lohman, 1989). One of the reasons for the need for spatial ability training is that student ability to manipulate and transform images in their minds may have an immense impact on their future.

Furthermore, spatial ability appears to be associated with a student's choice of future occupations and academic performance (Law, Pellegrino, & Hunt, 1993; Skorupan, 1998; Smith, 1964). The study hypothesized that interventions that encourage students to recognize visual spatial relationships through the use of images displayed on computer screens could enhance student spatial ability and perhaps facilitates their understanding of geometry. This study was directed toward students with ADHD, but the computer-based interactive learning intervention could be a solution to better performance in spatial ability and in geometry for everyone.

CHAPTER 3. METHODOLOGY

The purpose of this study was to assess the effectiveness of spatial training for students with and without ADHD. This chapter contains the overview of the research process that was utilized in the current study. The explanation of participants, the testing environment, experimental tasks, and conditions are addressed in this chapter. In addition, there is a brief description of the experimental design and data analysis that was used in the study.

3.1. Participants

Seventh and eighth grade students with and without ADHD from local middle schools participated in the study. The researcher obtained written consent for participation from the school superintendents and principals prior to contacting teachers for cooperation. Recruitment for participants was accomplished by teacher nominations from those schools that agreed to participate. Thus, teachers were also asked to sign any necessary consent forms related to the current study (see Appendix B). Once the teacher nomination forms were completed, they were provided with a letter for research participation recruitment and parents' consent forms for students to take home (see Appendix C).

When the researcher received signed consent forms from the parents who were interested in participating, the researcher asked teachers to complete Conner's Teacher Rating Scale-Revised (CTRS-R). CTRS-R is a standardized rating scale that is used to identify students with ADHD (Conners, 1997). Students who received a T-score of 65 or greater (i.e., 1.5 standard deviations above the mean) on the Hyperactive and Inattention index were selected and compared with typical comparison students who received T-scores of 50 or below. The T-score for comparison students could be interpreted as being in the "below average" to "slightly below average" range on the ADHD index. The T-score of 65 or greater could be interpreted as being in the "above" to "very much above average" range on the ADHD index (Bennett, Zentall, & French, 2006; French, Zentall, & Bennett, 2003). The students who were selected to participate in the study were asked to sign a consent form immediately before the testing.

The researcher also asked parents to release participating student standardized test scores in English and mathematics prior to participation. This step enabled the researcher to have information concerning the participant's base academic performance ability and further analyze the data based on the student's demographics.

There was a possibility that the participants may have been diagnosed with co-occurring disabilities such as behavioral disabilities or Oppositional Defiant Disorder/Conduct Disorder. Furthermore, several participants may or may not have taken psychostimulant medication, and their parents may have been reluctant to have their children stop taking these medications during the study. In order to minimize bias caused by drug intakes, participants in this study were tested at the same time of the day to reduce the differential effects of the time of medication being administered on performance (Lee & Zentall, 2002). This information was already noted and could not be controlled by the researcher (see Chapter 1, Delimitation).

3.1.1. Human Subjects

An application was completed and submitted to Purdue University's Institution Review Board (IRB) regarding the use of human research subjects (see Appendix A). Along with the application, an explanation of the study and copies of any testing instruments that were used in the study prior to any testing on human subjects were included. By doing so, the researcher was considering confidentiality and the welfare of any test subjects before the assessment of spatial training material.

3.2. Instruments

The following section describes the test instruments that were used and treatment instruments that were developed for the purpose of this study.

3.2.1. Test Instruments

The researcher utilized a battery of tests to measure performance, visual working memory, and spatial ability of students with ADHD before and after the treatment.

3.2.1.1. Scholastic Ability

The current study utilized two tests for measuring participant scholastic ability, *Indiana State Test of Educational Performance* (I-STEP) and the *Peabody Picture*

Vocabulary Test-Revised (PPVT-R). PPVT-R has been recognized as a test that measures one's verbal ability; however, it has been indicated that PPVT-R also provides performance measures for general intelligence or general scholastic ability (Tilinghast, Morrow, & Uhlg, 1983). There are two forms of the PPVT-R, Form L and Form M. Tilinghast, Morrow, and Uhlg (1983) reported a reliability value for the PPVT-R of .82 to .92, and when these two forms were combined into a longer test instrument the reliability value reached .91, .95, and .93 for fourth, fifth, and sixth grade students. PPVT-R has also been used in several studies that involve mathematics learning for students with ADHD to assess their basic scholastic ability (Zentall & Dwyer, 1988; Zentall & Ferkis, 1993).

3.2.1.2. Spatial Ability

There are only limited studies currently available to depict deficiencies for students with ADHD in three widely recognized spatial factors: spatial relation, spatial orientation and spatial visualization. Thus, students were given a spatial test from the *Kit of Factor Referenced Cognitive Tests* (the Kit) from Ekstrom, French, and Harman, (1976) to determine their area of deficiencies in spatial ability. There are 72 sub-tests in the Kit, and it has been widely recognized as a test package that addresses broad cognitive aptitude. For the purpose of this study, four sub-tests were selected from the Kit, which focus on visual/spatial factors and one's ability to retain visual memory. These tests will be further discussed in the following paragraphs.

3.2.1.2.1. Spatial Relation

Lohman and Kyllonen (1983) have defined spatial relation factor as the ability to solve spatial-related problems quickly. The majority of the tests in the kit have short time limits. Some of tests from the Kit could be completed within 1.5 minutes to 6 minutes. The time limits not only allow the researcher to administer the test quickly, but also to measure participant spatial relation ability.

3.2.1.2.2. Spatial Orientation

The spatial orientation factor is defined as the ability to mentally imagine how a visual stimulus such as spatial patterns will appear from another location or viewpoint with respect to the reference object (Ekstrom et al., 1976; Lohman & Kyllonen, 1983). The spatial orientation factor was measured by using the *Cube Comparison Test*. The *Cube Comparison Test* showed participants two cubes with letters, numbers, or figures on each side of the cubes. The participants were asked to determine whether the two cubes are the same or different from one another. The participants were also given the instruction that they must complete the 21 problems within three minutes. When the *Cube Comparison Test* was administered to college students, Ekstrom et al. (1976) reported the reliability value of .80 to .84.

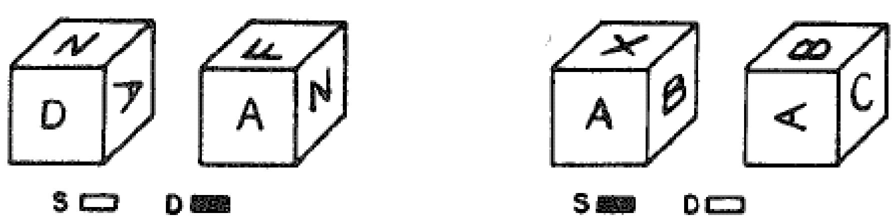

Figure 3.1 An example of the Cube Comparison Test (Ekstrom et al., 1976).

3.2.1.2.3. Spatial Visualization

Since studies have indicated that spatial visualization factors influence student performance in geometry, a separate spatial visualization test was administered to participants for closer examination. The *Paper Folding* and the *Surface Development Tests* were selected from the Kit to address the current research hypotheses and measure the research participants' spatial visualization ability.

In the *Paper Folding Test*, the participants must imagine what a piece of paper might look like when it has been folded and hole punched, which is indicated by lines and circles. There were ten items to be completed in three minutes. Even though Ekstrom et al. (1976) reported the reliability of *Paper Folding Test* values to be .75 and .77 for their study of high school students, the *Paper Folding Test* has been used on middle school children to measure spatial visualization factors (Fennema & Tarter, 1985; Tillotson, 1984).

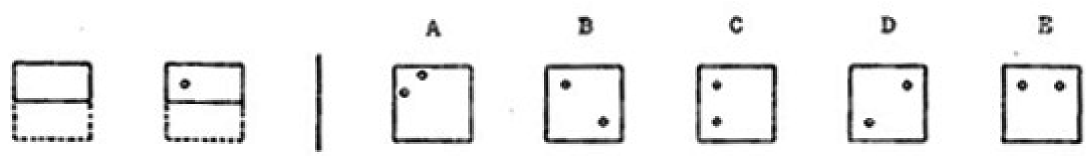

Figure 3.2 An example of the Paper Folding Test (Ekstrom et al., 1976).

For the *Surface Development Test*, the participants were asked to mentally fold a two-dimensional flat image and form it into a three-dimensional object, and to match corresponding edges of each image. There were thirty items in the *Surface Development Test*, and the participants were asked to complete this task within six minutes. Ekstrom et al. (1976) once again reported reliability values for the *Surface Development Test* of .90

with college students, but this test also has been used on middle school children (Fennema & Tarter, 1985; Tillotson, 1984).

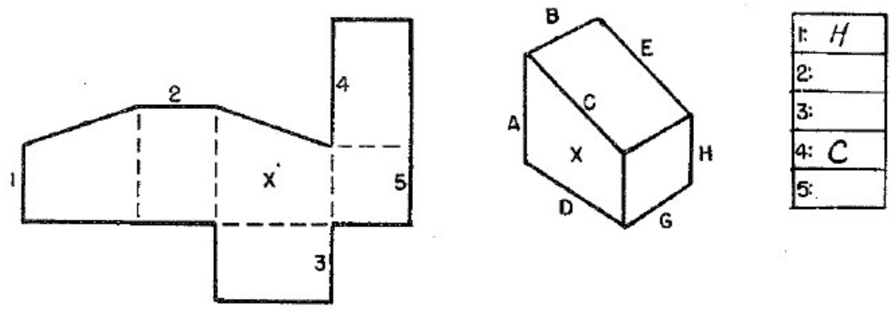

Figure 3.3 An example of the Surface Development Test (Ekstrom et al., 1976).

<u>3.2.1.3. Memory</u>

Studies suggested that one's ability to retain visual information in his or her mind plays a significant role in performance on the spatial tests. For that reason, the participants were administered the *Shape Memory Test*. This test requires the participants to memorize abstract images for four minutes, and then identify previously memorized images from the list of images. There were 16 questions in the *Shape Memory Test*. Students were asked to memorize images for four minutes and given four minutes for the testing. Even though the reliability coefficients were not reported by Ekstrom et al. (1976), they indicated that it is suitable for middle school students.

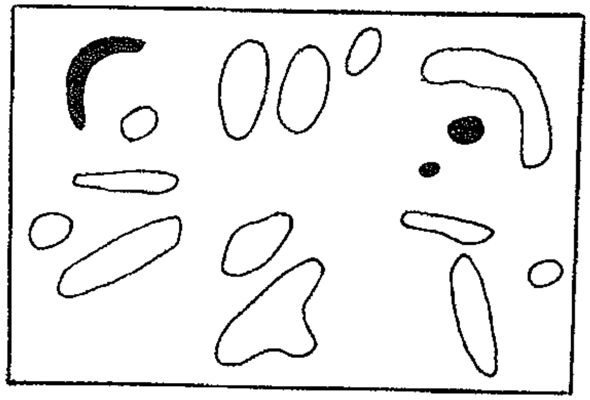

Figure 3.4 An example of the Shape Memory Test (Ekstrom et al., 1976).

3.2.1.4. Pretest and Posttest

Two sets of test forms (Form A and B) were constructed by the researcher. A pool of questions was selected from the Kit. There were two sections to the tests, *Paper Folding Test* and *Surface Development Test*. Form A or B was randomly assigned to the participants, such that half the students with and without ADHD in each condition received each order. The Form X was also constructed by the researcher from the *Shape Memory Test* and *Cube Comparison Test* to measure participants' visual working memory and spatial orientation factor. Half the participants received Form X before the training session and the remaining half received Form X after the training session to minimize the order effect.

3.2.2. Treatment Instruments

The treatment instruments for the study were developed prior to the beginning of the Fall 2008 academic semester at Purdue University. Two treatment instruments of static and dynamic condition were developed by utilizing Adobe Illustrator and Flash CS3 software package. In the dynamic condition, the treatment was developed based on Salthouse (1987), Salthouse, Babcock, Mitchell, Palmon, and Skovronek (1990), and Kyllonen, Lohman and Snow's (1984) studies. For the instructions on the paper folding tasks, the dynamic treatment instruments provided an animated demonstration of the process of folding, punching, and unfolding the paper (Kyllonen, Lohman, & Snow, 1984). In this tutorial, there was an introductory screen with text information of "Tutorial One" and "Start." When the participants rolled over the text "Start" with a mouse the text color changed, and once participants pressed the text with a mouse the training began. A total of three objects were animated and the animation lasted approximately ten seconds for each object (see Appendix E).

Once the training on paper folding concluded, another screen appeared on the computer monitor and displayed the text of "Tutorial Two" and "Start." Similar to "Tutorial One," the training started when participants press "Start" button with a mouse. The instruction on surface development consisted of an animated demonstration of folding a two-dimensional flat image into a three-dimensional object (Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Shepard & Feng, 1972). A total of three objects were also animated and animation lasted approximately 30 seconds for each object (see Appendix F).

The static treatment consisted of still and unanimated illustrations. The static treatment of paper folding and surface development started in the same manner as the dynamic treatment. A total of three unanimated objects were shown in both paper folding and surface development tutorials. Participants viewed the tutorials for the same amount of time as the dynamic tutorial (see Appendix G & H). To establish the reliability and validity of the treatment instruments, both instruments were evaluated by four experts in the field of geometry, spatial ability, and ADHD.

3.3. Procedures

The following sections describe the overview of the procedures utilized in the study, which includes the description of the experimental setting, tasks, and conditions that participants would encounter during the study.

3.3.1. Experimental Setting

The study was conducted in a conference room within the participant schools. Laptops were utilized in this study. A laptop and a mouse were situated in front of the participant. The researcher attempted to provide a similar environment at other schools as needed.

3.3.2. Tasks

The participants were escorted into the testing room. After they acclimated to the surroundings, the researcher provided an overview of the current study. Students were told that their performances on pretest and posttest will not become any of their course grades. The participants were asked to verbally summarize the initial instruction to the researcher to ensure that they understood the tasks and procedures.

The participants were given a paper and pencil-based pre and posttest. The participants that were assigned to the order Form A as the first order from the pretest were to be administered Form B for the posttest with a similar reversal order for Form B. They also received Form X containing the *Cube Comparison* and *Shape Memory Test* either before or after the treatment. Students were given verbal instructions indicating that there was a time limit to each section. Between each section of the test, there was a stop page, indicating to the students to stop working and not to proceed to the next section. Students were asked to raise their hands if they finished with a section earlier than the time restriction or asked to stop once the limit was met. They were asked to raise their hands once they finish each section of the test. Once the participants had completed their pretest, they were dismissed with thanks from the researcher. The treatment was given on the following day. Two participants, who were not able to make it on the following day due to illness, participated in the subsequent day after their absences from the school.

Before the treatment began, the participants were asked to sit in front of a laptop computer. They were provided with a portable mouse that was connected to the laptop. The students viewed and interacted with the treatment. They were asked to stop if the interaction with treatment lasted more than 12 minutes. They were also asked to raise their hands when they finished with the instrument. The students were given a paper and pencil-based posttest to measure their performance and Form X was given to those students who did not receive it for the pretest. The same restrictions and rules for the pretest applied in the posttest (see Appendix I, J, & K).

Also, half the subjects were given PPVT-R before the pretest and the other half of the subjects were given the test after the posttest.

