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WHAT IS THE EFFECT OF REAL VERSUS AUGMENTED MODELS FOR THE ADVANCEMENT OF SPATIAL ABILITY BASED ON HAPTIC OR VISUAL LEARNING STYLE OF ENTRY-LEVEL ENGINEERING GRAPHICS STUDENTS?

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For the degree of Master of Science

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For my family, especially my parents, Janet and Jack Huffman, for always believing in me and pushing me to do my best in everything I do. It is also for Lucky and Molly.

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ABSTRACT

Huffman, Katie L. M. S., Purdue University, December 2011. What is the Effect of Real Versus Augmented Models for the Advancement of Spatial Ability Based on Haptic or Visual Learning Style of Entry-Level Engineering Graphics Students? Major Professor: Dr. Craig L. Miller.

This research study conducted during the Fall Semester of 2011 at Purdue University compared the use of augmented reality and real blocks instructional methods, for advancing spatial abilities in students of different learning styles (visual/haptic). This study implemented augmented reality and real models as visualization aids for first year engineering students enrolled in an entry level engineering graphics course. This thesis presents the significance of this research study, the research methodology, and the statistical findings. The results of the study conclude that there is no significant interaction between learning style of visual or haptic and instructional method of augmented reality or real blocks. This result infers that either instructional method would aid students in advancing visualization skills equally. This thesis suggests future studies and applications for the integration of both augmented and real models as visualization aids to advance the spatial abilities of introductory engineering students.

CHAPTER 1. INTRODUCTION

Spatial ability and spatial skills are important competences for engineering students. Research shows that in fields of science and engineering, students' development of spatial abilities aids in their performance (Nordvik & Amponsah, 1988). There is a link between spatial ability and STEM (science, technology, engineering, and math) programs and occupations. Students that have high spatial ability do better in engineering and science. Likewise, students who have low spatial ability have a harder time in these subjects. Having a good understanding of concepts found in the STEM programs has a lot to do with having high spatial abilities (Sorby, 2009).

Learning styles are imperative to how students learn in and outside the classroom (Veurink, Hamlin & Kampe, 2009). This study focuses on two learning styles: haptic and visual. Haptic learning style is learning through tactile feel and touch. Visual learning style is learning through seeing and visualizing (Study, 2001). This study tries to determine the advancement of spatial abilities with learning style and engineering graphics.

Engineering graphics is a field where rotations, visualization, and spatial relations of mechanical parts and products are described through engineering drawings and 3D computer-aided design (CAD) models. Engineering graphics requires high levels of spatial ability. Advancing spatial skills in introductory engineering students can be beneficial to them in both their academic and professional careers. One method of advancing their skills through engineering graphics courses is exposure and repeated practice. Certain exercises in engineering graphics can enhance spatial abilities in students such as describing objects in different views (Mohler & Miller, 2008; Sorby, 2009).

This study utilized isometric cut-block images that were coupled with an augmented reality cut-block or real cut-block that is a replica of the object. Students were asked to sketch the front, top and right side views of cut-block objects on an orthographic grid. Construction of orthographic views from cut-block objects are one method for validating whether augmented reality or real block instructional methods help advance spatial ability (Miller, 1992). The creation of orthographic views from cut-block objects can be considered as one indicator if how instructional approaches could help engineering students to advance their spatial abilities based on their learning style. More of the methodology is discussed in Chapter 3.

1.1. Statement of Problem

The problem that this study addressed is how to advance students' spatial abilities depending on whether they are visual or haptic learners. Currently, spatial abilities are taught through engineering graphics courses, but learning style may not be considered in the instructional delivery. Students that do not possess advanced visual abilities might struggle with the abstract approaches of traditional engineering graphics curricula. The purpose of this study was to help determine whether learning with real or augmented reality blocks would aid in advancing the spatial abilities of engineering students, based on the learning style of visual or haptic.

1.2. Research Question

What is the effect of real versus augmented models for the advancement of spatial ability based on haptic or visual learning style of entry-level engineering graphics students?

1.3. Scope

The scope of this study evaluated first and second year engineering students at Purdue University. Specifically, students that were enrolled in CGT 163, *Introduction to Engineering Graphics* participated in the study. These subjects were undergraduate students that were enrolled in the mechanical or aerospace engineering programs. All students enrolled in CGT 163 were able to voluntarily participate in this study.

1.4. Significance

The significance of this study was to build upon and advance spatial ability research with engineering students based on their learning style with the goal of advancing their spatial abilities. The research has shown that advanced spatial ability is necessary and a vital for success in engineering graphics and engineering education in general (Mohler & Miller, 2008; Sorby, 2009). This study addressed if different types of blocks aided in advancing visualization skills in engineering students focusing particularly on the learning style of the students. This focus allowed the researcher to develop conclusions and recommendations about using certain types of visualization aids in the classroom, which is discussed in Chapter 5.

1.5. Definitions

- Augmented reality- "three dimensional virtual objects are integrated into a three-dimensional real environment in real time" (Azuma, 1997).
- Engineering/technical graphics- "the total field of problem solving, including two major areas of specialization, descriptive geometry, and working drawings" (Earl, 1987).
- Haptic learning style- "a normal-sighted person who prefer to orient him/herself to the world of experience through touch, bodily feelings, muscular sensations, and kinesthetic fusions" (Lowenfield, 1945).
- Orthographic Projection- "the projection system that engineers use of manufacturing and construction drawings" (Luzadder & Duff, 1989).

- Real model- “a physical object that replicates a line drawing or scaled version of an actual object” (Miller, 1992).

- Spatial Ability-“individual differences used in the processing of non-linguistic information… [or] individual differences in performance on spatial tests” (Elliot & Smith, 1983).

- Spatial Cognition- “the spatial feature, properties, categories, and relations in terms of which we perceive, store, and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations” (Olson & Bialystok, 1983).

- Spatial Orientation- “involving the comprehension of arrangement of elements within visual stimulus pattern” (McGee, 1979).

- Spatial Visualization- “the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli” (McGee, 1979).

- STEM- “Science, Technology, Engineering, and Math programs” (Griffith, 2010)

- Visual learning style- “a normal-sighted person who depends on his/her eyes as a primary intermediary in perception” (Lowenfield, 1945).

1.6. Assumptions

Assumptions for this study were:

- Students in the sample did the best of their abilities on the assignments.
- Students in the sample were honest and did not help each other with the assignments.
- Students enrolled in CGT 163 at Purdue University are a representative sample of engineering students in the United States.
- The Purdue Spatial Visualization Test was a valid test of visual ability.
- The Haptic/Visual Discrimination Test was a valid test of visual/haptic learning style.

1.7. Limitations

Limitations for this study were:

- The number of students enrolled in CGT 163 at Purdue University.
- The cooperation of students within the study.
- The amount of time available in CGT 163 to administer the discrimination tests.

1.8. Delimitations

Delimitations for this study were:

- The use of real and augmented reality blocks as instructional method as the experimental treatment.
- The use of the Purdue Spatial Visualization Test to determine the high or low visual abilities.
- The use of Haptic/Visual Discrimination Test to determine visual or haptic learning style within each instructional treatment group.

1.9. Summary

In summary, this study targeted students of CGT 163 *Introduction to Engineering Graphics*. They were mostly sophomores in mechanical, aeronautical, and first year engineering at Purdue University. This study utilized augmented reality and wooden cut-blocks. It aimed to help understand different ways of developing spatial abilities in students based on their learning style. The research focused only on visual and haptic learning styles. Students who learn visually typically have an advantage over students who are designated as haptic learners, because in most classroom settings especially in engineering graphics, the content material is visual. This study aimed to discover if different instructional methods for advancing spatial abilities in engineering students made a significant difference in their scores on a cut-block activity. This study also focused on different types of learning styles including visual and haptic learners, to determine if certain instructional methods were more or less helpful for certain learners.

CHAPTER 2. LITERATURE REVIEW

This study analyzed different instructional methods to advance spatial abilities using engineering graphics, for students possessing different learning styles (visual and haptic). The literature review defines and explains spatial abilities, including the history, cognition, developmental theories, learning and training, and spatial tests. The literature review also defines engineering graphics, and explains the history, education, and relates engineering graphics to spatial ability. Learning styles of visual and haptic are described. Since augmented reality is a factor in this study, thus it is defined and explained. Examples are given of augmented reality uses in education.

2.1. Spatial Abilities

Spatial abilities and spatial tasks are an essential part for succeeding in STEM (science, technology, engineering, and math) programs. Spatial ability has been defined many different ways by many different researchers over the years. Eliot and Smith (1983) define it as, "individual differences used in the processing of non-linguistic information… [or] individual differences in performance on spatial tests." According to Lohman (1988), spatial ability can be broken down into three main factors: visualization, spatial orientation, and spatial relations.

Different researchers have used the definitions of these terms interchangeably (McGee, 1979; Thurstone, 1950; Lohman, 1988). McGee (1979). Defines visualization as “the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli” (p. 3). Spatial orientation is defined as, “involving the comprehension of arrangement of elements within visual stimulus pattern” (McGee, 1979, p.3).