3.3.3. Conditions

The study evaluated two spatial ability training conditions, static and dynamic. The participants were each assigned to one condition, and they were instructed on the *Paper Folding* and the *Surface Development*. The static condition had visual images without any elements of movement. The dynamic condition had visual images with necessary movement (animation) incorporated with an image. The text information in the two conditions remained the same.

3.4. Design

The participants were randomly assigned to one of two conditions (see Table 3. 1). Twelve to 13 subjects were assigned to each treatment (total of 50 participants).

Table 3.1

Experimentation Design

	Condition	
Group	Static	Dynamic
ADHD	12	12
Comparison	13	13

3.5. Data Analysis

The participant performances were measured after the treatment by comparing the results of their performance on the pretest and posttest. Performance measures consisted of the number of problems completed correctly on those tests. These data were analyzed by using a mixed design analysis of covariance (*ANCOVA*) with between group factors: two groups (ADHD and comparison) by two conditions (static and dynamic). Pretest scores were used as the covariate to determine whether it affected the posttest score (Kirk, 1982). Furthermore, the multiple regression analysis was used to examine the correlation between visual working memory and three spatial factors: spatial orientation, spatial relation, and spatial visualization.

Group, condition, and interaction between group and condition in collected data were measured at a significance level $\rho < .05$. The correlation of coefficient R^2 value was used for regression analysis. The value of 0 to 0.3 (0 and -0.3) indicated a weak relationship, 0.3 to 0.7 (-0.3 to -0.7) as a moderate, and 0.7 to 1.0 (-0.7 to -1.0) as having a strong relationship between variables.

3.6. Summary

Chapter three provides an overview methodology that was used in the current study. The participant selection process, test and treatment instruments, experimental setting, and tasks and conditions were also described in this chapter. Finally, the chapter concluded with the experimental design and explanation of data analysis procedures that was used in the study.

CHAPTER 4. RESULTS

Chapter four presents the data analyses that were conducted to answer each of the research questions that were posed in the earlier chapter. Demographic analysis, descriptive statistics, regression, analysis of variance, and covariance analyses were utilized for that reason.

To restate from the previous chapter, the participant performance was measured to determine the effectiveness of the treatments in enhancing spatial visualization skill. Even though students took the *Cube Comparison Test* (a measure of the spatial orientation factor) in the pretest, the main interest of the study was to examine the effects of participant spatial visualization skill after the treatment. The *Paper Folding Test* and *Surface Development Test* measure such a skill. Therefore, the scores of these tests were considered separately and used in the analyses for this study. Performance measures of these tests consisted of the number of problems completed divided by correct answers after the treatment. If a participant completed only 15 items in the test out of 20 questions and answered six items correctly, the score would be 0.4. The main analyses were explained using a significance level of $\rho < 0.05$.

Demographic Analysis

An initial examination was made to see whether there were preliminary differences in participant general scholastic ability. For this purpose, analysis of variance (*ANOVA*) was conducted. Group and condition interaction from the *ANOVA* with participant *Indiana State Test of Educational Performance* (ISTEP) verbal, math, and *Peabody Picture Vocabulary Test-Revised* (PPVT-R) scores were also examined. This particular process allowed the researcher to examine group distribution within the static and dynamic treatments. Having *no* significant interaction between the two groups and the two conditions ensured that not all low (or high) academic performers were assigned to one condition. Tables 4.1, 4.2, and 4.3 present the *ANOVA* results for participant performance in ISTEP verbal, ISTEP math, and PPVT-R.

Table 4.1
ANOVA Results for ISTEP verbal

Source	*df*	*MS*	*F*	$\rho < .05$
		Between subjects		
Group (G)	1	49102.32	10.63	0.003
Condition (C)	1	11353.72	2.46	0.125
Group x Condition (G x C)	1	5879.55	1.27	0.266
Within-subjects				
Error	46	(4620.30)		

Note. * $\rho < .05$

Table 4.2
ANOVA Results for ISTEP math

Source	*df*	*MS*	*F*	*ρ< .05*
		Between subjects		
Group (G)	1	18795.54	4.81	0.033
Condition (C)	1	1672.75	0.43	0.517
Group x Condition (G x C)	1	799.28	0.20	0.654
Within-subjects				
Error	46	(3907.44)		

Note. * $\rho < .05$

Table 4.3
ANOVA Results for PPVT-R

Source	*df*	*MS*	*F*	*ρ< .05*
		Between subjects		
Group (G)	1	146.14	0.35	0.558
Condition (C)	1	1333.95	3.18	0.082
Group x Condition (G x C)	1	99.68	0.24	0.629
Within-subjects				
Error	46	(420.11)		

Note. * $\rho < .05$

The findings of ISTEP verbal (F (1, 46) = 10.63, $\rho = 0.003$, $\eta^2 = 0.434$) and ISTEP math (F (1, 46) = 4.81, $\rho = 0.033$, $\eta^2 = 0.328$) indicated that there were significant initial group differences in the state's standardized tests, which participants take every year. The ISTEP score of 480 is considered a passing score and the average of ISTEP verbal scores for students with ADHD was 462.46 (*SD* = 78.39). By comparison, average scores for students without ADHD was 527.86 (*SD* = 58.02). The mean of ISTEP math scores for students with ADHD resulted in 486.13 (*SD* = 65.53), and 526.59 (*SD* = 57.88) for students without ADHD. These finding suggested that students with ADHD appeared to score significantly lower in both ISTEP verbal and ISTEP math compared with students without ADHD. Nevertheless, the analysis also indicated that there was no significant difference between students with and without ADHD in PPVT-R (*F* (1, 46) = 0.35, $\rho = 0.558$, $\eta^2 = 0.087$), which measures participant scholastic aptitude (i.e., their verbal skills and IQ).

The group and condition interaction of *ANOVA* analyses on ISTEP verbal (*F* (1, 46) = 1.27, $\rho = 0.266$) and ISTEP math (*F* (1, 46) = 0.20, $\rho = 0.654$) and PPVT-R (*F* (1, 46) = 0.24, $\rho = 0.629$) showed that the participants were assigned to a condition and not all low or high academic performers were allocated within one condition (see Table 4.1, 4.2, and 4.3 for Group x Condition).

The *Pearson's Chi Square analysis* on gender was also utilized to explain whether gender has an effect within each condition. The results indicated no significant association between the distribution of gender and type of condition that participants were assigned during the study, χ^2 (1) = 0.159, $\rho = 0.554$.

Research Questions and Main Analyses

The next section presents each of the research questions and the results that were associated to these questions. The first analysis involved comparisons of the two groups in the pretest data to see if there were any initial differences. For the main analyses, the data from the spatial visualization factor was subjected to an *Analysis of Covariance* with pretest score as the covariate in a two group (comparison and students with ADHD) by two condition (static and dynamic*)* design. Given the differences observed only in the posttest performance data between groups, additional examinations were made based on the *a priori* hypotheses that the two groups would respond differently to the two conditions. Only students with ADHD were examined in two conditions followed by evaluation of only the comparison group.

Because there were an insufficient number of boys and girls to be included in the overall model, the researcher conducted supplementary analyses including the factor of gender. Furthermore, regression analysis was used to examine the correlation between working memory performance and spatial factors.

Research Question 1

For the purpose of this study, it was assumed that students with ADHD have a considerably lower spatial ability than their peers. However, there are few studies currently available that address this assumption. Research question one is stated as follows.

Research Question 1*: Were there initial performance differences on spatial ability (i.e., spatial orientation, relation, and visualization) among seventh and eighth grade students with and without ADHD before instruction on spatial visualization?*

To answer this particular question, an *independent sample t-test* was conducted to examine whether there were performance differences in spatial ability (i.e., spatial orientation, relation, and visualization) between students with ADHD and without ADHD.

The results indicated that there was no initial difference between groups in spatial orientation ability (i.e., accuracy) (*t* (48) = -0.64, ρ = 0.517). Furthermore, there was also no group difference in spatial visualization ability (i.e., accuracy) in *Paper Folding* (*t* (48) = 0.91 ρ = 0.358) and *Surface Development* (*t* (48) = 0.20, ρ = 0.840). Even though there was no significant difference in spatial relation ability (i.e., speed) on the *Surface Development* (*t* (48) = - 0.86, ρ = 0.392), there was a difference in the *Paper Folding* (*t* (48) = -3.30, ρ = 0.002). In *Paper Folding,* (as shown in Table 4.4), the comparison students (*M* = 84.27, *SD* = 16.85) were able to solve spatial-related problems faster than students with ADHD (*M* = 68.29, *SD* = 15.87).

Table 4.4
Participants Pretest Scores

Groups	Spatial Factors	*M*	*SD*	*SE*	*MIN*	*MAX*
Students w/ ADHD (*N* = 24)	SO	50.16	13.11	2.67	23.0	85.0
	SR: *PF*	68.29	16.85	3.44	35.0	100.0
	SR: *SD*	48.46	18.88	3.85	10.0	82.0
	SV: *PF*	52.42	23.27	4.75	0.0	92.0
	SV: *SD*	41.79	18.67	3.81	0.0	83.0
Students w/o ADHD (*N* = 26)	SO	52.27	8.41	1.79	35.0	67.0
	SR: *PF*	84.27	15.88	3.39	50.0	100.0
	SR: *SD*	53.05	17.06	3.64	20.0	83.0
	SV: *PF*	46.64	19.43	4.14	15.0	75.0
	SV: *SD*	40.68	18.26	3.89	9.0	82.0

Research Questions 2 and 3

Kirk (1982) stated that the analysis of covariance (*ANCOVA*) in pretest-posttest analyses treats the pretest score as a covariate, a continuous variable that represents sources of variation that have not been controlled for in the experiment and are believed to affect the expected value of the posttest score. Thus, pretest scores were used as the covariate to answer research questions two and three. If there were any significant main effects or interactions, planned contrasts were conducted as a follow- up analysis. Research questions two and three are stated as the follows.

Research Question 2: *Would dynamic images improve student spatial performance more than static images?*

Research Question 3: *Would spatial performance of seventh and eighth grade students with and without ADHD improve differently with instruction on spatial visualization?*

The covariate, *Paper Folding* pretest was not significant in the model. After controlling for the effect of participant pretest scores, an *ANCOVA* yielded a trend for group difference, F (1, 45) = 3.84, $\eta^2 = 0.074$, $\rho = 0.057$ (see Table 4.5). When the two groups adjusted pretest and posttest scores of the *Paper Folding* were plotted, students with ADHD (M = 52.42, SD = 23.27) scored somewhat higher on the pretest than comparisons (M = 46.63, SD = 19.43) (see Figure 4.1). Both groups were able to increase scores on the posttest, which may be due to a practice effect. However, the changes in pretest to posttest scores were significantly higher for comparisons. There was no evidence of a main effect on the *Surface Development* test, which also measures spatial visualization ability (see Table 4.6).

Table 4.5
Analysis of Covariance on Adjusted Postt4est Scores of Paper Folding Performance

Source	*df*	*F*	η^2	$\rho < .05$
		Between subjects		
Pretest	1	4.71	0.021	0.036
Group (G)	1	3.84	0.074	0.057
Condition (C)	1	0.00	0.000	0.969
Group x Condition (G x C)	1	0.64	0.012	0.429
Within-subjects Error	45	(217.49)		

Note. * $\rho < .05$

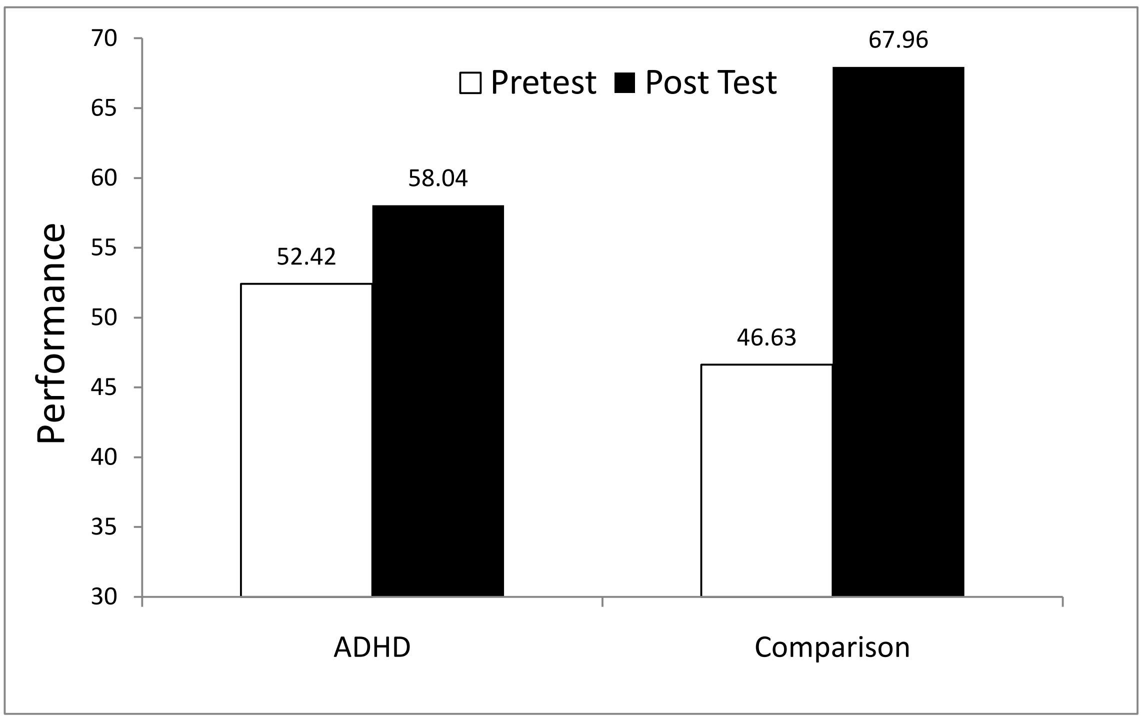

Figure 4.1 Students with ADHD and comparison students performance in pretest and posttest.

Table 4.6

Analysis of Covariance on Adjusted Posttest Scores of Surface Development Performance

Source	*df*	*F*	η^2	$\rho < .05$
		Between subjects		
Group (G)	1	0.05	0.001	0.819
Condition (C)	1	2.29	0.049	0.138
Group x Condition (G x C)	1	0.65	0.014	0.426
Within-subjects				
Error	46	(219,66)		

Note. * $\rho < .05$

A Priori Hypotheses Testing

Groups were separately examined based on the *a priori hypotheses.* The purpose of these separate examinations was to see how each group responded to the treatment. The results yielded no significant performance difference in the comparison group between the static and dynamic condition. However, there was a significant performance trend in the adjusted *Surface Development* posttest scores for students with ADHD who were assigned to the dynamic condition compared to those who were assigned to static condition (t (11), = 2.13 $\rho = 0.08$). Specifically, students with ADHD who were in the dynamic condition were able to increase their scores on an average of 16 points (*SD* = 14.64), whereas students in the static condition increased only on an average of 2.65 points (*SD* = 26.61) in the adjusted *Surface Development* posttest (see Figure 4.2).

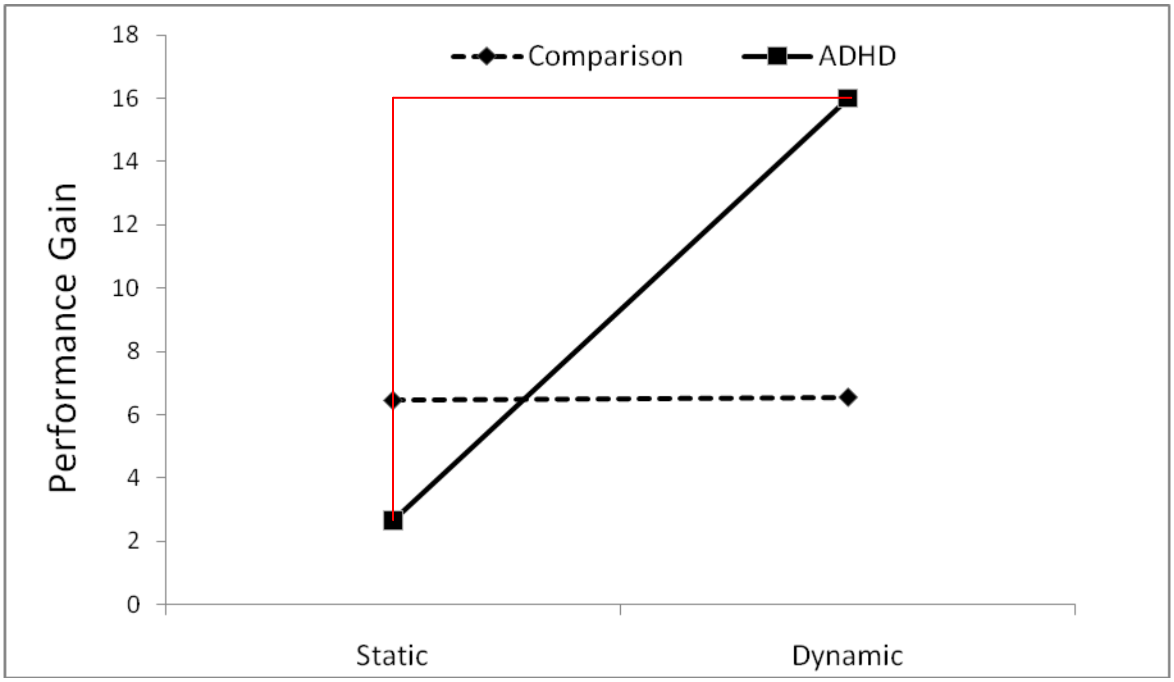

Figure 4.2 Evaluation of performance increases in the posttest within two conditions for the *Surface Development*. There is a significant performance increases for students with ADHD in static to dynamic.

An additional simple t-test was conducted to evaluate which condition was better for spatial ability training. All the students who were assigned to dynamic condition were examined, followed by an examination of all the students in the static condition. In the static condition, there were no significant performance differences between students with ADHD and the comparison group. However, the results indicated that the comparison group performed significantly better (M = 70.27, SD = 17.86, SE = 5.39) than students with ADHD (M = 55.83, SD = 14.92, SE = 4.31) in the dynamic condition for the *Paper Folding* (t (23) = -2.11, ρ = 0.049). The comparison students were able to increase their scores on an average of 26.55 points (SD = 32.57) in the dynamic condition, whereas students with ADHD increased 1.75 points (SD = 25.11).

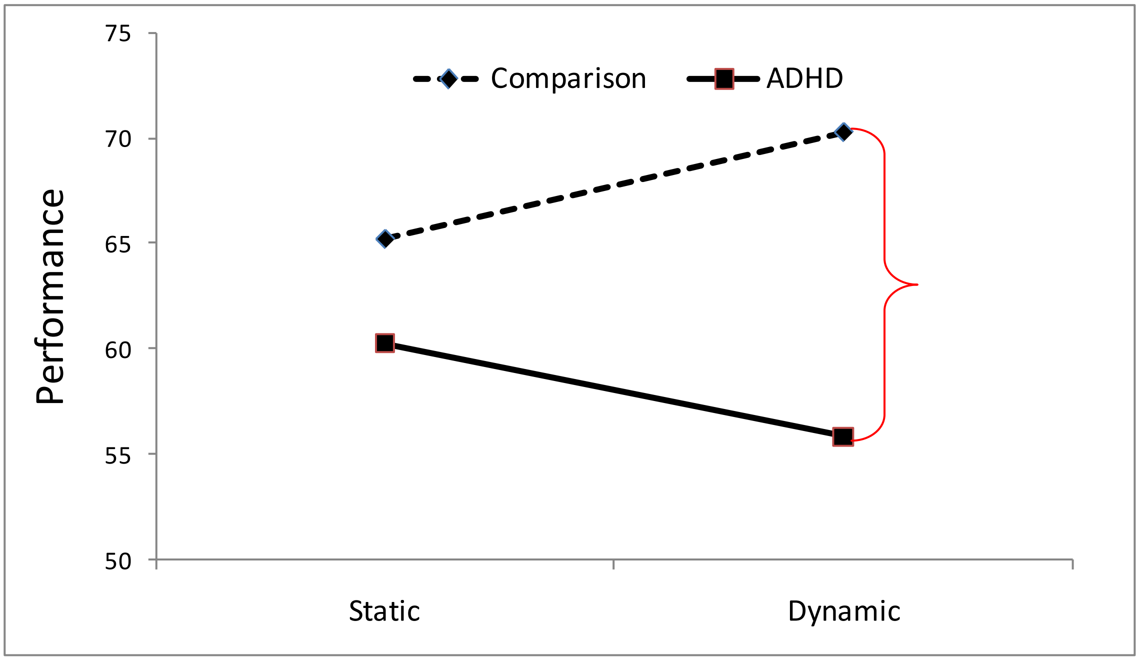

Figure 4.3 Evaluation of two treatments in the Paper Folding Test. Significant group differences were shown in dynamic condition.

Post Hoc Hypotheses Testing

There has been evidence from numerous studies on gender differences in spatial performance that showed significant performance from males than females. *Post hoc* testing allows researchers to compare all different combinations of the treatment group when researchers are interested in further exploring the data for any differences between groups. Therefore, the current study examined the initial gender differences and evaluated whether there were any gender and group differences among them after the training. A total of 21 females (six females with ADHD and 15 females without ADHD) and 29 males (18 males students with ADHD and 11 males without ADHD) participated in the study.

The results showed that there was no initial performance difference between females and males in spatial orientation ability (i.e., accuracy) (*F* (1, 49) = 0.46 ρ = 0.503), relation (*F* (1, 49) = 0.33 ρ = 0.564), and visualization (*The Surface Development Test*: *F* (1, 49) = 0.07 ρ = 0.793; *The Paper Folding Test*: *F* (1, 49) = 0.84, ρ = 0.364). Further examination was made separately on female and male performance in each condition. There was no significant performance difference between females with ADHD and without ADHD in either static or dynamic conditions. However, there was a significant main effect shown in a group (*F* (1, 24) = 4.47 ρ = 0.047) and group and condition interaction (*F* (1, 24) = 7.25, ρ = 0.014) for males in *Paper Folding* (see Table 4.7).

Table 4.7
Analysis of Variance on Male Performance in Paper Folding Test

Source	*df*	*F*	η^2	*ρ< .05*
Between subjects				
Group (G)	1	4.47	0.143	0.047
Condition (C)	1	0.67	0.039	0.506
Group x Condition (G x C)	1	7.25	0.233	0.014
Within-subjects Error	24	(150.97)		

Note. * *ρ* < .05

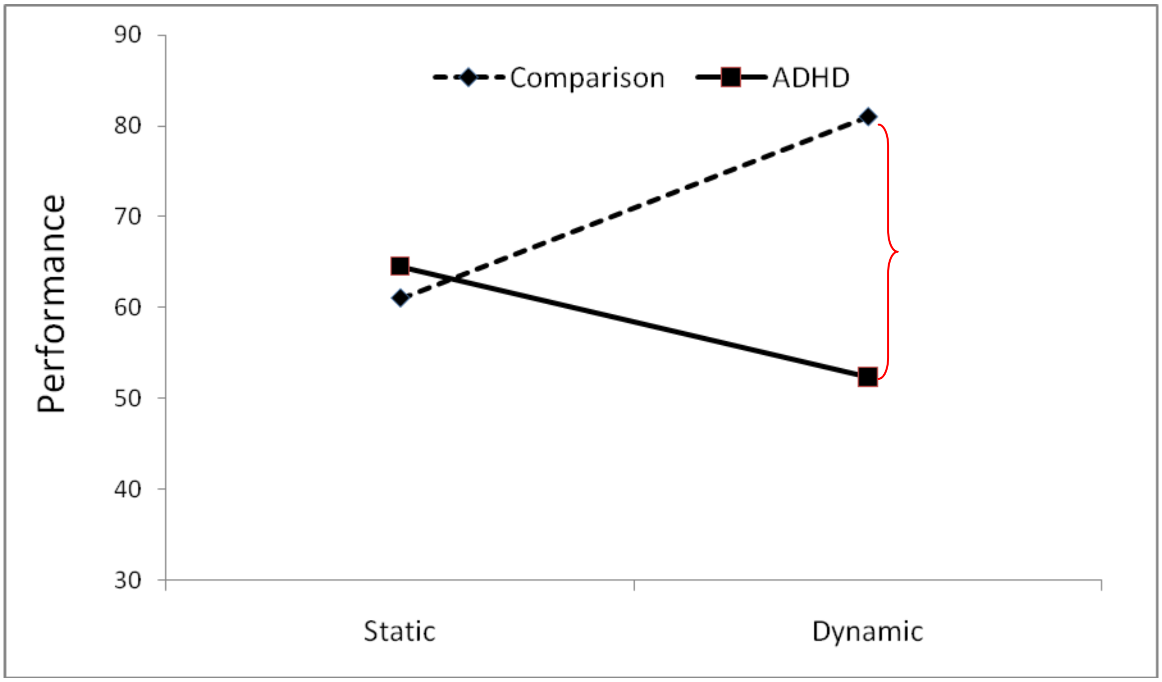

Figure 4.4 Significant group and condition interaction for male students in the *Paper Folding Test.*

Additional examination indicated that the male group with ADHD performed significantly lower (*M* = 52.33, *SD* = 13.34, *SE* = 4.45) for the *Paper Folding* in the dynamic condition than comparison males (*M* = 81.00, *SD* = 4.24, *SE* = 3.00). The difference between them resulted in *t* (1, 9), = -5.34, ρ = 0.001 (see Figure 4.4).

Research Question 4

It was predicted that students with ADHD have a working memory deficit, which could be one of the reasons for poor performance in spatial-related tasks. Simple Regression Analysis was conducted to evaluate overall participant differences in working memory and correlation with spatial factors. Research question four is stated as follows.

Research Question 4: *Was there a correlation between visual working memory and spatial performance in students with and without ADHD?*

According to the findings there was no significant difference in working memory for both groups of students (F (1, 46) = 0.02, ρ = 0.881). Furthermore, there were no strong correlations between working memory and any of the spatial factors. The results indicated correlation R^2 values all less than 0.1 (see Table 4.8, 4.9 & 4.10).

Table 4.8
Simple Regression Analysis on Spatial Orientation and Working Memory

Variable	*B*	*SE B*	β
Step 1			
SO	-0.136	0.155	0.384
Group	-0.217	3.383	0.949

Note. $R^2 = 0.018$ for Step 1 (ρ < 0.05)

Table 4.9
Multiple Regression Analysis on Spatial Relation and Working Memory

Variable	*B*	*SE B*	β
Step 1			
SR: Paper Folding	0.065	0.105	0.539
Group	-1.547	3.778	0.684
Step 2			
SR: Paper Folding	0.136	0.112	0.232
SR: Surface Development	-0.166	0.102	0.111
Group	-1.915	3.714	0.609

Note. $R^2 = 0.009$ for Step 1: $\Delta R^2 = 0.068$ for Step 2 (ρ < 0.05)

Table 4.10
Multiple Regression Analysis on Spatial Visualization and Working Memory

Variable	*B*	*SE B*	β
Step 1			
SV: Paper Folding	0.019	0.081	0.813
Group	-0.393	3.427	0.909
Step 2			
SV: Paper Folding	-0.005	-0.084	0.948
SV: Surface Development	0.098	0.098	0.324
Group	-0.426	3.427	0.902

Note. $R^2 = 0.002$ for Step 1: $\Delta R^2 = 0.025$ Step 2 (ρ < 0.05).

Summary

Chapter four provided an overview of data analyses that were used in the current study. Descriptive statistics, regression, and *ANCOVA* analyses were utilized to test each of the research hypotheses. The findings, relevant tables, and figures were presented according to the analyses. The next chapter will discuss the results, implications, and suggestions for the future studies.

CHAPTER 5. DISCUSSION AND CONCLUSIONS

This chapter provides a discussion of the results from the data analyses that were conducted in the previous chapter. The overview of the study was reiterated to highlight the concluding remarks. Along with possible responses to each research question, implications and recommendations for future research studies are also presented.

5.1. Overview of the Study

Students with ADHD underachieve in mathematics despite their average IQ scores. One of the subjects of mathematics, geometry, has received much attention lately due to the higher order of thinking skills that are required to perform successfully in the subject. Among other spatial abilities, the spatial visualization skill appears to be highly correlated with student performance in geometry. The purpose of the current study was to evaluate the use of assistive instructional technology as a training method to enhance student spatial visualization skills. The current study also predicted that overall the treatments would produce better performance for the participants and that the dynamic training tool would be more effective than the static tool. Participants of the study interacted with one of the treatments for approximately 12 minutes. Their pretest and posttest performance scores on spatial visualization tests (i.e., *The Surface Development Test* and *The Paper Folding Test*) were gathered to evaluate the effectiveness of the treatment and the images that were integrated within the instructional technology. In addition, participant performance scores in the *Cube Comparison Test* and *Shape Memory Test* were also collected and analyzed to examine the correlation of student working memory to different spatial factors.

5.2. Conclusions

The initial analysis indicated that students with ADHD performed significantly lower than comparison students in the state's annual standardized tests. However, as noted in the beginning of this study, the literature suggested that a majority of students with ADHD have an average IQ, although their scholastic performance suffers due to the symptom caused by the disability. The current study concurs with this statement as there was no performance difference between the current study participants in IQ scores (according to PPVT-R). Also, additional examination ensured that participants were randomly assigned so that not all low or high performers in standardized tests were allocated in one specific treatment. When the gender distribution of each treatment was examined, there was no association between the distribution of gender and the type of condition to which participants were assigned during the study. These preliminary and demographic analyses provided attest to the validity of the design of the study. The subsequent sections discuss results from the data analyses that were conducted to answer the research questions that were posed in the study.

5.2.1. Research Question 1

The first research question addressed whether there was an initial performance difference between students with ADHD and comparison students in spatial-related tasks. The initial finding suggested that there was no initial difference between these two groups in two spatial factors, spatial orientation and visualization. However, comparison students answered the spatial visualization questions more rapidly (i.e., spatial relation ability) than students with ADHD. The accuracy of their performance is open to discussion because their performance appeared to be affected by their ability to solve the problems quickly. Students with ADHD were able to surpass comparison students in the pretest and were able to answer more questions correctly, even though it took them longer to solve the spatial problems. This is a unique finding that is worthy of further pursuit, because the literature indicates that students with ADHD have a tendency to solve less problems with not as good as accuracy (Zentall, 1990; Zentall & Ferkis, 1993; Zentall & Smith, 1993; Zentall, Smith, Lee, & Wieczorek, 1994).