The following section of the literature review explores the history of spatial ability research, explaining the key researchers and their theories. The second section, spatial cognition, explains spatial abilities and individual differences. Developmental theories explain different theories on how spatial abilities are developed including evolution theories and Piaget theories. Additionally, a section on learning, training, and experience, answers the question of whether spatial abilities are an inherit factor or a factor that can be learned. Finally, the last section touches on different spatial tests, why they are given, and what they test.

2.1.1. History of Spatial Ability Research

Spatial ability research can be split into four phases: pioneering era, defining era, paper and pencil era, and technology era (Mohler, 2011). The first, the pioneering era, is when researchers acknowledged there was some kind of spatial factor related to intelligence. The first scientist to acknowledge this factor was Galton (Eliot & Smith, 1983). He is famous for composing the “breakfast table experiment.” He was interested in the “imagery factor” and wanted to understand the process of spatial visualization (Eliot & Smith, 1983, p.1). Galton focused on visualization, and how close the mind’s imagination is to reality.

Still in the first phase, Spearman developed a two-factor intelligence test in 1904. The two-factor intelligence test had a “G” Factor and an “S” Factor. The “G” Factor was those factors that were general ability. “Factor ‘G’ represented that which a test had in common with all other tests of ability” (Eliot & Smith, 1983, pp.1-2). “Factor ‘S’ represented specific abilities (e.g. spatial) which were assumed to be peculiar to each test” (Eliot & Smith, 1983, p.2).

Spatial testing and acknowledgement developed out of intelligence testing. As intelligence tests began to develop, some researchers noticed there were other factors that affected intelligence that were non-language. Non-language tests, composed of tasks like wire bending, tapping, object assembly, foam board test, or picture completion, were slow to be accepted as intelligence testing and there was some controversy over them (Eliot & Smith, 1983; Lohman, 1988).

In 1935, El Koussy made and administered new spatial tests. After his study, he concluded, “that there was no evidence for a group factor running through the whole field of spatial perception,” but he did find a group factor he called “K” (Eliot & Smith, 1983, p.3). El Koussy’s “K” Factor represented “the ability to obtain and the facility to utilize visual spatial imagery” (Eliot & Smith, 1983, p.3). This was the first time a researcher looked for evidence for the existence of a group factor of spatial ability in which a variety of spatial tests were used (Eliot & Smith, 1983; El Koussy, 1935).

In the United States, Kelley found evidence for a statistical factor that involved “sensing and retention of visual forms” (Eliot & Smith, 1983; Kelley, 1928). This differed from another factor that “required the manipulation of spatial relations” (Eliot & Smith, 1983; Kelley, 1928). These two factors that Kelley found are important because they imply that spatial ability is more than just “the facility to manipulate spatial imagery” (Eliot & Smith, 1983, p.3).

Another researcher, Thurstone, compiled a multiple-factor methodology that allowed a researcher “to discover statistically the number of factors present in a matrix of correlations among tests” (Eliot & Smith, 1983, p.4). After doing large-scale study of college graduates, he discovered thirteen spatial factors, and labeled nine of them (Thurstone, 1950).

The second era, known as the defining era started in about 1941 and continued to about 1965 (Mohler, 2011). During this era, researchers and scientists tried to define spatial abilities and describe the factors that affect them. The first of these researchers was Thurstone continuing his research from the previous era. His primary factor, the “space” factor, had high loading on several spatial tests such as flags, pursuit, and cubes; but also had high loadings on some verbal tests such as syllogisms and verbal classification (Eliot & Smith, 1983; Thurstone, 1950).

During World War II, the United States Army Air Force did large-scale testing with Army Alpha and Army Beta tests. Army Alpha was a language test, and Army Beta was a spatial test. The tests were used to determine if an individual would be a successful pilot that would not lose their orientation in flight. These tests are important because they were the first large-scale tests for spatial testing. These studies also supported the research that there are two, maybe three spatial factors (Anderson, Fruchter, Manuel, & Worchel, 1954; Eliot & Smith, 1983).

In 1951, J. W. French reviewed early research and military research on spatial factors. He concluded that there was enough evidence to support at least three factors. The first spatial factor he defined as, “an ability to perceive spatial patterns accurately and to compare them with each other” (Eliot & Smith, 1983, p.4). The second factor he found evidence for was spatial orientation. French defined this as “the ability to remain unconfused by varying orientations in which a spatial pattern may be presented” (Eliot & Smith, 1983, p.4). The third factor that French found was visualization. He defined it as “an ability to comprehend imaginary movement in three-dimensional space or to manipulate objects in imagination” (Eliot & Smith, 1983, p.4; McGee, 1979).

After World War II, attention in the United Kingdom was turned to how children are affected by spatial abilities. In light of this, many researchers created new spatial tests for school-aged children (Eliot & Smith, 1983; Carroll, 1993). The beginnings of this research raised many new important questions about age and sex differences related to the spatial ability tests. During a new era from about 1965 to 1989, which was called the paper and pencil era, researchers focused on many sub factors of spatial ability. These sub factors include differences in gender, environment, age, speed and efficiency, and hemisphere specialization (Mohler, 2011). There are several sub factors under environment as well. These include biology differences, cultural differences, social-economic differences, and educational differences (Mohler, 2011). The paper and pencil era explored these factors as they relate to spatial abilities.

During the paper and pencil era, Piaget studied age-related differences and developmental differences in spatial ability (Eliot & Smith, 1983). He theorized that young children have figurative thinking “involving the perception of static patterns and formation of static images” (Eliot & Smith, 1983, p.6). He postulated that as children grow older, they develop operative thinking. Operative thinking is the “perception of pattern in the movement of figures or objects as well as the manipulation of images” (Eliot & Smith, 1983, p.6). Piaget’s developmental theories were important as the researchers began to explore how spatial abilities are developed or learned.

In 1979, Lohman declared that there are three spatial factors and defined them. Spatial relations are the first factor, which was defined as “performance on tasks requiring the mental rotation of figures or objects” (Eliot & Smith, 1983, p.8). The second factor is spatial orientation, meaning “the ability to imagine how a stimulus array would appear from a different perspective” (Eliot & Smith, 1983, p.8). Finally, the third factor, visualization is “performance on such tasks as surface development tests” (Eliot & Smith, 1983, p.8). Lohman also found minor factors such as “visual memory, speed of matching visual stimuli, speed in left-right discriminations” (Eliot & Smith, 1983, p.8; Lohman, 1988).

The last era in the history of [spatial ability], is the currently developing technology era. Contemporary researchers are focusing on how computer technology has impacted spatial ability. Research suggests that things like animation, virtual and augmented realities, and computer three-dimensional videos games could be having a great impact on spatial abilities. There appear to be endless possibilities of how technology is impacting spatial abilities from, for example, developmental, training and learning.

2.1.2. Spatial Cognition

Spatial cognition is concerned with how the brain understands, “visual orientation in space” (Thurstone, 1950, p.517). Over the years, there have been some disagreements with what exactly qualifies as a space factor and how many space factors exist. Thurstone (1950) defined three space factors: S1, S2, and Sg. Generally, most researchers agree that there are three spatial factors. Lohman, for instance, agreed with Thurstone that there were three spatial factors. He defined them as spatial relations, spatial orientation, and visualization (Eliot & Smith, 1983).

The first spatial factor, spatial relations, is defined as “performance on tasks requiring the mental rotation of figures or objects” (Eliot & Smith, 1983, p.5). Spatial relations allow the brain to manipulate and rotate an object mentally. This is especially important for certain professions including engineering, science, and even surgery or dentistry. Professionals in these fields need to be able to mentally manipulate objects without being able to physically manipulate them.

The second factor, spatial orientation, is defined as “the ability to imagine how a stimulus array would appear from a different perspective” (Eliot & Smith, 1983; Lohman, 1988). This spatial skill differs from spatial relations because in spatial relations the object is being rotated, whereas in spatial orientation the viewer’s perspective is being changed. With spatial orientation the difference might be a “bird’s eye view” versus a “front side view.” Being able to move oneself and look at the object from a different perspective is integral to spatial orientation.

The third spatial factor, visualization, is defined as “performance on such tasks as surface development tests” (Eliot & Smith, 1983, p.5). Visualization is a more general space factor, which allows one to mentally imagine an object or image. Visualization is an important task because it allows one to picture in mind what it is to be built, made, sketched, etc. before actually using resources (Lohman, 1988; Thurstone, 1950).

2.1.3. Developmental Theories in Spatial Abilities

There are many different theories about how the development of spatial abilities occurs in the human brain. Some are biological theories that focus on different hormones and how the brain is neurologically wired. Others are biological theories that focus on genetics and how spatial abilities are inherited. Still, other theories are environmental, which focus on how one's surroundings influence how their spatial abilities develop.

Biological theories focus on hormones, genetics, and neurological influences. It has been theorized that spatial abilities do not develop until hormonal changes happen during puberty (Maccoby & Jacklin, 1974; McGee, 1979). There is also evidence that shows spatial abilities are genetic (McGee, 1979). Biological theories of development propose nature as responsible for the development of an individual's spatial abilities.