5.2.2. Research Question 2

The second research question attempted to compare the effectiveness of dynamic and static images in the instructional technology. The result indicated that the treatments did produce group differences in the posttest for the *Paper Folding Test*, but not in the *Surface Development Test*. Both are measures of spatial visualization ability.

Further investigation revealed that both groups of students were able to achieve higher scores in posttest (possibly an indication of a practice effect), but the changes from pretest to posttest scores were significantly higher for comparison students in *Paper Folding*. Interacting with treatments for 12 minutes did increase some of participant test scores. However, the correlation between pretest and posttest suggested that those who performed well on the pretest also performed well on the posttest.

A follow up test to examine each treatment (static and dynamic) and its effectiveness also showed no significant performance difference for the groups. The assistive technology with dynamic images or static images used for this experiment did not appear to help students with their performance.

5.2.3. Research Question 3

There was indeed some improvement in spatial visualization performance for a number of participants after the instruction. Also, given the differences observed in the posttest, and to follow up on *a priori* prediction, the current study examined the group by condition interaction, even though this interaction failed to achieve significance. For comparison students, there was no significant performance difference between those who were assigned to either the static or dynamic condition. However, the dynamic treatment appears to be a better training tool for students with ADHD when they were given the *Surface Development* test. There were more significant score improvements in the posttest for those students in the dynamic condition than in the static condition. When the two treatments were examined, comparison students performed significantly better than students with ADHD in the dynamic condition in *Paper Folding*. Consequently, the result showed the score improvement in the posttest for *Paper Folding* were also significantly higher for comparison students than for students with ADHD in dynamic condition. Comparison students also scored higher in posttest after static treatment, but the performance difference compared with students with ADHD was insignificant.

There have been numerous studies concerning the gender differences in spatial-related tasks. After examining groups and conditions separately, the current study conducted *post hoc* hypotheses testing that male and female students perform differently in all spatial factors. However, the analyses indicated that there was no initial performance difference before and after the treatment. When males and females were looked at individually, there was no performance difference between comparison female students and females with ADHD in either treatment. This is also a unique finding because there is a little to no research available to address spatial performance differences between females with and without ADHD. Nevertheless, there was a group and condition interaction in *Paper Folding* for male comparison students and males with ADHD. It appeared that for males with ADHD, performance diminished after the dynamic instruction, although they outperformed comparison males in the static condition. The analysis also showed that this was different for comparison students. They performed best with dynamic condition, also.

5.2.4. Research Question 4

It has been acknowledged that the majority of students with ADHD have a working memory deficit. Working memory deficits may contribute to the fact that students with ADHD also perform poorly on spatial tasks. Specifically, students have a difficult time holding visual information in their minds to transform, orient, and manipulate that information. There have not been many research studies addressing the relationship of working memory and spatial ability. Furthermore, even fewer studies address working memory deficits and spatial functioning for students with ADHD. Therefore, correlation analysis was conducted for those reasons.

The result of student performance related to individual spatial factors indicated that there was no association between working memory and spatial orientation, relation, and visualization.

5.3. Implications

The educational implications of these findings are that the integration of static and dynamic images in spatial visualization training may be powerful enough to increase the performance for comparison students and some students with ADHD. More importantly, the dynamic treatment was more helpful for comparison students, who performed better with dynamic conditions than static, as shown in the results for the participant visualization test (i.e., *Paper Folding Test*). Even though the current study assumed that dynamic provided more visual novelty than static, (which presents additional stimulations for students with ADHD), the dynamic treatment was not beneficial for some students with ADHD.

Specifically, when male participants were separately analyzed, students with ADHD performed worse after going through dynamic training. In contrast, comparison male student performance increased significantly with dynamic training rather than static for the *Paper Folding Test*. Evidence that a high spatial performer finds dynamic images more useful than lower spatial performer has been discussed (Cohen, 2005; Mayer, 2005). However, this is not the case for the current study because there was no evidence of any initial spatial performance difference between students with ADHD and the comparison students. One can only presume that students with ADHD may find the dynamic treatment interferes with their spatial training (potentially due to cognitive overload).

Nevertheless, among students with ADHD who were assigned to static or dynamic condition, the dynamic treatment appeared to be more beneficial because their performance increased in the *Surface Development* posttest. When the current study examined the adjusted mean scores, those students with ADHD who were assigned to dynamic treatment were even able to outperform comparison students who were in the same condition. This phenomenon is actually surprising because participants took the *Surface Development Test* as the last section in both pretest and posttest. Experts in the field of attention focus research may assume that students (and especially students with ADHD) should have become fatigued as they reached the end of the test. Because they were low in energy, the current study expected participants to perform worse in the *Surface Development Test* than in any other test. However, the result suggested that the dynamic treatment may have provided sufficient stimulation for students with ADHD in this particular test that they were able to increase their performance.

Even though there was no main effect, there were performance increases after both treatments. One may specify that all participants were involved in the optimal computer treatment with self-pacing and interactive technology, which alone can serve as intervention for students (Zentall, 2006). Even though McCuiston's (1990) study dealt with mental rotation, the current study's result also agrees with McCuiston's conclusion that static treatment assists students to achieve a higher performance score and dynamic treatment assists increase in their scores from the pretest to posttest.

Finally, the current study predicted that a working memory deficit is one reason behind students with ADHD's low performance in spatial-related tasks. The correlation between these two variables would indeed indicate that a working memory deficit is a reason for poor spatial ability. There were, however, no conclusive findings with regard to the correlation between working memory and the three spatial factors. There are multiple implications as to why there were almost no associations between these variables for the current study. One reason is that there was no performance difference between students with ADHD and comparison students in initial examination for working memory. Students might have had equivalent working memory function. Stated in another way, everyone was performing at the same level in working memory and both groups might not have had working memory deficit to correlate with spatial factors. Perhaps for this reason, all the groups performed similarly on the problems regardless of condition, and it may also explain why there was no significant main effect from the key analysis.

5.4. Recommendations for Future Research

A number of suggestions emerged for future research studies as a result of the current study. Obtaining participants with disabilities was more difficult than was originally anticipated. Additional participants could have led to more conclusions from the data analysis. Another weakness in this study is that the participants might have been medicated and could have been diagnosed with other disabilities. Unfortunately, school districts did not grant access to student records to confirm or negate**.**

Furthermore, students with ADHD performed significantly low after dynamic treatment, which led the researcher to question the process that students take in order to transfer moving/animated visual information in their minds. It would be interesting to see how the results might be different if *dynamic spatial ability* were to be considered as one of the spatial factors to be analyzed. Dynamic spatial ability has been described as the "ability to deal with moving elements and relative motion" (Carroll, 1993). It was suggested that dynamic spatial ability depicts the estimation of movement between visual information. It is a fairly new factor in the realm of spatial ability, but it has been acknowledged by many others (Colum, Contreras, Shih, & Santacreu, 2003; Contreras, Colom, Hernandez, & Santacreu, 2003; Contreras, Colom, Shih, Alava, & Santacreu, 2001; Hunt, Pellegrino, Frick, Farr, & Alderton, 1988). Perhaps students with ADHD performed poorly based on the time sequences of movement in dynamic images, as suggested by Law, Pellegrino, and Hunt, (1993) as well as Kyllonen and Chaiken (2003). However, it is difficult to ascertain the reason behind students with ADHD's poor performance with dynamic images because there is no prominent research available that address children's dynamic spatial ability. Also, there are no studies concerning students with ADHD as subjects for dynamic spatial ability.

Some students were able to increase their performance after one training session that lasted 12 minutes. In the current study, there was an evidence of practice effect, and those who did well in pretest also did well in posttest as well. Studies indicated that actual learning would occur only if learners were able to retain the information and to recall it as necessary (Mayer, 2005; Mayer & Sims, 1994). Thus, future research may consider the retention of information through spatial training material after longer periods of times have passed.

Ekstrom, French, Harman and Dermen (1976) stated that, “Differences in apparent test difficulty can occur as a result of modification in the directions or content of the tests and certainly when the population being studied is different from the experimental group (p.7).” There was no modification in the directions or content of the tests in the current study; however student with ADHD took longer to solve the Paper Folding tests than students without ADHD. For that reason, students with ADHD may have found the paper folding tasks more difficult to solve. Examining the underlying reason behind the difficulty level of paper folding could have significant impact on future studies.

Given the above limitations and recommendations, the findings of this study have raised enough questions to further investigate the use of spatial ability training technology for students with and without attentional problems. Repeating this study will likely strengthen the claims made in the current study’s findings and might allow for the depiction of the advantages and disadvantages of the use of static and dynamic images in spatial ability instruction.

5.5. Summary

The final chapter provided concluding remarks for the research study. The overview of research study was presented, and as well as an explanation of the initial examination that was conducted prior to data analyses. Each research question was further addressed with implications presented based on the results. Following the conclusions, suggestions for future research studies were also discussed. Furthermore, the impact of spatial instructional technology is highlighted as a means to effectively improve the spatial ability of students with and without disabilities in the future.

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APPENDICES

Appendix A: Human Review Research Board Approval & Renewal

PURDUE
UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	JAMES MOHLER KNOY 347
From:	RICHARD MATTES, Chair Social Science IRB
Date:	07/15/2008
Committee Action:	**Expedited Approval**
Approval Date:	07/15/2008
IRB Protocol #:	0806006948
Study Title:	Effectiveness of Spatial Visualization Training for Children with Attention Problems
Expiration Date:	07/14/2009

The above-referenced protocol was granted approval following review by the Institutional Review Board (IRB). If written informed consent was submitted as part of your protocol, the IRB-stamped and dated "master" consent form(s), approved by the IRB for this protocol only, are attached. Please make copies from the attached "master" document(s) for subjects to sign upon agreeing to participate. The original consent forms signed by subjects should be placed in your study files and maintained for a period no less than three (3) years following the termination of the protocol. A copy of the signed consent form should be given to the subject.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be reported or published as research data. If you do not wish to continue approval, please notify the IRB of the study closure.

Adverse Events: All adverse events that occur at a Purdue University research site must be reported to the IRB within three (3) business days of recognition/notification of the event. If the adverse event occurred at an external site as part of a multi-site research project for which Purdue University is the lead institution, it must be reported to the IRB within ten (10) business days.

Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB. No new procedure may be implemented until IRB approval has been granted.

If you have any questions or concerns, please contact our office.

Hovde Hall of Administration ▫ 610 Purdue Mall ▫ West Lafayette, IN 47907-2040 ▫ Phone: (765) 494-5942 ▫ Fax: (765) 494-8323

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	JAMES MOHLER KNOY 347
From:	RICHARD MATTES, Chair Social Science IRB
Date:	06/22/2009
Committee Action:	**Renewal**
Approval Date:	~~07/15/2008~~ 6/17/09
IRB Protocol #:	0806006948
Study Title:	Effectiveness of Spatial Visualization Training for Children with Attention Problems
Expiration Date:	06/16/2010

The above-referenced protocol was granted approval following review by the Institutional Review Board (IRB). If written informed consent was submitted as part of your protocol, the IRB-stamped and dated "master" consent form(s), approved by the IRB for this protocol only, are attached. Please make copies from the attached "master" document(s) for subjects to sign upon agreeing to participate. The original consent forms signed by subjects should be placed in your study files and maintained for a period no less than three (3) years following the termination of the protocol. A copy of the signed consent form should be given to the subject.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be reported or published as research data. If you do not wish to continue approval, please notify the IRB of the study closure.

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Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB. No new procedure may be implemented until IRB approval has been granted.

If you have any questions or concerns, please contact our office.

Ernest C. Young Hall, 10th Floor ▪ 155 S. Grant St. ▪ West Lafayette, IN 47907-2114 ▪ Phone: (765) 494-5942 ▪ Fax: (765) 494-9911

Appendix B: Teacher Information Sheet

Research Project Number _0806006948__

Attachment B: Teacher Information Sheet

"Effectiveness of spatial visualization training for children with attention difficulties."

James L. Mohler, Principal Investigators & Helen Kang, Co- Investigators
Purdue University, Department of Computer Graphics Technology

Purpose of Research

Some students with attentional problems also have difficulty in the field of mathematics, especially in geometry, due to embedded shapes and figures. The purpose of this study is to assess the value of different spatial training that may assist student in the learning of geometry. This research will determine if there is a difference in the students' performance when these instructions are used.

The person in charge of the activities has training and experiences in the field of computer graphics technology. This study will be used to assist teachers and parents in determining additional ways to help students be more successful in mathematics.

Specific Procedures to be Used

You will be asked to do:

1. 'Nominate' 4 to 5 students who you believe had or currently have services for attention deficit disorder **as well as** those who may have characteristics of:
   - Inattention - Changes in the focus of play or free-time activities, being visually and verbally off task (for example, off the subject), and lack of concentration
   - Impulse - Disrupt and interrupt
   - Hyperactivity - Restlessness, inability to sit still
   - Social negativity –
     - Verbal: Disagree/argue/command/verbal statement
     - Physical: Negative physical contact with another or noncompliance or nonperformance of a request or an assigned task

   = 4 to 5 students nominated per class. see next page for nomination form.

2. Then give the enclosed parent and student consent forms for students to take home with recruitment letters.
3. You will be asked to fill out a Conners rating scale for each student selected and for whom consent has been obtained (see Attachments B2).
4. Return the Signed Teacher Information Sheet and Conner rating scale in the envelope marked "To the Office for Mohler/Kang"

Duration of Participation

Participation on the students' part will be no more than 30 minutes. Duration of the entire study will be no longer than 1 year and at that time all documents will be destroyed.

APPROVED
JUN 17 2009
EXPIRES 6/16/10
PURDUE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Initials ______ **Date** ______

Research Project Number _0806006948__

Benefits to the Individual
There are no direct benefits to the subject. However, benefits to participant could occur only as she/he might be receiving individual attention and new materials related to geometry. Although *we are not using* students' names and identifying data, you may request to review or have copies of any of the surveys that we are using at any time during or after students' participation. Benefits to the adults who teach students may occur when teaching in mathematics, which in turn might help your students. In addition, the student will have the opportunity to access new materials related to geometry. The teachers may be able to better help students in mathematics education.

Risks to the Individual
The risks are no more than your students would encounter in everyday life.

Compensation
In appreciation, all children with permission and who participate in this study will receive monetary compensation of **five dollars**).

Confidentiality
All information and materials used in this study will be strictly confidential and your students' name will **not** appear anywhere in a published study nor on any records. Numbers will identify students instead of names. The data will be kept in a file cabinet in a locked room (Knoy building Rm. 355 at Purdue University) and will be destroyed within one year after the completion of the study. Furthermore, the project's research records may be reviewed by departments at Purdue University responsible for regulatory and research oversight.

Voluntary Nature of Participation
I do not have to participate in this research project. If I agree to participate I can withdraw my participation at any time without penalty.

Human Subject Statement:
If you have any questions about this research project, you can contact Dr. James L. Mohler. This research will be conducted by Helen Kang, under the direction of Sydney S. Zentall, Ph.D., Professor of Educational Studies. If you have any questions about this project, contact Dr. Mohler at 765/494-9089 or through e-mail: jlmohler@purdue.edu or Dr. Zentall at 765/494-7347 or through e-mail: zentall@purdue.edu. If there are concerns about the treatment of research participants, contact the Committee on the Use of Human Research Subjects at Purdue University, Ernest C. Young Hall, 10th Floor-Room 1032, 155S. Grant Street, West Lafayette, IN 47907-2114. The phone number for the Committee's secretary is 765/494-5942. The email address is: irb@purdue.edu.