On the contrary, environmental theorists support nurturing as to how the development of spatial abilities occurs. Such theories argue that the environment one grows in influences the way that one develops abilities, especially spatial ones. For instance, toys that children play with can reinforce spatial ability and help this ability grow or can inhibit such development. Toys such as Legos, blocks, and video games can nurture a child's spatial ability and develop the child's mind in a way that allows it to perform better at spatial tasks (Fisher-Thompson, 1990; Maccoby & Jacklin, 1974). Environmental theories suggest that being in an environment that is rich in stimuli can also nurture spatial ability.

Piaget developed different biological phases of development. Piaget theorized that there are three different development stages when it comes to spatial ability. The first stage, topological skills are learned (Sorby, 2009). These skills are two-dimensional and usually happen between ages three and five. In these skills, children can recognize the closeness of objects to group or isolate objects in a larger environment (Sorby, 2009; Newcombe & Learmonth, 2005). Children with this skill can put together puzzles. The second stage in Piaget's theory of development is for children to have acquired the skill of projective spatial ability (Sorby, 2009; Newcombe & Learmonth, 2005). This stage involves visualization in three-dimensional objects and the ability to visualize objects in different orientations or rotations (Sorby, 2009; Newcombe & Learmonth, 2005). This skill is developed by the teenage years. The thirds stage involves the developmental skill of being able to "visualize concept area, volume, distance, translation, rotation, and reflection" (Sorby, 2009, p.461). In this last stage of development, people can combine measurement concepts with their projective skills (Sorby, 2009, Newcombe & Learmonth, 2005).

2.1.4. Gender Differences in Spatial Ability

Research has suggested that some men perform better on spatial tests than some women (McGee, 1979; Maccoby & Jacklin, 1974; Harris, 1978). Men especially perform better at mental rotations. There have been many different theories as to why men have somewhat better spatial abilities than women. Like the developmental theories of spatial abilities, some theories focus on biology (nature) whereas others focus on environmental factors (nurture). There have been numerous studies on gender differences in spatial ability. There are many different aspects to the biological factors that affect spatial ability. Hormones are a large factor that has been researched by Thurstone. It has been shown that high levels of testosterone found in males reflect higher spatial ability; whereas lower levels of testosterone found in females reflect lower spatial ability. This might account for why some males generally perform better at spatial tasks than some women (Thurstone, 1950; McGee, 1979).

Another biological factor that might affect spatial abilities is hemisphere specialization. Hemisphere specialization has shown that the right brain is specialized for spatial processing. Since men have a larger right brain, they may perform better in spatial cognition (McGee, 1979; Harris 1978).

Another category of gender difference theories is environmental. One such theory is the hunter-gatherer theory (Eals & Silverman, 1994). This theory explains the development of spatial abilities through the evolution of mankind. Men were hunters who would track and hunt using their spatial abilities of mapping and orientation to succeed in this task; women, however, were gatherers who would stay close to home. They would also use their pattern recognition abilities to gather berries and know where to pick the best berries. The hunter-gatherer theory explains mankind evolved with these skills (Eals & Silverman, 1994).

Other, more recent theories explain that a child's development can influence how their spatial abilities develop, particularly, what kind of toys they play with. Since males and females play with different toys as children, gender roles might be a factor in how spatial abilities are developed. Boys who play with Legos and blocks might be better at spatial tasks than girls who play with dolls and tea sets. These different toys for different genders, may have given males an advantage in spatial tasks (Newcombe & Learmonth, 2005; Maccoby & Jacklin, 1974; Harris 1978).

2.1.5. Learning and Training in Spatial Abilities

The question that researchers have been trying to answer is whether nature or nurture factors affect spatial ability. In this study, it is believed that nurturing has a large effect on spatial ability. While nature still plays a role in spatial abilities, for this study, it is believed that spatial abilities can be developed through training. Training with feedback may be one way to help students understand spatial visualization, spatial orientation, and spatial relations (Lohman, 1988).

Lohman and Kyllonen (1983) claim that training students in spatial ability was effective, but the effectiveness was dependent on the students' aptitude profiles. High spatial ability subjects did not benefit as much from the training as low ability subjects (Lohman & Kyllonen, 1983; Newcombe & Learmonth, 2005).

The majority of the literature supports that spatial ability tasks can be developed and trained (Mohler & Miller, 2008).

2.1.6. Spatial Tests

There are many different spatial tests that were developed to test three-dimensional projective skill levels. Engineering graphics educators used these test to conduct educational research (Sorby, 2009). Some of these tests include the Mental Cutting Test (MCT), the Differential Aptitude Test: Spatial Relations (DAT:SR), and the Purdue Spatial Visualization Test: Rotations (PSVT:R) (Sorby, 2009).

The Metal Cutting Test was developed for a university entrance exam (Sorby, 2009). In each problem within this test, a cut block is sliced with a plane, and students must choose the correct cross-section from the answers (Sorby, 2009).

The Differential Aptitude Test: Spatial Relations asks students to choose the correct three-dimensional object from the answers “that would result from folding the given two-dimensional pattern” (Sorby, 2009, p.462).

The Purdue Spatial Visualization Test: Rotations was developed in 1977 by Guay. This test asks students to choose the correct answer after an object has been rotated in space (Guay, 1980).

2.2. Engineering Graphics

Engineering and technical graphics is an important aspect of engineering and science. It allows engineers, scientists, and technologists to represent ideas as graphic sketches, drawings or digital 3D models. Being able to graphically represent an idea or concept can greatly increase the understanding for others. Graphics can also allow the expression of an idea that cannot be written as a math equation or spoken verbally (Mohler & Miller, 2008).

It is important to teach engineering graphics along with spatial visualization, relation, and orientation. It has become a concern that engineering graphics is being taught too analytically and that the visual, tactile, and sensory aspects are disappearing (Sorby, 2009; Mohler & Miller, 2008). This potential prioritization of the analytical is contrary to what Sorby (2009) suggests as the initial role of engineering: “The earliest engineers were artists first, and engineers second” (Sorby, 2009, p.460). They understood how important these spatial abilities were to understanding engineering and science.

In order to understand where engineering graphics developed and the conventions used today, the history to engineering graphics must be examined. Additionally, understanding the role that spatial abilities play in engineering graphics and the importance of visualization and the other spatial factors in developing engineering graphic skills are crucial.

2.2.1. History of Engineering/Technical Graphics

The history of Engineering and technical graphics dates back to engineers such as Francesco di Giorgio, Leonardo da Vinci, Georg Agricola, and Martiano Taccola (Sorby, 2009). These engineers used graphics to express their ideas. Technical drawing and descriptive geometry were first established during the Renaissance period (Sorby, 2009; Connolly, 2009).

During World War I and World War II, the need for technical drawing increased, especially with an emphasis on orthographic views and descriptive geometry. The United States was rapidly innovating engineering design, in that the technical graphics side was improving and standards in industry were developing. During this period, engineering and technical graphics gave engineers a way of expressing their ideas and blueprints of their inventions (Sorby, 2009; Connolly, 2009).

World War II aided in the evolution of the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) (ANSI website, 2010). These two organizations helped standardize working drawings for many different kinds of engineers. Some of these groups included, American Institute of Electrical Engineers (IEEE), the American Society of Mechanical Engineers (ASME), the American Society of Civil Engineers (ASCE), the American Institute of Mining and Metallurgical Engineers (AIME), and the American Society for Testing Materials (ASTM). The standardization of working drawings helped the flow of ideas and made it possible for all these different organizations to speak in a common graphic language (ANSI website, 2010; Connolly 2009).

During the space age, computers and three-dimensional modeling software became popular although it was expensive and only the large companies could afford the new technology. As years passed, the software became more powerful and less expensive. Today many engineering firms, from large global companies such as The Boeing Company to much smaller companies, use three-dimensional modeling to model their products (Connolly, 2009).

2.2.2. History of Engineering Graphics Education

Engineering graphics serves two purposes in education. One is to teach technical standards, and the second is to develop spatial ability to visualize in three-dimensional space (Mohler & Miller, 2008; Connolly, 2009). In the 1960's, instructional methods were designed to teach two-dimensional objects that were transformed to three-dimensional objects. Other instructional methods such as isometric drawings and models also aided the advancement of spatial abilities. As computer technology evolved in the 1970's, it was used to enhance visualization and teach students using virtual images. The use of computers contributed greatly to teaching visualization and other spatial factors (Connolly, 2009).

Even though computers can aid in visualization and help students perceive objects in three-dimensional space, sketching and drawing are key components in developing students' spatial visualization skills (Mohler & Miller, 2008). Mohler and Miller (2008) contend that seven out of the ten studies showed that sketching and drawing helped students improve their spatial abilities; further giving evidence that sketching and drawing should be included in engineering graphics education.

Even though teaching engineering and technology students CAD software is important, the most important skill being taught in engineering graphics courses are three-dimensional visualization skills (Connolly, 2009). Students need to be able to visualize in three-dimensional space to be successful at this occupation, both as a student and in industry. Sketching isometric and orthographic objects helps students enhance their visualization skills (Mohler & Miller, 2008).

2.2.3. Spatial Abilities and Engineering/Technical Graphics

Sketching and drawing contribute to developing students' spatial abilities, especially visualization (Mohler & Miller, 2008; Connolly, 2009). Engineering and technical graphic courses gives students' opportunities to sketch the isometric or orthographic views, helping their visualization skills. Usually they would be given one view of an object, and asked to sketch the other view(s). These exercises help students visualize objects from a multi-view form into a pictorial form or vice versa, thereby improving their spatial ability (Mohler & Miller, 2008).

In today's engineering graphics classes, a computer aided design (CAD) system is usually taught to students. This adds to their visualization learning. Students that are able to model in a three-dimensional CAD system are able to use their spatial ability to visualize the object in their imagination. Then they can model the object using the functions of the CAD system (Sorby, 2009; Mohler & Miller, 2008).

2.3. Learning Styles

Students with different learning styles may be affected by different instructional methods. Although there are numerous learning styles, this review of literature focuses on haptic and visual learners. Haptic learners are those that learn through touch and feel, whereas, visual learners are those that learn through sight (Lowenfeld, 1945). These two learning styles are the basis for understanding how students learn according to individual differences.

2.3.1. Visual Learning Style

Visual learning is a vital part of (Science, Technology, Engineering, and Math) STEM education. However, some professors in these educational fields lecture and have students take notes enabling their verbal learning style. Many STEM concepts can be explained and clearly illustrated in diagrams and images.

Mohler & Miller, (2008) site research that contends “communicating technological data information visually is becoming the norm rather than the exception” (p.19).

Study (2001) reported that “the eyes are the most powerful of our sensory receptors and therefore are the most powerful source of information to our brain.” She continues, “30% of the nerve cells in the brain’s cortex are devoted to visual processing” (Study, 2001, p.19). This information shows that being able to see or visualize is a crucial part in students’ learning. Study (2001) also explains, “in general, people can read five times as fast as the average person can talk and process a full color image that would be equivalent of one megabyte of data, in a fraction of a second” (p.19). Visual learning is inherent to most students. Seeing, perceiving, and visualizing data is a process our brains are built for. Most students learn in this fashion, especially with material from STEM fields.

2.3.2. Haptic Learning Style

Haptic learning style is concerned with learning through tactile processes such as touch or feel. Particularly, students “who rely on non-visual sensory stimuli and are concerned primarily with body sensations are haptic” (Study, 2001). Study (2001) mentions only 8% of nerve cells are devoted to encoding through a touch sensation.

However, most people are not fully visual or fully haptic learners. Instead their learning occurs somewhere between these two styles. Usually more individuals have visual tendencies than haptic tendencies. As was previously mentioned visual cues account for about 30% of nerve cells encoding information, whereas touch only accounts for 8% (Study, 2001).

2.4. Augmented reality

Augmented reality is a middle ground between virtual reality and the real world. Azuma (1997) defines augmented reality as three-dimensional virtual objects that are integrated into a three-dimensional real environment in real time. This is different from virtual reality because in virtual reality the user is immersed and cannot see the real world (Azuma, 1997). With augmented reality, the user can see his real world surroundings; the real world and the virtual one become blurred. Augmented reality supplements the real world, rather than replacing it (Azuma, 1997).

Augmented reality is used for "enhancing a user's perception of and interaction with the real world" (Azuma, 1997). Using augmented reality, the user can perform better at the given task. Augmented reality is an example of intelligence amplification wherein the computer becomes a tool to make a task easier for a person (Azuma, 1997). Augmented reality can be used for many different reasons as cited by Azuma. Many of these applications are integrated into a learning process. Some applications mentioned are medical, maintenance and repair, annotation, robot path planning, entertainment, and military aircraft navigation and targeting (Azuma, 1997). Most of these applications of augmented reality are for learning in that particular field. For example, medical uses of augmented reality are to learn how to do complex surgeries in a virtual world, before performing the surgery on a real person (Azuma, 1997).

2.4.1. Augmented Reality used for Learning

Research claims that augmented reality can used to enhance education and learning. There have been many instances in which augmented reality is a supplement to learning. Thus, it may be contended that augmented reality as a learning aid, could help students to advance their spatial abilities. There have been other studies that have used augmented reality for the purpose of education.

Kaufmann and Meyer (2008) presented a study that used augmented reality to aid in physics education. The augmented reality describes motion of the objects with the Newton’s three laws (Kaufmann & Meyer, 2008). Another study that utilized augmented reality in education was in Hartman, Connolly, Bertoline, and Heisler’s (2006) study with computer graphics education. They developed a virtual reality test based off of the Mental Cutting Test. Using virtual reality based test gives the test a three-dimensional aspect unlike the paper-and-pencil tests prior to this. This allows the student to view the object in three-dimensional space, enhancing the student’s perception of the object (Hartman, Connolly, Bertoline & Heisler, 2006).

These studies showed success with augmented reality in education. Using this technology has helped the students’ level of understanding in the particular subject. The physics education augmented reality helped students understand force and counterforce, speed and velocity, and accuracy and robustness (Kaufmann & Meyer, 2008). The computer graphics study from Hartman, including the virtual Mental Cutting Test, is hypothesized to give students the ability to “visualize complex cutting operations” (Hartman, et. al., 2006). These studies show that augmented reality can be used successfully for education purposes. However in this study, it was found that augmented reality blocks were not significantly more beneficial than real blocks. Students in the study that used real blocks seemed to score equally to students that used augmented reality blocks. This indicates that using augmented reality for educational purposes might only be beneficial for certain types of applications.

2.5. Summary

The literature review gave an overview of the literature that supported the need for this study. It started with an in depth look at spatial abilities. This included the history of spatial research, spatial cognition, developmental theories, gender differences, learning and training, and spatial tests. Literature defining and describing engineering graphics including the history and education was covered next. The literature review explored visual and haptic learning styles. Finally, using augmented reality for education was described, since augmented reality was used in this study. This literature review gives insight into topics that affect this study.

CHAPTER 3. METHODOLOGY

This chapter explains the methodology of the study. First a step-by-step guide is given so the study can be replicated. The target population and setting of the study is clarified. The hypotheses are given, as well as the instrumentation that was used. Finally, the internal validity risks that were inherent with the study are explained.

3.1. Methodology

The methodology and experimental design for this study are laid out in this section. The participants of this study were students enrolled in CGT 163, an introductory engineering graphics course at the West Lafayette, Indiana campus of Purdue University. The study is quantitative, splitting students into two groups of different learning styles (visual and haptic) and applying different instructional methods (augmented reality or real blocks) to different subjects in each group. The experimental design is shown below, see Figure 3.1.

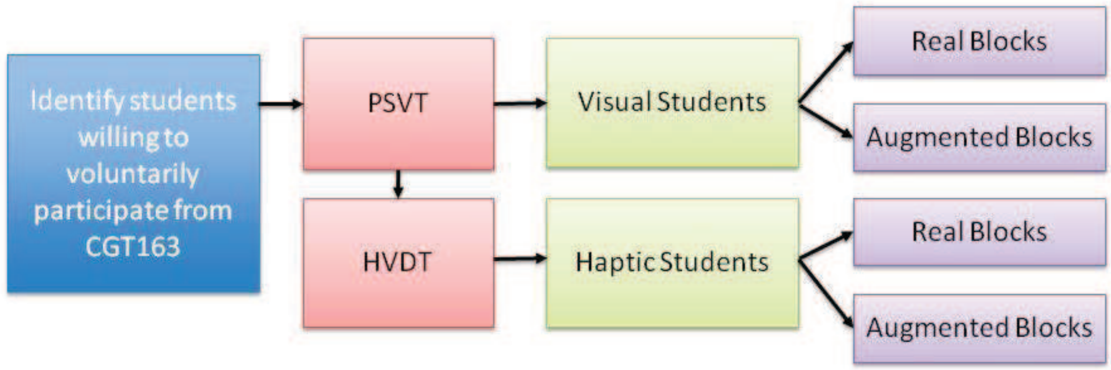


Figure 3.1: Experimental Design

- Students from CGT 163 were recruited to participate in this study, on a strictly volunteer basis, although extra credit was offered.
- Students in CGT 163 were given the Purdue Spatial Visualization Test (PSVT) during lecture on August 25, 2011 as an attendance/participation grade for their course. These scores were also used to determine the visual group of students. Students who scored a 95% or above on this test were asked to sign up in the visual group for the block testing at the Envision Center.
- Students who did not score a 95% or higher were asked to sign up to take the Haptic/Visual Discrimination Test (HVDT) during the week of August 29 - September 2, 2011. Students who scored a normal score above 100 (average) were asked to sign up in the haptic group for the block testing at the Envision Center.
- The participants were then split into two groups based on the PSVT and the HVDT: visual and haptic. Each participant received eight different worksheets with eight different cut-blocks illustrated in an isometric view.