Appendix C: Parent/Guardian Consent Form

Research Project Number _0806006948__

Attachment C: Parent/Guardian Consent Form

"Effectiveness of spatial visualization training for children with attention difficulties."

James L. Mohler, Principal Investigators & Helen Kang, Co- Investigators
Purdue University, Department of Computer Graphics Technology

Purpose of Research

Some children who have difficulty maintaining attention have difficulty in the field of mathematics, especially in geometry, due to embedded shapes and figures. The purpose of this study is to assess the value of spatial trainings that may assist students' performance in geometry. This research will determine if there is a difference in the students' performance when these training are utilized.

Your child's teacher has volunteered to participate to help us learn more about effectiveness of spatial training. This study does not involve grading your child or talking to the teacher about your child. The person in charge of the activities has training and experiences in the field of computer graphics technology. This study will be used to assist teachers in determining additional ways to help students be more successful in mathematics.

Specific Procedures to be Used

We need your permission to:

(a) Review your child's school records for math test scores, grades, birthday, and past/current record of special services.

(b) Allow your child's teacher to complete an attentional/behavioral rating scale, so we can determine whether there is a difference in response to main interventions for students with differences in attention behavior.

(c) Allow your child to solve mathematic problems before and after they watch instruction presented on a computer screen.

(d) The parents have the right to view all the materials that will be given to the students.

Duration of Participation

- Participation on the students' part will be no more than 30 minutes. Duration of the entire study will be no longer than 1 year and at that time all documents will be destroyed.

Benefits to the Individual

There are no direct benefits to the subject. We cannot guarantee that your child will have any benefits from this study. However, benefits to your child could occur only as she/he might be receiving individual attention and new materials related to geometry. Although *we are not using* students' names and identifying data, you may request to review or have copies of any of the surveys that we are using at any time during or after your child's participation. Benefits to the adults who teach students may occur when teaching in mathematics, which in turn might help your child. In addition, your child will have the opportunity to access new materials related to geometry. The teachers may be able to better help your child in mathematics education.

Initials ______ Date ______

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PURDUE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Research Project Number _0806006948_

Risks to the Individual
The risks are no more than your child would encounter in everyday life.

Compensation
In appreciation, all children with permission and who participate in this study will receive monetary compensation of **five dollars**.

Cost
This research will be conducted as an after school activity. It is the parents' responsibility to pick up their child after the research study activities.

Confidentiality
All information and materials used in this study will be strictly confidential and your child's name will **not** appear anywhere in a published study nor on any records. Numbers will identify students instead of names. The data will be kept in a file cabinet in a locked room (Knoy building Rm. 355 at Purdue University) and will be destroyed within one year after the completion of the study. Furthermore, the project's research records may be reviewed by departments at Purdue University responsible for regulatory and research oversight.

Voluntary Nature of Participation
My child does not have to participate in this research project. If my child agrees to participate he/she can withdraw participation at any time without penalty.

Human Subject Statement:
If you have any questions about this research project, you can contact Dr. James Mohler. This research will be conducted by Helen Kang, under the direction of Sydney S. Zentall, Ph.D., Professor of Educational Studies. If you have any questions about this project, contact Dr. James Mohler at 765/494-9089 or through e-mail: jlmohler@purdue.edu or Dr. Zentall at 765/494-7347 or through e-mail: zentall@purdue.edu. If there are concerns about the treatment of research participants, contact the Committee on the Use of Human Research Subjects at Purdue University, Ernest C. Young Hall, 10th Floor-Room 1032, 155S. Grant Street, West Lafayette, IN 47907-2114. The phone number for the Committee's secretary is 765/494-5942. The email address is: irb@purdue.edu.

I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT.

I ALLOW MY CHILD TO PARTICIPATE IN THIS STUDY.

Signature of Parent / Guardian	Signature of Parent / Guardian
Name (Print) Parent / Guardian	Name (Print) Parent / Guardian
Date	Parent / Guardian Telephone Number

Appendix D: Participant Consent Form

Research Project Number _0806006948__

Attachment D: Student Assent Form

We are doing a research study. A research study is a special way to find out about something

You can be in this study if you want to. You may be asked to solve math problems. Then you will learn something about geometry on a computer for 12 minutes. After that we will ask you to solve other math problems. It will take about 30 minutes altogether.

We want to tell you about some things that might happen to you if you are in this study. You will spend a little time in front of the computer doing simple math problems.

If you decide to be in this study, some good things might happen to you. You will learn a few basics about geometry, which might help you in the future math classes. Your answers may help your teacher know how to help you and students in your class do better in math. But we don't know for sure that these things will happen.

When we are done with the study, we will write a report about what we found. We won't use your name in the report.

You don't have to be in this study. You can say "no" and nothing bad will happen. If you say "yes" now, but you want to stop later, that's okay too. No one will hurt you, or punish you if you want to stop. All you have to do is tell us you want to stop.

If you want to be in this study, please sign your name.

I, ___________________________________, want to be in this research study.
(Write your name here)

Participant's Name____
Investigator's signature ______________________________________
(Date)

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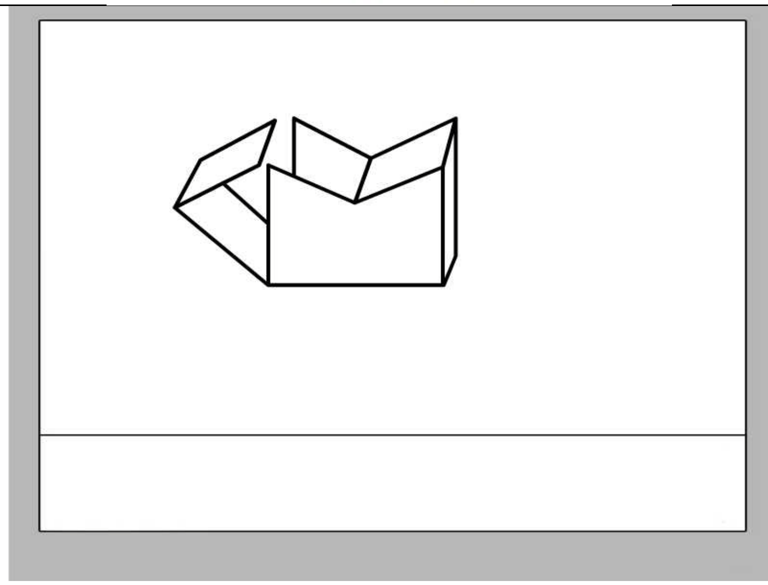
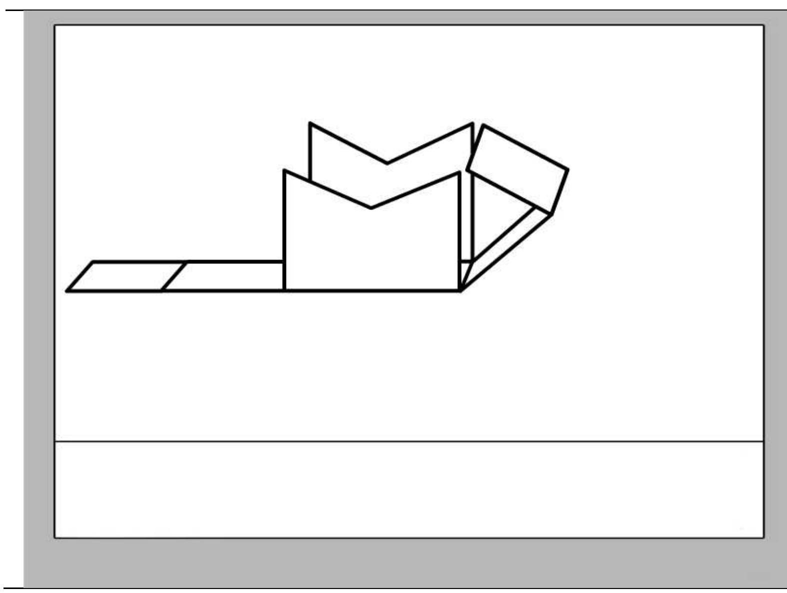
Appendix E: Dynamic Tutorial – Paper Folding Example

Tutorial One

START

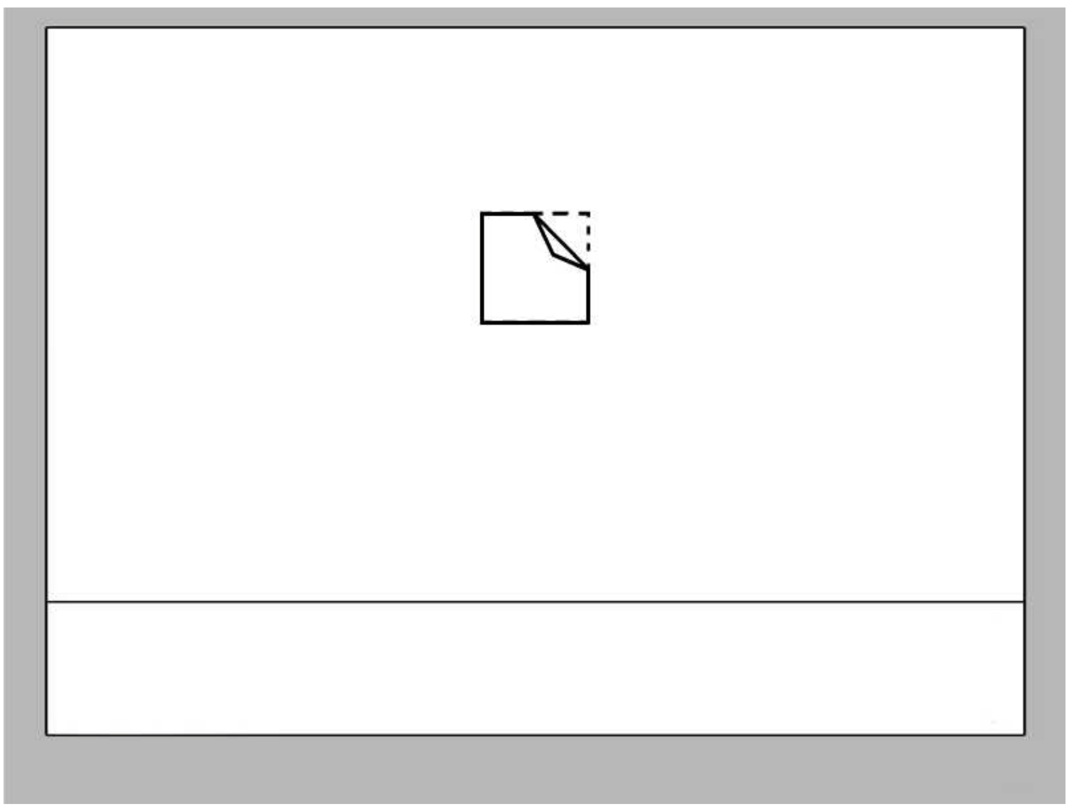


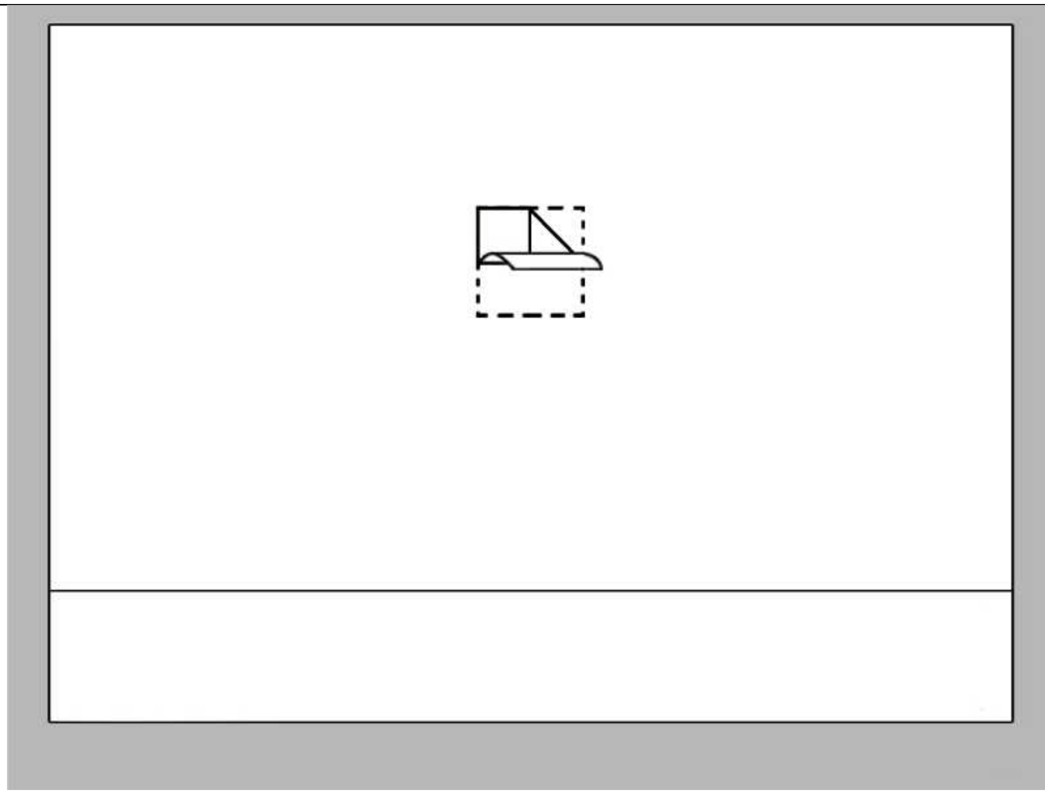


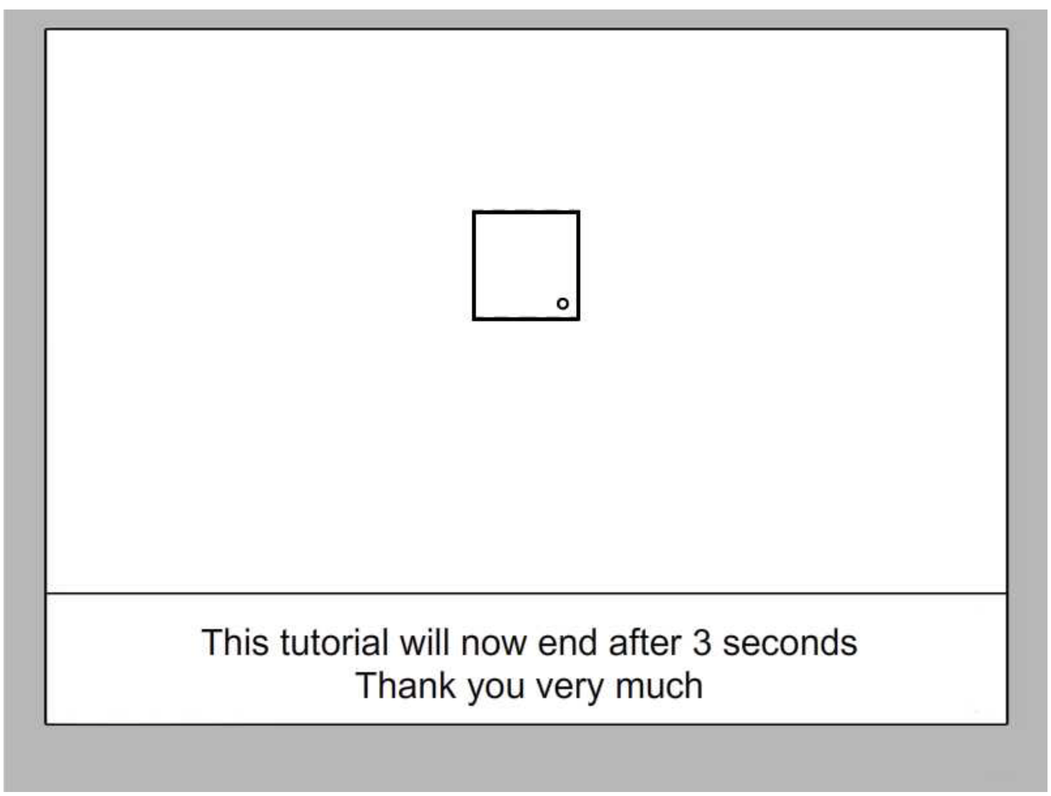
Appendix F: Dynamic Tutorial – Surface Development Example