The cut-blocks are illustrated in Figure 3.2. The worksheets are available in Appendix A.

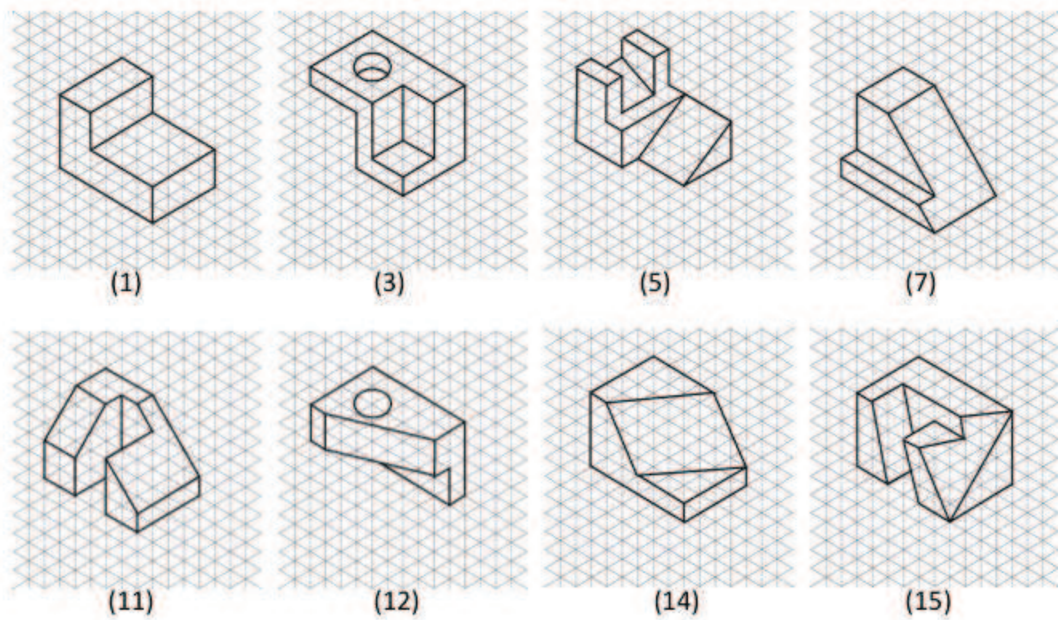


Figure 3.2: All cut-block shapes

- The participants were asked to sketch the multi-view of the cut-block for each worksheet. Any given participant was randomly assigned real blocks or augmented reality blocks. Depending on the assignment each participant used either the real wooden block aids or the augmented reality block aids for all eight worksheets. Students were given all eight blocks one at a time, in the same order.
- Approximately half of the students used augmented reality blocks to aid them in their visualization. These students used a program called Vizard and 3-D video glasses to view 3-D images of the cut-blocks. An example

of augmented cut blocks can be seen in Figure 3.3 and Figure 3.4. The images could be turned and rotated. However, they could not be viewed from the bottom. These blocks could not be touched because they are just an image displayed in the glasses. This method used augmented reality technology to help students complete the worksheets. See Figure 3.5 and Figure 3.6 for the set-up of the augmented reality technology

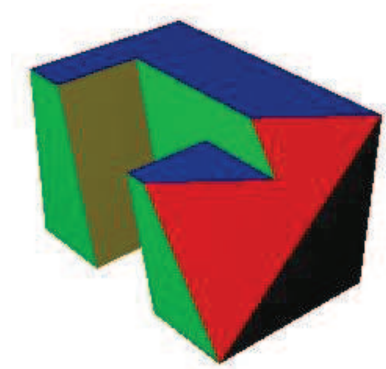


Figure 3.3: An example of an augmented reality block

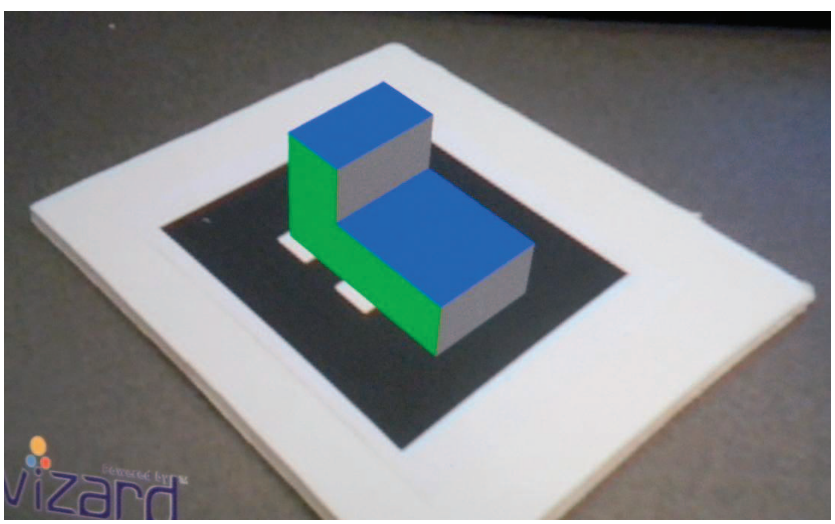


Figure 3.4: Augmented reality block with marker on computer screen

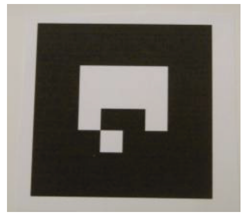


Figure 3.5: Marker for Augmented Reality

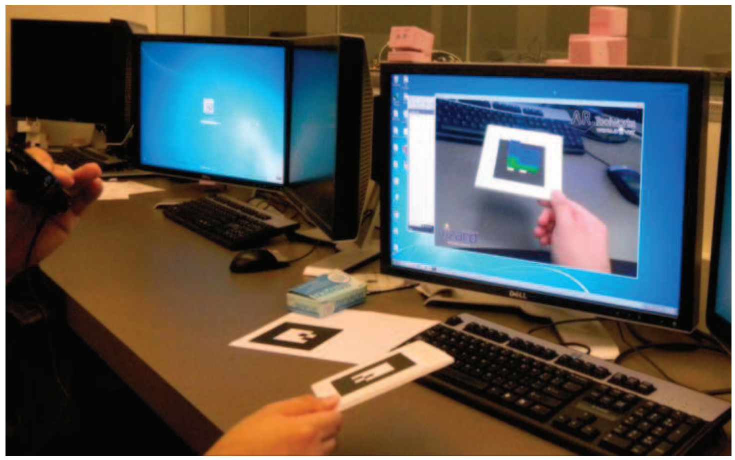


Figure 3.6: Set-up of augmented reality station

- The other half of students used real wooden cut-blocks depicting the shape to aid them in their visualization. These looked identical to the augmented reality blocks; however, they could be touched and flipped upside down. An example can be seen in Figure 3.7.

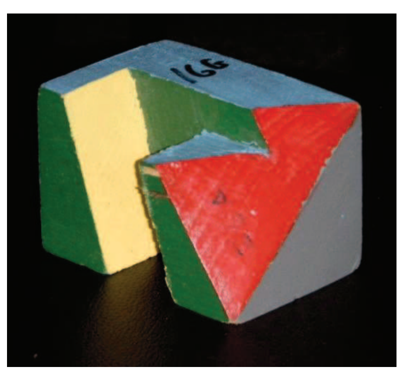


Figure 3.7: An example of a real block

- The cut-blocks were picked by the complexity of their planes and/or features. Blocks that have no inclined or oblique planes and no holes were classified as simple blocks thus easier to visualize than blocks that have inclined and/or oblique planes and holes (Bertoline & Wiebe, 2005). The cut-blocks in this group of eight vary from easy in block 1 to very difficult in block 15. This group of blocks has a varied difficulty level according to the types of planes and features. The researcher wanted blocks that varied in complexity level from easy to difficult to hopefully get a range of understanding of which kind of blocks are easier and harder for students to visualize with the augmented reality and real block aids.
- The worksheets were then scored to determine how accurate the subject represented the object, using sketches, and thus their visualization of it. The researcher used scoring sheets for each block to make sure the evaluation was consistent. The scores sheets for each type of cut-block can be found in Appendix B. Time was not a factor in this study, the worksheets were only scored for accuracy. The scores were judged off a 100 point rubric for each of the blocks. The scoring sheets were based on the features of the block and if each feature was represented in each view correctly. More points were taken away for inaccurate visualization representation errors than for engineering graphics standards, since the study is focused on the student’s visualization of objects. Although time was not data that was collected, each participant had a maximum of 15

minutes per block to complete the assignment. The scores were then used in the statistics to determine which hypothesis is statistically significant.

3.2. Target Population

The target population of this study was entry-level engineering students. The primary purpose was to advance the spatial abilities of the students based on their visual and haptic learning styles through the use of two different instructional methods. Students that make up the sample set were undergraduate engineering students in their first or second year of their engineering curriculum at the West Lafayette campus of Purdue University who were enrolled in CGT 163. This class is an introduction to engineering graphics course, and is designed to expose students to engineering graphics and three-dimensional modeling in a CAD package, graphics standards, sketching, and visualization.