Tutorial Two

START



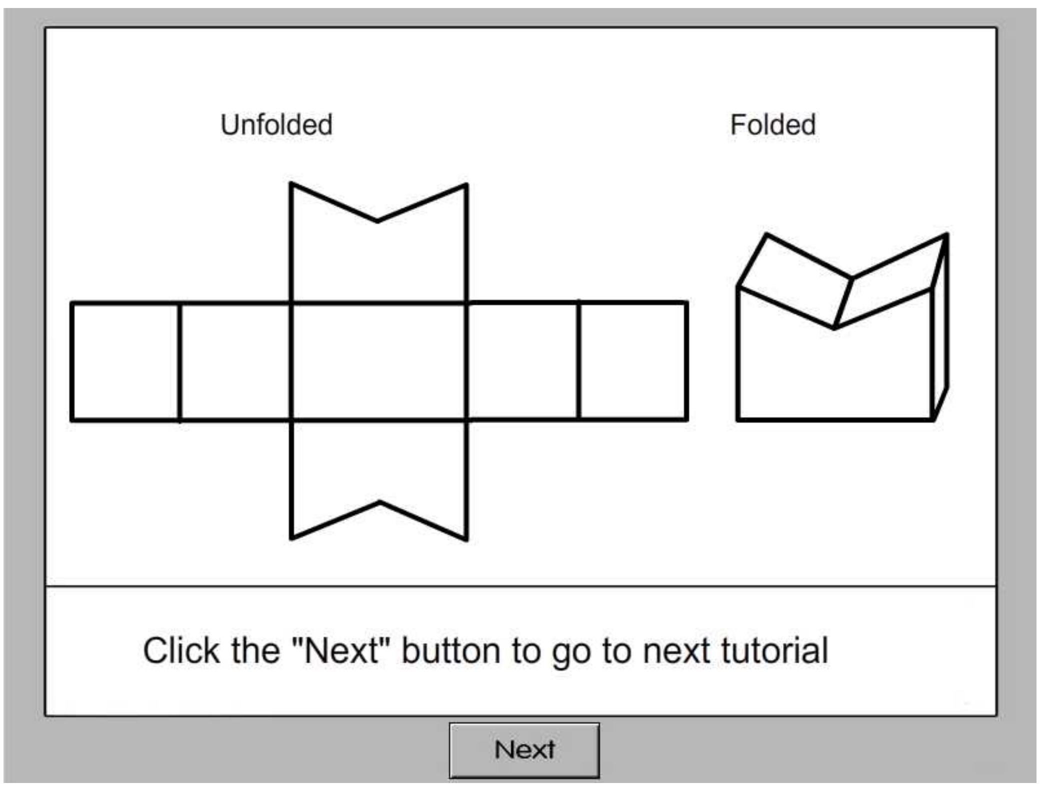



This tutorial will now end after 3 seconds
Thank you very much

Appendix G: Static Tutorial – Paper Folding Example

Tutorial One

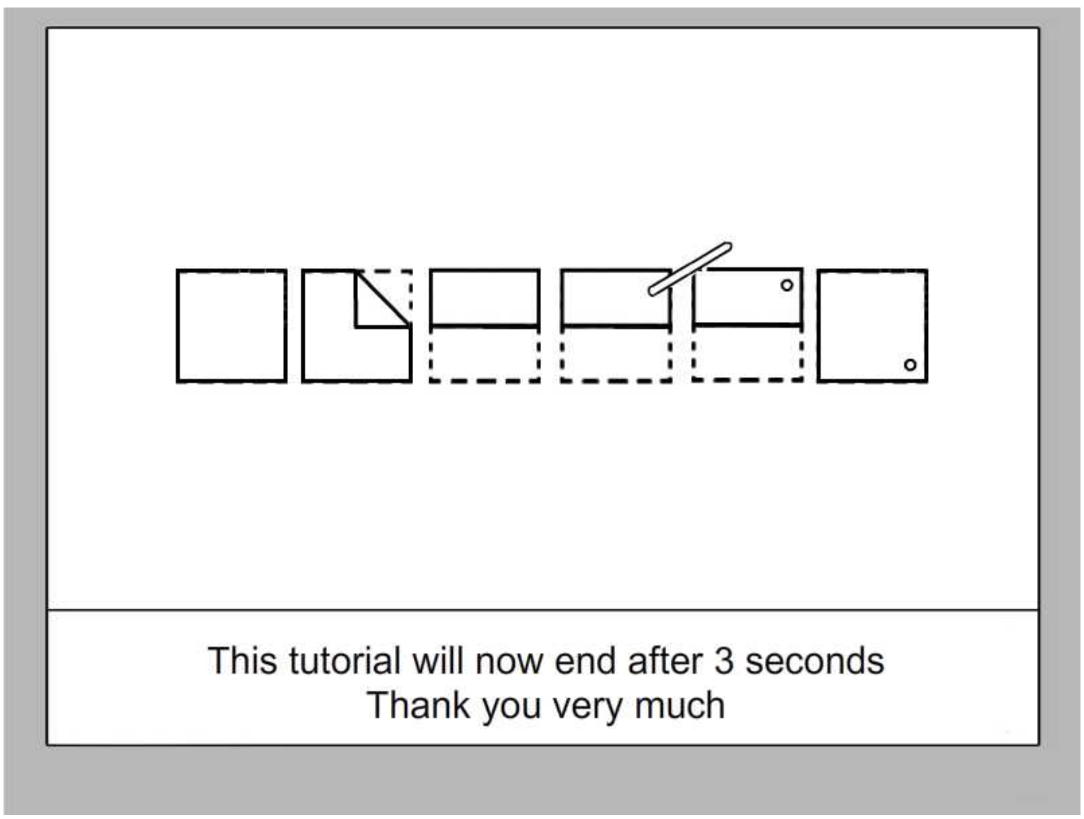
START



Appendix H: Static Tutorial – Surface Development

Tutorial Two

START

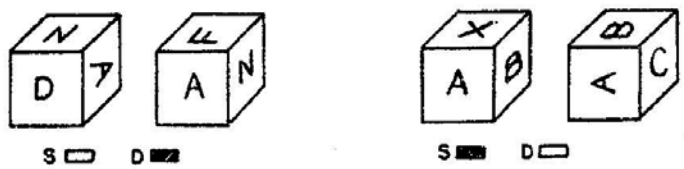


Appendix I: Cube Comparison Test

Name ____

CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.

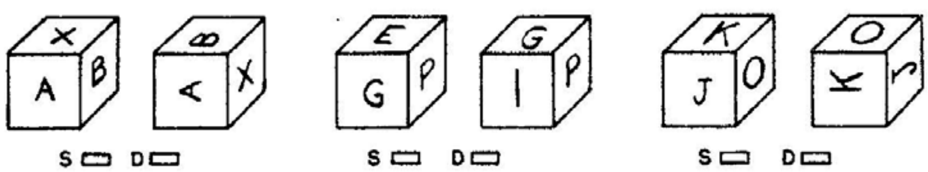


The first pair is marked D because they must be drawings of <u>different</u> cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

<u>Note</u>: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, <u>any</u> letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.



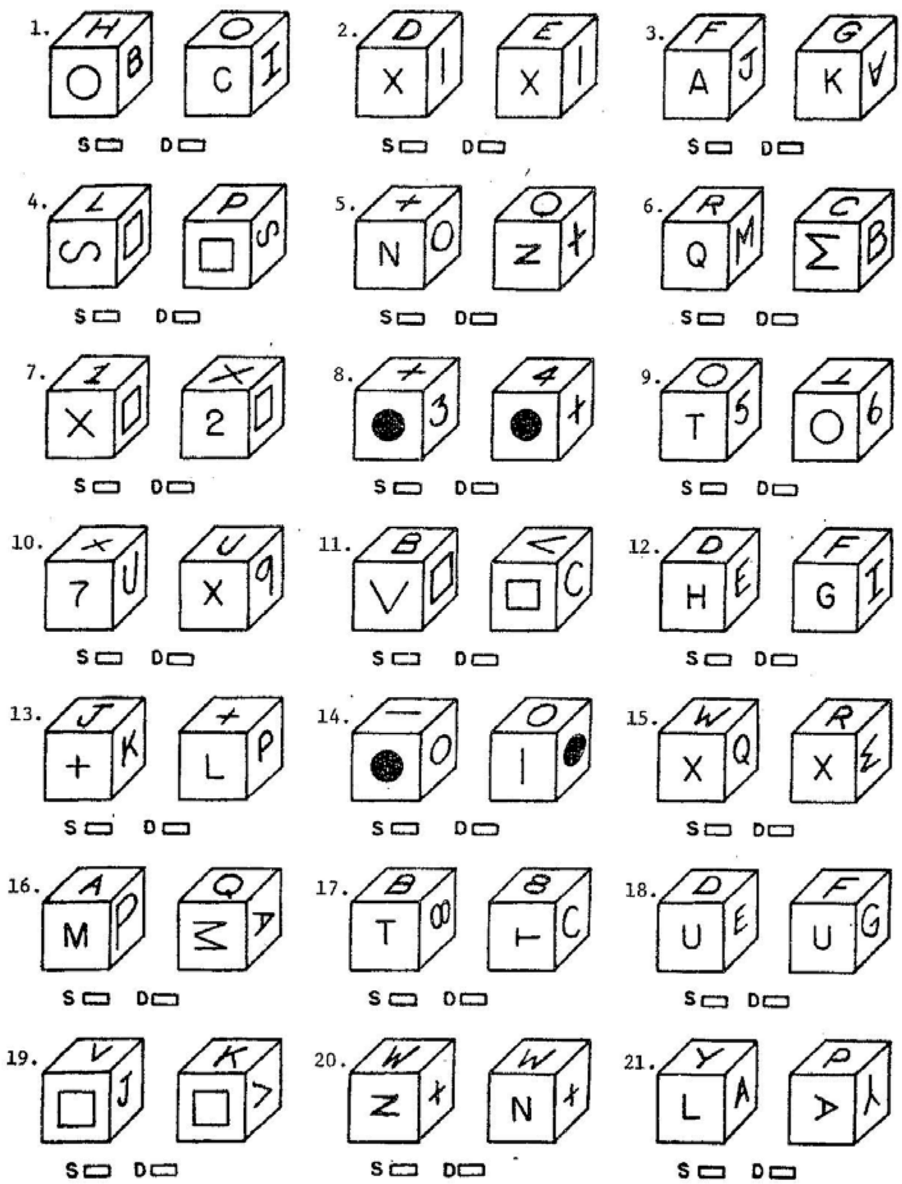
The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because P has its side next to G on the left hand cube but its top next to G on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will <u>not</u> be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have <u>3 minutes</u> for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

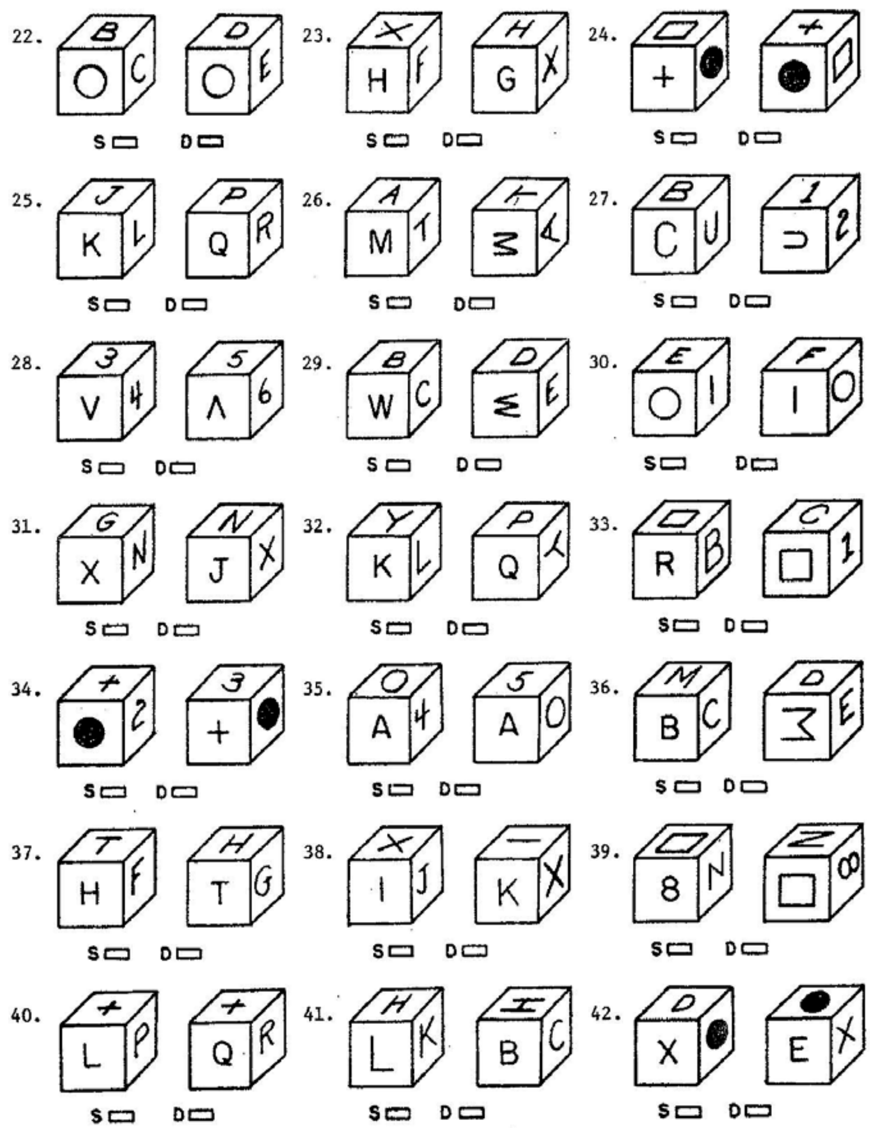
DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.

Part 1 (3 minutes)



DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO. STOP.

Part 2 (3 minutes)



DO NOT GO BACK TO PART 1 AND

DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO. STOP.