Using the specific demographic of engineering students enrolled in CGT 163, allowed the researcher to infer to a larger population of engineering students. The goal of this research was to allow academia a better understanding of how to advance the spatial abilities of students based on the different learning styles of haptic and visual through the use of real and augmented cut blocks. Prior research indicates that spatial abilities are an important factor for students to be successful in the professional engineering setting (Sorby, 2009).

3.3. Setting of the Study

The PSVT was administered Fall Semester 2011 during the second lecture of the first week of CGT 163 to 370 students. Students who scored high on this test were asked to sign up for the block test at the Envision Center as visual subjects. Students who did not score high were asked to sign up for the HVDT. The HVDT test was administered to each student individually. Students who scored above average were asked to sign up for the block test at the Envision Center as haptic subjects.

Students who participated in the block test were asked to come to Purdue University's Envision Center. The Envision Center is located inside the Purdue University Student Union and allowed for the augmented reality blocks to be viewed and manipulated. The Envision Center is a data perceptualization center at Purdue using computer graphics and visualization techniques to enhance learning and discovery ("Envision Center", 2011). At this meeting participants were asked to use the augmented reality or real block instructional methods to complete the sketch assignments. Each student completed eight different exercises, using either augmented reality blocks or real blocks, but not both. The students had up to 15 minutes to complete each sketch, although time was not a factor in the study.

The study used eight different cut blocks that were developed from a text book for Dr. Craig Miller's dissertation work at The Ohio State University. For the purposes of this study, the same cut blocks were used. The worksheets have been modified to appear neater and are easier to distinguish the shapes; the worksheets are essentially the same.

3.4. Demographics of Study Participants

Students from CGT 163 were asked to participate in this study on a strictly voluntarily basis. Students who participated would receive extra credit for CGT 163. Overall 67 students from this course participated in the study. This chapter breaks down the demographics of the participants, including age, gender, major, and class standing.

3.4.1. Age

The majority of participants were 19 years old. All the participants were between 18-24 years of age.

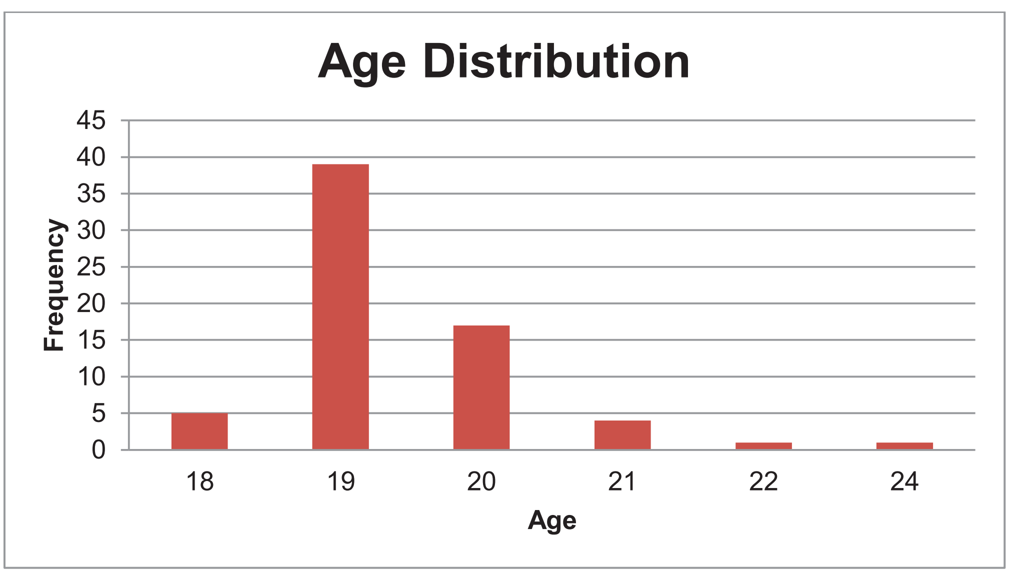


Figure 3.8: Distribution of Age

Table 3.1: *Distribution of Age*

Age	Frequency	Percent
18	5	7.46
19	39	58.21
20	17	25.37
21	4	5.97
22	1	1.49
24	1	1.49
Total	67	100.0

3.4.2. Gender

The majority of participants were male (80.6%).

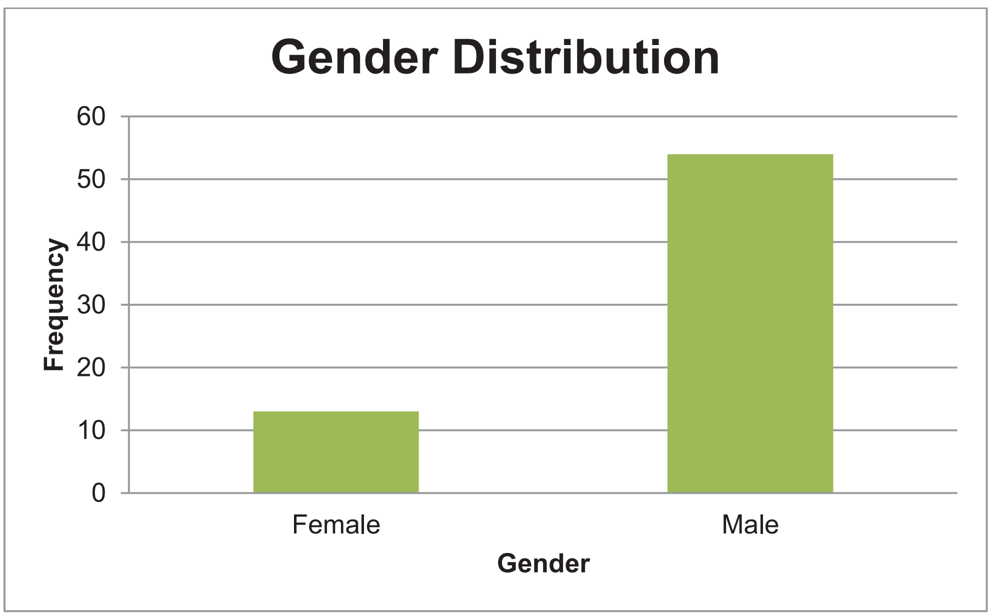


Figure 3.9: Distribution of Gender

Table 3.2: *Distribution of Gender*

Gender	**Frequency**	**Percent**
Female	13	19.40
Male	54	80.60
Total	67	100.0

3.4.3. Majors

All of the participants' were engineering majors, either first year, aeronautical, or mechanical engineers, with the most participants in first year engineering, approximately 44%.

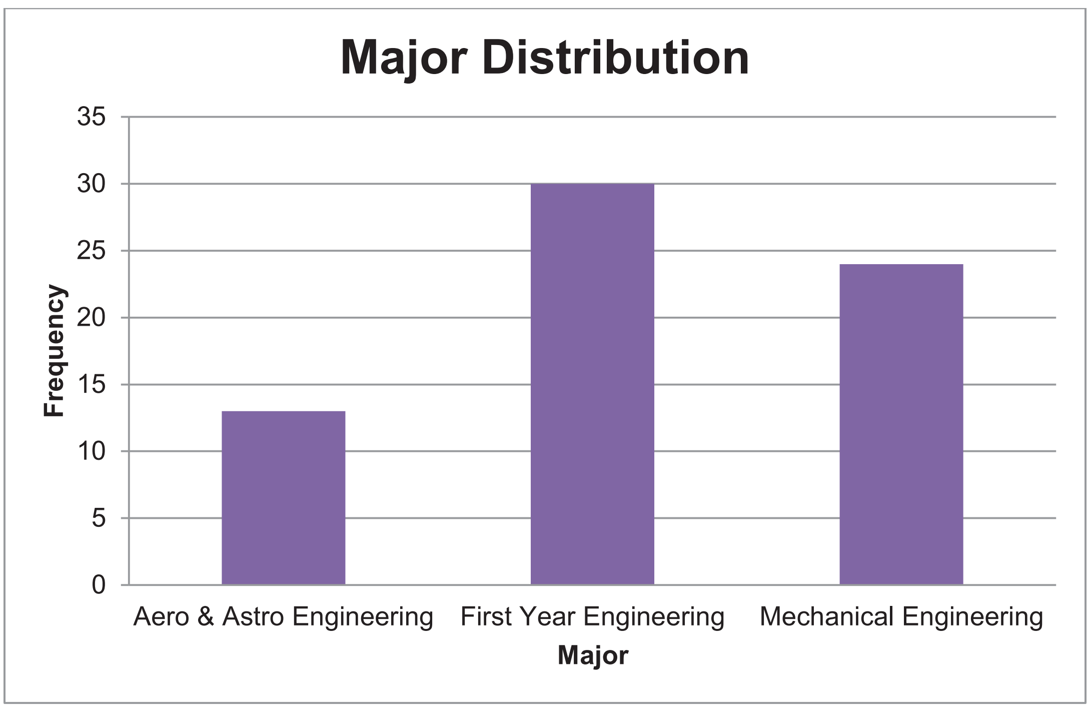


Figure 3.10: Distribution of Majors

Table 3.3: *Distribution of Majors*

Major	Frequency	Percent
Aero & Astro Engineering	13	19.40
First Year Engineering	30	44.78
Mechanical Engineering	24	35.82
Total	67	100.0

3.4.4. Class Standing

The majority of the participants were sophomores (3rd or 4th semester), meaning they are in their 2nd year of study at Purdue University or have enough credits to be considered in their 2nd year. 88% of the participants were sophomores.

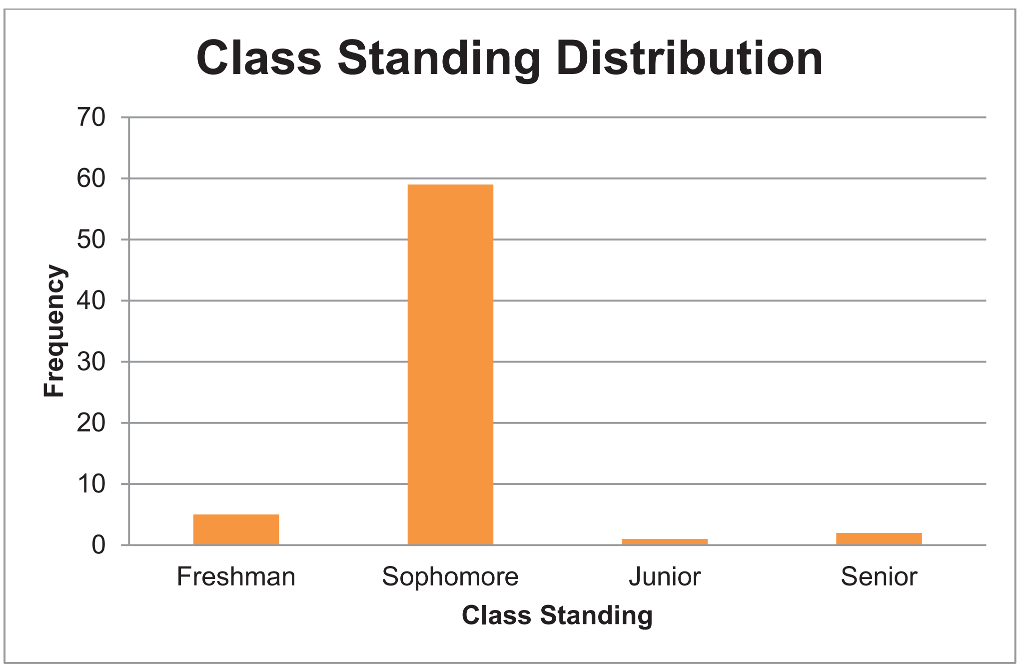


Figure 3.11: Distribution of Class

Table 3.4: *Distribution of Class Standing*

Class Standing	**Frequency**	**Percent**
Freshman	5	7.46
Sophomore	59	88.06
Junior	1	1.49
Senior	2	2.99
Total	67	100.0

3.5. Hypothesis

The statistical hypothesis is listed below in null form:

Ho: There is no significant difference between the type of instructional method used and type of learning style of student participants.

3.6. Instrumentation

There were two main instrumentation tests used in this study. The first test was, the Purdue Spatial Visualization Test (PSVT), to determine students who tend to learn visually. The second test, the Haptic/Visual Discrimination Test (HVDT), allowed the researcher to identify which participants tend to learn more haptically.

The reliability and validity coefficients of the PSVT are between 0.65 and 0.67 (Branoff, 2000; Guay, 1980). The reliability and validity coefficients of the HVDT are between 0.90 and 0.93 according to McCarron and Dial in 1979 (Berry & Genskow, 1986; Study, 2003).

3.6.1. Purdue Spatial Visualization Test

The PSVT is a visual test used to measure a participant's spatial ability. This test consists of three parts: developments, rotations, and views (Guay, 1976). Developments are the folding of shapes into three-dimensional objects (Guay, 1976). Rotations are designed to "help visualize the rotation of a three-dimensional object" (Guay, 1976, p.6). Views are what the three-dimensional object looks like from different views (Guay, 1976).The participants took the entire test, as all parts of the test are related to engineering graphics. The PSVT has been validated to measure spatial ability using construct validity with several tests including the DAT: space relations (Guay, 1980).

3.6.2. Haptic/Visual Discrimination Test

The HVDT is an individual test that determines if a participant can learn haptically; that is, learn with tactile and touch as opposed to visually. The test consists of a participant reaching through a screened frame (where they cannot see what is through the screen) and holding an object. Next, the participant is asked to identify the object in their hand, without looking at it, from an identification chart. There are four criteria: shape, size, texture, and configuration. The student receives a score depending on how well they identify these characteristics of the object (Study, 2001). This score classifies students as being more haptically or less haptically inclined. See Figure 3.12, Figure 3.13, and Figure 3.14 for test set-up details.

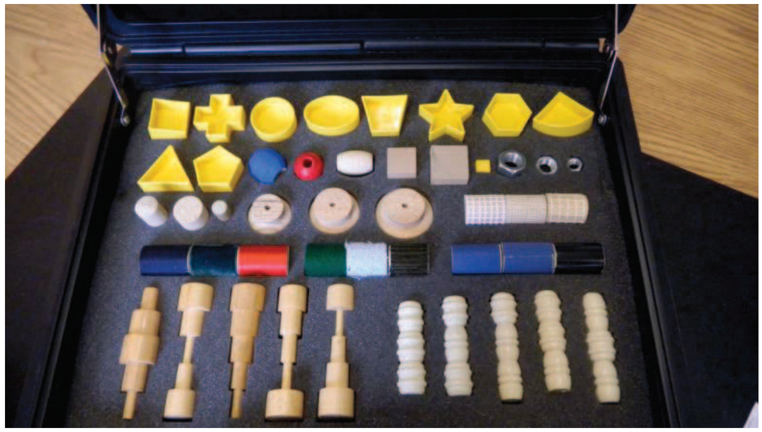


Figure 3.12: Objects from the HVDT

Figure 3.13: HDVT test set-up from the instructor's point-of-view

Figure 3.14: HDVT test set-up from the participant's point-of-view

3.7. Internal Validity

All experiments can be affected by internal validity, “confounding factors that might still be present that could offer rival explanations as to what is causing the dependent variable” (Sekaran & Bougie, 2010, p.235). This study is no exception. This section explains factors that might affect the study’s internal validity.

3.7.1. History

History is a confounding internal validity variable that could have affected the study. History is “certain events or factors that have an impact on the independent variable-dependent variable relationship [that] might unexpectedly occur while the experiment is in progress” (Sekaran & Bougie, 2010, p.235). In this study, participants were students in CGT 163 were learning similar techniques as the instructional methods. This might have had a confounding effect on the study, inferring whether students advanced their spatial skills from the instructional methods in the study or the class work of CGT 163.

3.7.2. Mortality

This study was on a volunteer basis; participants were allowed to drop out of the study at any time for any reason. For this reason, mortality can become a confounding factor that might have a cause-and-effect relationship with the dependent variable. If enough students were to drop out of the study, it would have been difficult to determine a relationship between the instructional methods and whether or not the students' enhanced their spatial skills to a point that is statistically significant.

3.8. Summary

In summary, this study recruited student participants, and administered the PSVT and the HVDT to them. The two tests split the participants into two groups: haptic and visual. Participants in each of these two groups received an instructional method of either real block or augmented reality block.

The hypothesis was that there is no significant difference between learning style and instructional method. The student participants in this study were selected from the population of CGT 163 at the West Lafayette campus of Purdue University. The sample set can be used infer to a larger population of entry level engineering students, to determine how to advance the spatial ability of students on visual and haptic learning styles.

CHAPTER 4. ANAYLSIS OF THE DATA

The purpose of this study was to determine if first year engineering students who possess either haptic or visual learning styles and who were exposed to different instructional methods (augmented reality block and real block methods) were aided by the instructional method thus allowing for the advancement of their spatial abilities. Students were identified as a haptic or visual learner. They were then given eight blocks to sketch the top, front, and right side orthographic views of the object. Students were randomly assigned to the augmented reality blocks or the real blocks as aids to help them with visualization.

This chapter discusses the test results and the statistical analysis that were necessary to answer the hypothesis: There was no significant difference between the type of instructional method (real verses augmented block) used and type of learning style (visual or haptic) of the student participants.

4.1. Test Results

This section starts by discussing the different instrumentation tests used to separate the students into two groups; those who are visual and those who are haptic. It gives all the results of the two instrumentation tests, and explains why each instrumentation test was used for this study. Next, this section examines the augmented reality and real block test by analyzing how the blocks were selected and how the blocks were scored.

4.1.1. Instrumentation for Evaluating Students

There were two instrumentation tests used in this study to classify students as visual or haptic; the Purdue Spatial Visualization Test (PSVT) and the Haptic Visual Discrimination Test (HVDT). The PSVT is a visually-based test, while the HVDT is a haptic-based test (Guay, 1976; McCarron & Dial, 1988).