Appendix J: Paper Folding Test

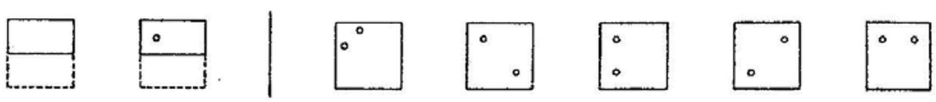
Name ____

PAPER FOLDING TEST — VZ-2

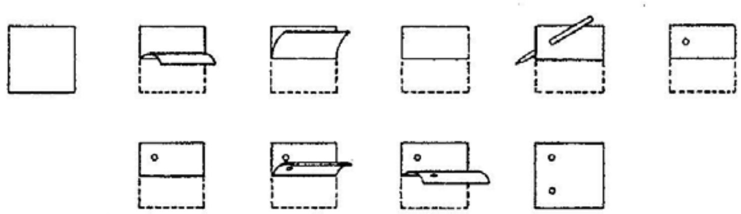
In this test you are to imagine the folding and unfolding of pieces of paper. In each problem in the test there are some figures drawn at the left of a vertical line and there are others drawn at the right of the line. The figures at the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched. Each hole is punched through all the thicknesses of paper at that point. One of the five figures at the right of the vertical line shows where the holes will be when the paper is completely unfolded. You are to decide which one of these figures is correct and draw an X through that figure.

Now try the sample problem below. (In this problem only one hole was punched in the folded paper.)

A B C D E



The correct answer to the sample problem above is C and so it should have been marked with an X. The figures below show how the paper was folded and why C is the correct answer.



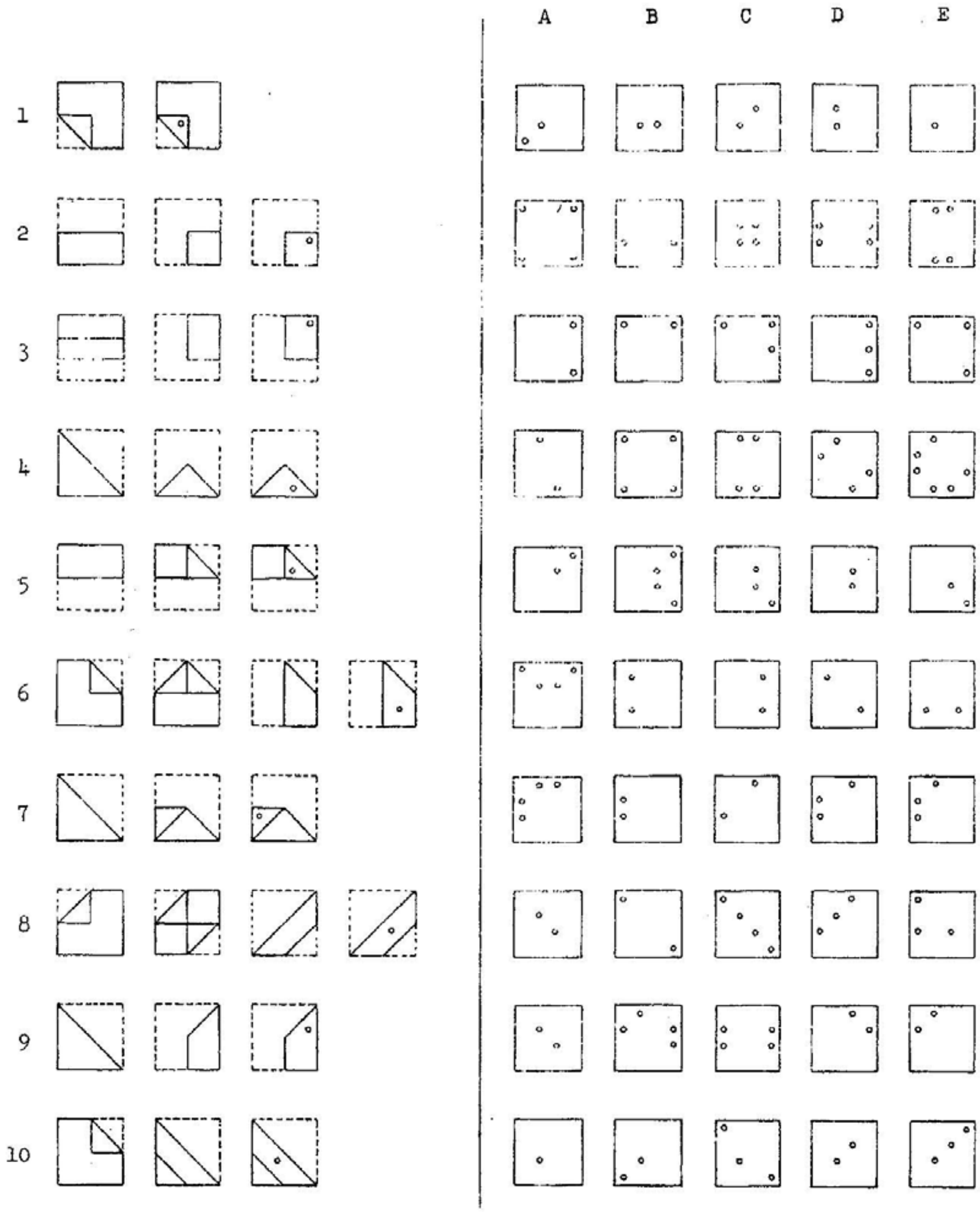
In these problems all of the folds that are made are shown in the figures at the left of the line, and the paper is not turned or moved in any way except to make the folds shown in the figures. Remember, the answer is the figure that shows the positions of the holes when the paper is completely unfolded.

Your score on this test will be the number marked correctly minus a fraction of the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

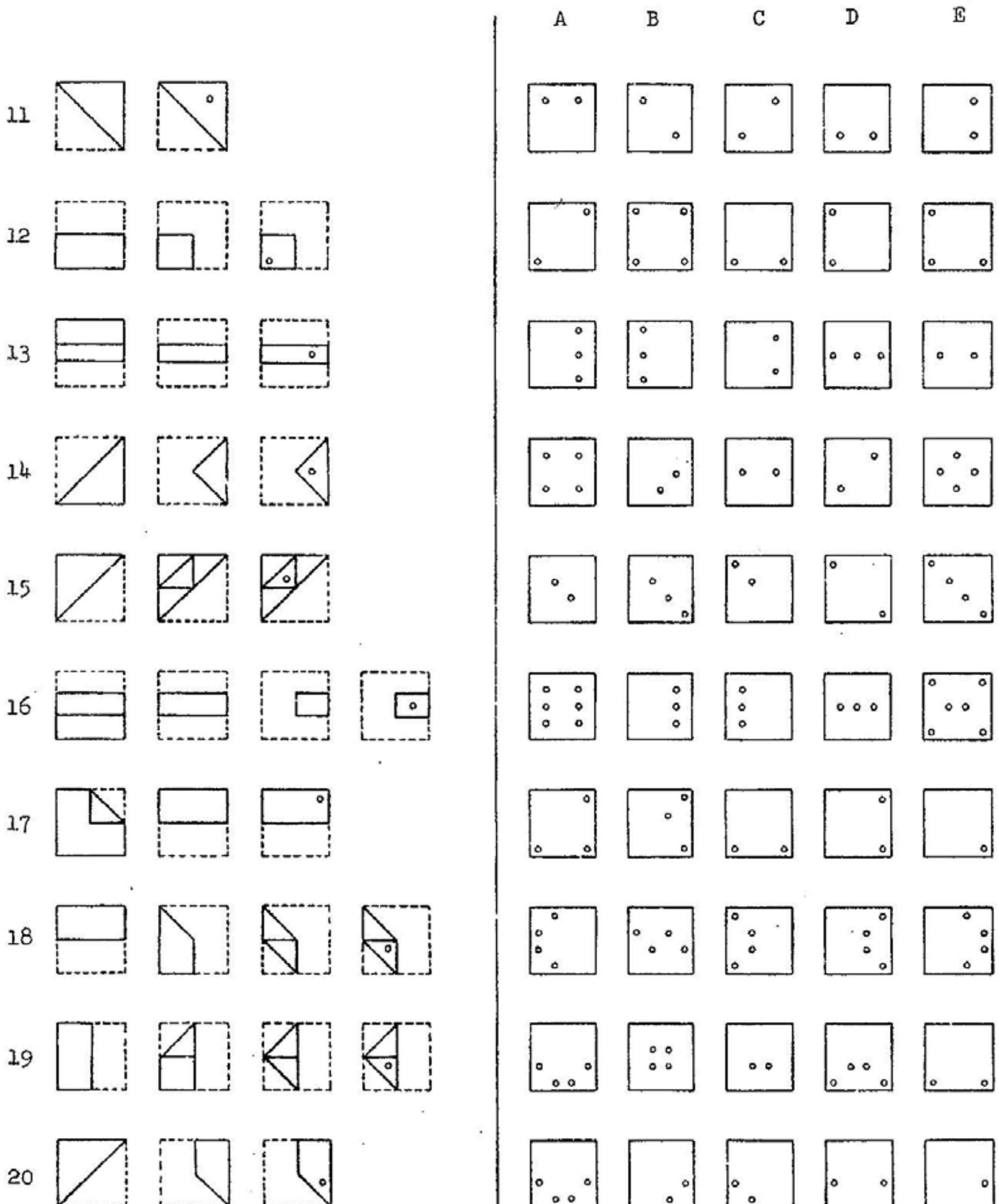
Part 1 (3 minutes)



DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO.

STOP.

Part 2 (3 minutes)



DO NOT GO BACK TO PART 1, AND

DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO. STOP.

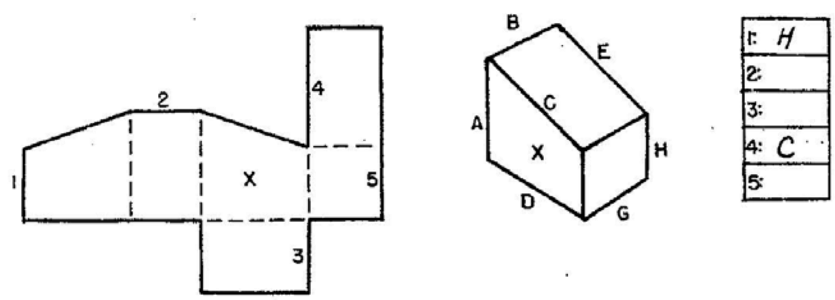
Appendix K: Surface Development Test

Name ____

SURFACE DEVELOPMENT TEST — VZ-3

In this test you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is of a piece of paper which can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.



NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.

In the above problem, if the side with edge 1 is folded around to form the back of the object, then edge 1 will be the same as edge H. If the side with edge 5 is folded back, then the side with edge 4 may be folded down so that edge 4 is the same as edge C. The other answers are as follows: 2 is B; 3 is G; and 5 is H. Notice that two of the answers can be the same.

Your score on this test will be the number of correct letters minus a fraction of the number of incorrect letters. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

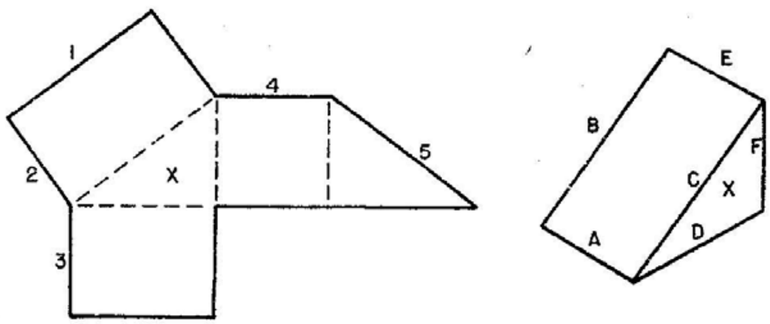
You will have 6 minutes for each of the two parts of this test. Each part has 2 pages. When you have finished Part 1 (pages 2 and 3), STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Page 2

Part 1 (6 minutes)

1



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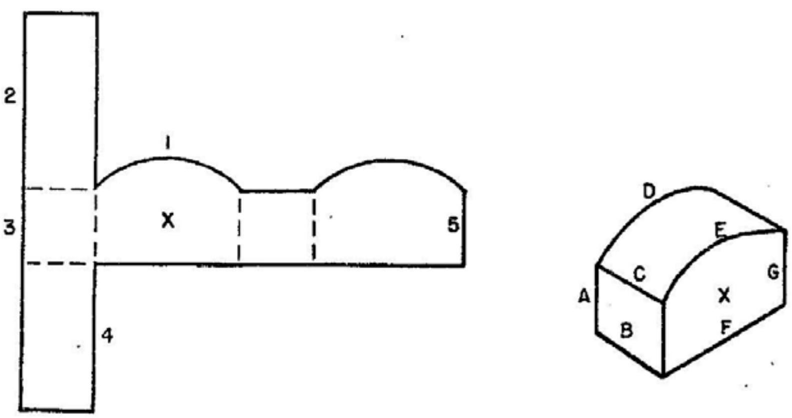

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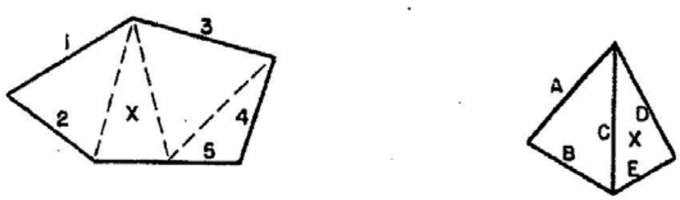

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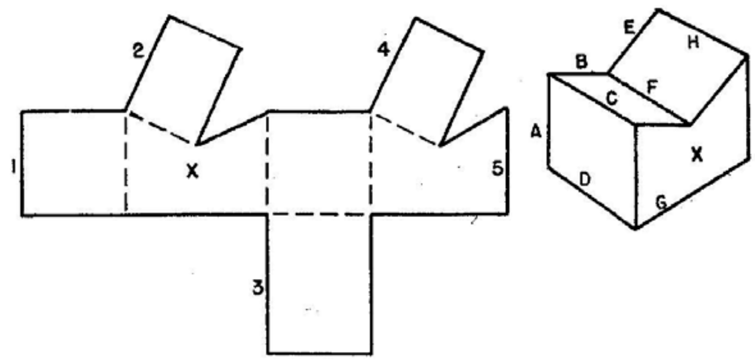
Part 1 (continued)

4



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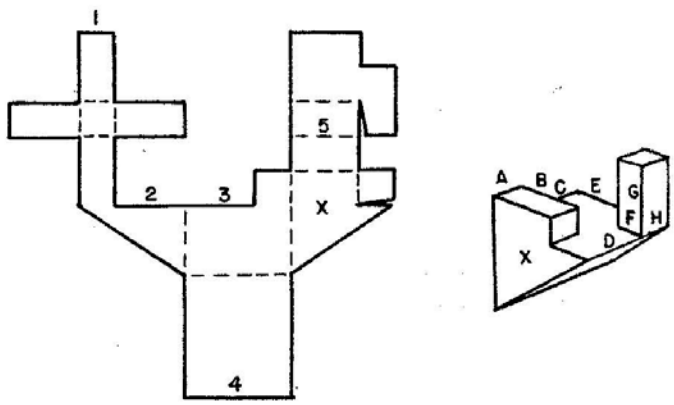

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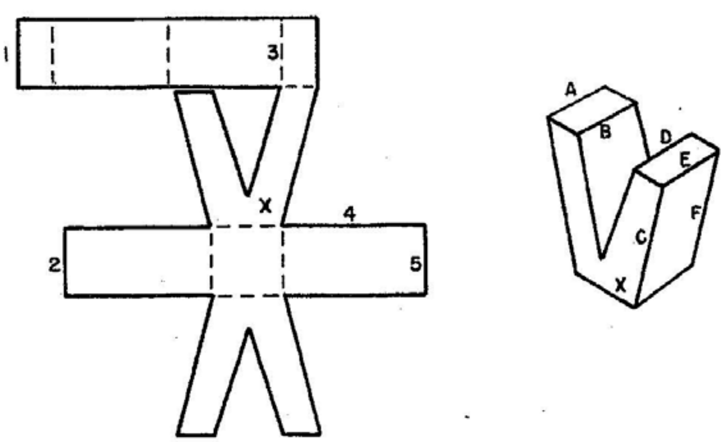

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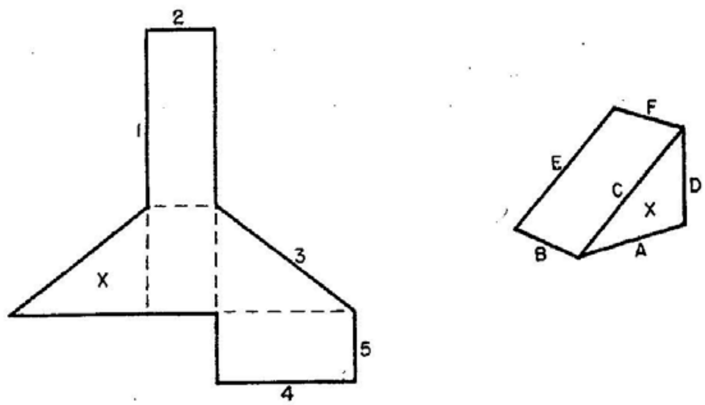
DO NOT GO ON TO THE NEXT PAGE UNTIL ASKED TO DO SO. STOP.

Page 4

Part 2 (6 minutes)

7



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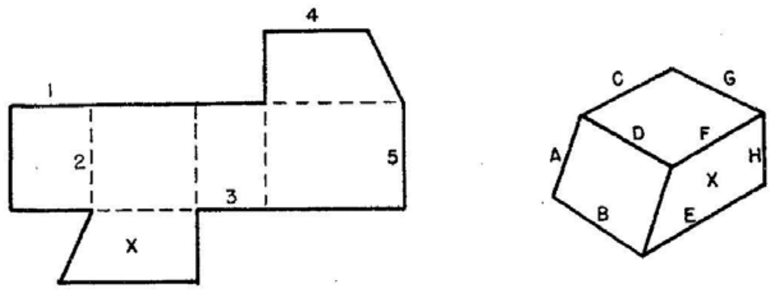

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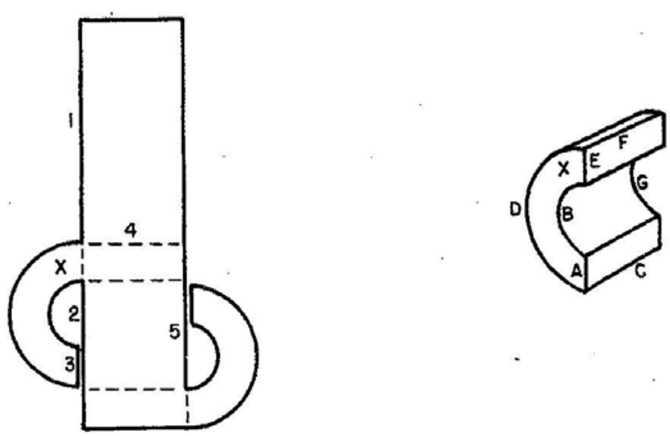

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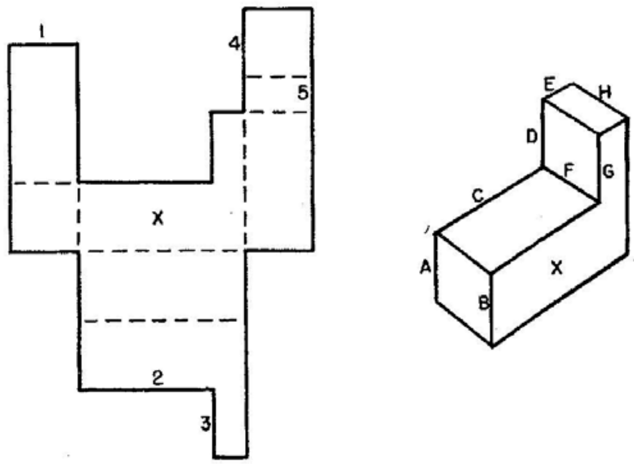
Part 2 (continued)

10



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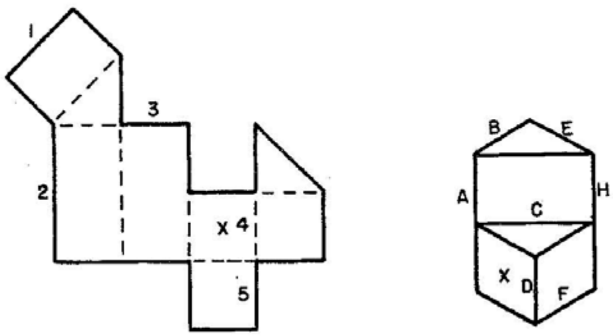

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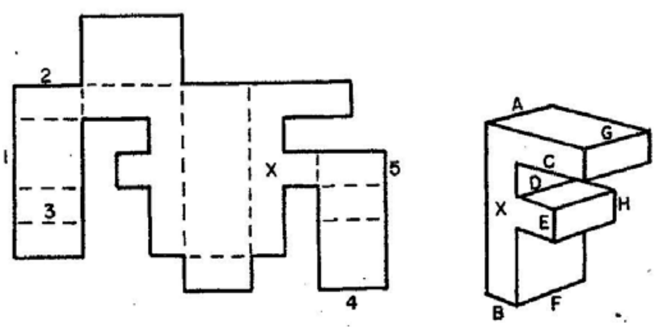

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DO NOT GO BACK TO PART 1, AND

DO NOT GO ON TO ANY OTHER TEST UNTIL ASKED TO DO SO. STOP.

VITA

VITA

Helen W. Kang

Office
Department of Computer Graphics Technology
Purdue University
Knoy Hall, 355
401 N. Grant Street
West Lafayette, IN 47907
Tel: (765) 494-8379

Home
838 ½ Judson Ave. 2B
Evanston, IL 60202
Tel: (765) 532-9369
E-mail: kangwy@purdue.edu

EDUCATION

Ph.D in Technology, Department of Computer Graphics Technology, Purdue University, West Lafayette, IN. Major field: Computer Graphics Technology. Minor field: Instructional Technology & Special Education. Research interests: Human Computer Interaction (HCI), user interface analysis, children with disabilities, visual perception, cognitive psychology, assistive technology development, spatial ability. Dissertation: *Effectiveness of Spatial Visualization Training for Children with Attention Deficit Hyperactive Disorder (ADHD)*. Chair: Dr. James Mohler & Dr. Patrick Connolly. **May, 2010.**

Master of Science, Department of Computer Graphics Technology, Purdue University, West Lafayette, IN. Specialization: Instructional Design, Special Education, Assistive Technology, Computer Graphics. Master's Thesis: *Effectiveness of Images in Mathematics for 2nd to 4th Grade Students With and Without Attentional Problems.* May, 2007.

Bachelor of Science, Department of Computer Graphics Technology, Purdue University, West Lafayette, Specialization: Animation. May, 2004.

PUBLICATIONS

Journals

Kang, H. W., Wright, A., Mohler, M., Watts, T., Barry, G. & Mohler, J. L. (In review). The effect of mental visualization on performance: A correlation study with collegiate swimmers. *Athletic Insight: The Online Journal of Sport Psychology.*

Kang, H. W. & Zentall, S.S. (In review). Computer-Generated Geometry Instruction for Students with and without Hyperactive and Inattention: A Preliminary Study. Journal of Mathematics Education

Proceedings (with presentation)

Kang, H. W. & Mohler, J. L. (April, 2009). Developing a Computer-based Spatial Assessment and Intervention Software for Learners with Attentional Problems. *2009 Annual Teaching and Learning Technologies Conference*, Purdue University, West Lafayette, IN.

Kang, H. W. (April, 2009). *Integration of Spatial Ability Training in 7th grade Math Curriculum.* National Science Foundation GK-12 Regional Meeting, Purdue University, West Lafayette, IN.

Kang, H. W., Mohler J. L., & Zentall, S. (March, 2009). The effectiveness of a spatial assistive technology training tool for children with ADHD. *Proceedings of the Society for Information Technology & Teacher Education International Conference*, Charleston, SC.

Kang, H. W. (March, 2007). Effectiveness of Images in Interactive Technology for Children with
Attentional Difficulties., *Graduate Student Scholarly Conference*, Purdue University, Hammond, IN.

Kang, H. W., Zentall, S., & Burton, T. (June 2007). Use of Images in Interactive Technology for Children with Attentional Difficulties., *Interaction Design and Children Conference 2007,* Aalborg, Denmark.

Li, J., Doyle, J., Kang, H. W., & Studach, L. (March 2010). Boiler Up: International Collaboration Research and Inquiry Learning in China. *National Science Foundation Conference 2010,* Arlington, VA.

Poster-Sessions (with presentation)

Kang, H. W. (2009, February). *How do you texture an animated character: Inquiry Based Geometry Lesson.* Poster session presented at the annual meeting of the Hoosier Association of Science Teachers, Inc. Indianapolis, IN.

Kang, H. W. (2009, March). *Effective use of graphics in spatial visualization training for students with and without ADHD.* Poster session presented at the Annual National Science Foundation, Arlington, VA.

Kang, H. W. & Brodman, J. (2009, April). *Sweetness in the Air- Integration of spatial ability training in math curriculum.* Poster session presented at the National Science Foundation GK-12 Regional Meeting, West Lafayette, IN.

Kang, H.W. & Brodman, J (2009, March). *Understanding spatial relationship to calculate surface area and volume of 3D solid figures.* Poster and Lesson Sharing session presented at the Annual National Science Foundation, Arlington, VA.

Works In Progress

Kang, H.W. Effective use of spatial training tool for students with ADHD.

Kang, H.W. & Burton, T. Use of Animation as an Edutainment in Assisting Children with Stuttering.

Kang, H. W. & Mohler, J. L. A Qualitative Study Examining the Spatial Ability Phenomenon from the Chinese Student's perspective.

Kang, H. W., & Mohler, J. L. Validating the Purdue Spatial Visualization of Rotations Test in China.

RESEARCH EXPERIENCE

Visiting Researcher – Harbin Institute of Technology, China & Purdue University
Evaluated and compare students in China's spatial ability from the students in United States. (Present)

NSF GK12 Fellowship Program – Visiting Scientist.
Investigated the implementation and effectiveness of Inquiry Based Learning. Appointed as a Visiting Scientist at Tecumseh Middle School. Designed, administered and assessed the new mathematic curriculums. (2008- Present).

Research Co-Investigator/Coordinator (2009)
Investigated Athletes visualization ability to their performance.

Behavior Observation Team Director (2006)
Coordinator and Director of Behavior Observation Team for the Research Project, *Effective Use of Images in Mathematics Instruction for Students and Without Attentional Problems*.
Responsible for Recruitment and Training Observers.
Behavior Observation Data Analyses Expert.

HONORS AND AWARDS

Bilsland Dissertation Fellowship – Awarded $18,000/year (2009-2010)
NSF GK12 Fellowship – Awarded $30,000/year (2008-2009).
Digital Learning Content (DLC) - Awarded $15,000 (2008-2009).
2007 NAIT Foundation Clois Kicklighter Doctoral Scholarship – Awarded $2500 (2007).
Sriver Graduate Student Scholarship – Awarded $500 (2007).
Service Learning Grant – Awarded $1500 (2007).

Outstanding Graduate Student (2009) – Awarded $100
Graduate School Excellence in Teaching Award Nominee (2009)
Teaching Academy Fellow (2009)
Outstanding Graduate Teaching Assistant (2007).
SIGGRAPH Annual Outstanding Graduate Teaching Assistant (2007).

PROFESSIONAL ACTIVITIES

2009-2010 Member of Hoosier Association of Science Teachers, Inc.
2009- Member of Purdue University Teaching Academy
2004-2007 Member, Association of Computing Machinery Special Interest Group on Graphics and Interactive Techniques

COLLEGE TEACHING EXPERIENCE

Lab Instructor (approximately 80 and more students each semester)

Spring 2005 to Spring 2007	Sketching for Visualization and Communication
Fall 2007	Raster Imaging for Computer Graphics
Spring 2008	Contemporary Problems in Applied Computer
Spring 2008	The Applied Computer Graphics Professional Life Cycle
Summer 2008	Internet Foundation Technology & Development
Fall 2008 to Spring 2009	Vector Imaging for Computer Graphics

Lecturer
Present	Vector Imaging for Computer Graphics

INVENTION/CREATIVE WORKS

Digital Spatial Visualization Training Instrument
Developed for ***Effectiveness of Spatial Visualization Training for Children with and without ADHD***.
Software used – Adobe Flash, Adobe Photoshop CS3 & Illustrator CS3

Computer Assisted Instruction Software Design for
Research of Effectiveness of Images for Children and Children with Attentional Difficulties
Software used – Macromedia Flash, Adobe Photoshop CS2 & Illustrator CS2, Alias Maya 7
Permission obtained from Saxon Publishers Inc. to use their text materials.
Hake, S. & Saxon J., (2004). *Saxon Math 5/4, Third Edition Teachers Manual.* Austin, TX: Saxon Publisher Inc.

Computer Aid instruction for CGT 112 students ***Flash Tutorial***
Software used – Macromedia Flash, Macromedia Freehand, and Camtasia Studio

Stuttering Foundation of America DVD, Stuttering for Kids by Kids
Distributed public libraries over United States
Streaming on-line (http://www.stutteringhelp.org/)
Software used – Alias Maya 7.0, Adobe Photoshop CS2 and Adobe AfterEffects

SERVICE & OUTREACH ACTIVITIES

Aug 2009 – Dec 2009	**Sponsor: CGT Senior Project.** Assisted undergraduate students developing experimental research project. Specialized in ethics, procedure and evaluation of research study.

October 2009	**GK-12 Inquiry Learning Expert**. NSF selected 4 Ph.D students from Purdue University and invited them to Nanjing, China to implement Inquiry learning method

Summer 2006-2008	**CGT Summer Camp.** Assisted with the annual summer camp for the Department of Computer Graphics Technology CGT 2006-08. Instructed on the use of Adobe Photoshop for camp members.

Summer 2008	**Cheerleading Camp.** Photoshop Demonstration.
Summer 2007	**Instructor for TAGS** (Technology Advancing Girls Scouts) Camp Instructed on the use of Adobe Photoshop for camp members.
Fall 2006	**Sponsor: CGT Senior Project**. Assisted and directed the development of a Purdue University CGT senior project intended to redesign the website for the School of Special Education at Purdue University.