4.1.1.1. Purdue Spatial Visualization Test

The PSVT was given to all students in CGT 163 during the second lecture meeting of the first week of classes on Tuesday, August 25, 2011. The PSVT that was given to the students had 36 questions and three parts. There were 12 questions in each section. The first section was developments, the next was rotations, and the last section was views.

The scores from this test were sorted, and the students who scored a 94.44% (34 questions correct) or higher were classified as being possessing a visual learning style and they were asked to volunteer for the visual group of the study. 370 students completed the PSVT in the first week of CGT 163. 96 students were asked to sign up for visual group of the PSVT. 38 students actually did sign up and agreed to participate in the visual group. The following charts explain the results of the PSVT from the entire class. The average score on the PSVT was 27.34 out of 36, with the minimum score of 6 and the maximum score of 36. Table 4.1 and Figure 4.1 illustrate the frequency of the scores. The students who's scores highlighted in ***bold italic*** in Table 4.2 were asked to participate in the visual group.

Table 4.1: *Results of PSVT Scores*

	N	Min	Max	Mean	Std Dev
Score	370	6	36	27.34	7.153

Table 4.2: *Frequency of PSVT Scores*

Score	**% on test**	**Frequency of students**	**% of students**
6	16.67	1	0.27
7	19.44	1	0.27
8	22.22	4	1.08
9	25.00	1	0.27
10	27.78	3	0.81
11	30.56	2	0.54
12	33.33	2	0.54
13	36.11	4	1.08
14	38.89	7	1.89
15	41.67	5	1.35
16	44.44	4	1.08
17	47.22	5	1.35
8	22.22	6	1.62
19	52.78	13	3.51
20	55.56	11	2.97
21	58.33	14	3.78
22	61.11	11	2.97
23	63.89	11	2.97
24	66.67	13	3.51
25	69.44	11	2.97
26	72.22	13	3.51
27	75.00	22	5.95
28	77.78	10	2.70
29	80.56	20	5.41
30	83.33	24	6.49
31	86.11	15	4.05
32	88.89	19	5.14
33	91.67	22	5.95
34	***94.44***	***37***	***10.00***
35	***97.22***	***34***	***9.19***
36	***100.00***	***25***	***6.76***
Total		370	100.00

(The students who's scores in ***bold italic*** above are 94.44% or greater and were asked to volunteer for the visual group).

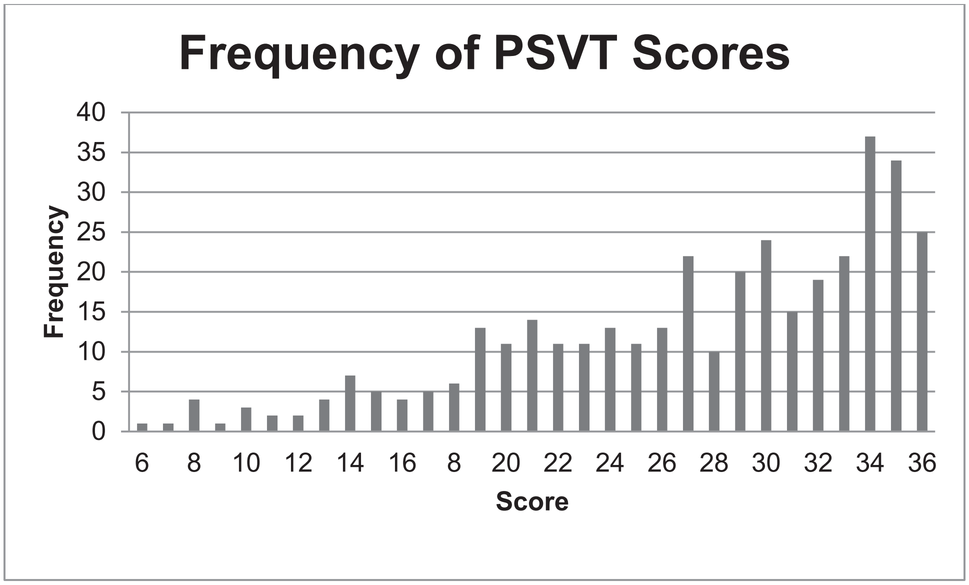


Figure 4.1: Frequency of PSVT Scores

4.1.1.2. Haptic Visual Discrimination Test

Students who scored below a 94.44% were asked to sign up during the second week of classes from August 29- September 2 2011 to take the HVDT. During the HVDT students were given 48 objects behind a screen. They were asked to feel objects without looking at them and determine what shape, size, texture, or configuration they were depending on the section of the test. Then the students were asked to choose the answer from a book depicting five possible answers. The number of answers the student answered correctly determined his/her score. The score was then translated to a standard score using a visual/haptic classification scheme in the HVDT. Students who scored above a standard score of 100, which is consider average, were asked to volunteer for the haptic group for block testing (McCarron & Dial, 1988).

71 students took the HVDT during this study. 31 students out of the 71 tested scored higher than a 100 on the standard score, thus they were classified as possessing a haptic learning style and were asked to volunteer for the study as a haptic student. 29 students volunteered and actually participated in the study. The following tables and figure illustrate the results from the test. Table 4.3 explains the mean standard score was 99.58 out of 142. Table 4.4 shows the frequency of scores. The scores in ***bold italic*** were asked to participate as haptic students in the study.

Table 4.3: *Results of HVDT Scores*

	N	Min	Max	Mean	Std Dev
Standard Score	71	55	142	99.58	16.79

Table 4.4: *Frequency of HVDT Scores*

Standard Score	**Frequency**	**% of students**
55	1	1.41
67	1	1.41
70	1	1.41
73	2	2.82
49	5	7.04
82	3	4.23
85	2	2.82
88	6	8.45
94	7	9.86
97	5	7.04
100	7	9.86
103	***5***	***7.04***
109	***5***	***7.04***
112	***8***	***11.27***
115	***7***	***9.86***
124	***2***	***2.82***
127	***1***	***1.41***
130	***1***	***1.41***
142	***2***	***2.82***
Total	71	100

(The students who's scores in ***bold italic*** above are a standard score of 100 or greater and were asked to volunteer for the haptic group).

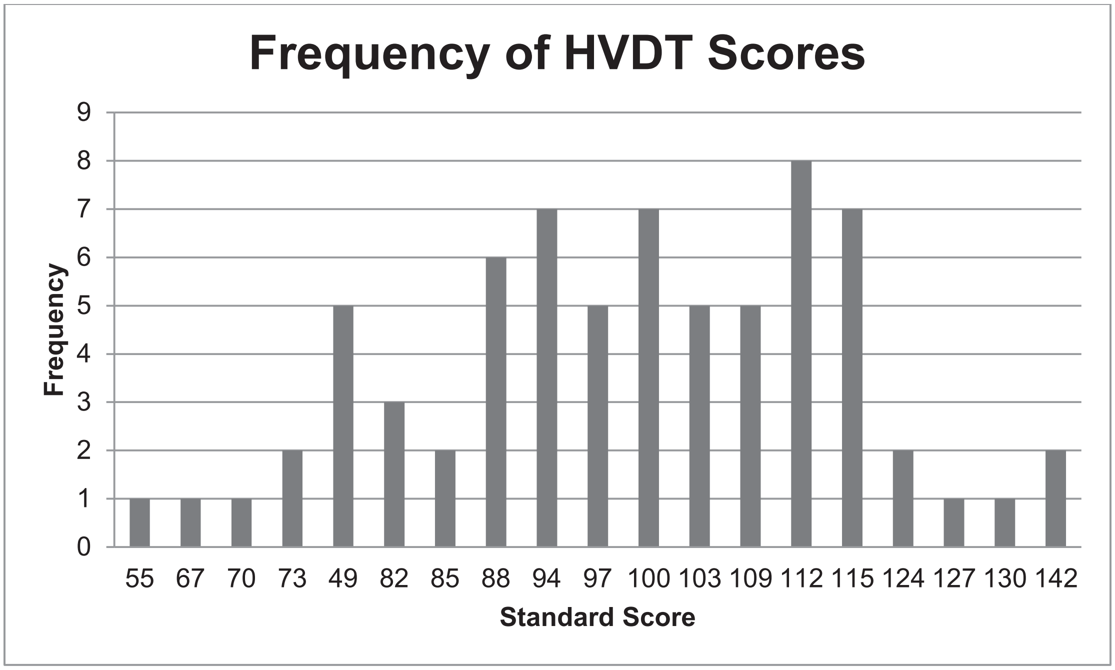


Figure 4.2: Frequency of HVDT Scores

4.2. Statistical Methodology

The following section explains the statistical results of this study. This section starts by giving an overview of several different average scores on each block. The section continues to explain the results of the two-factor nested ANOVA test, the results that were statistically significant, and a possible explanation of these results.

4.2.1. Average Score on Blocks

The block scores were analyzed by each individual block, comparing how students of visual and haptic learning styles scored taking the instructional method into account. On every block visual students out-scored haptic students, independent of instructional method. There is not a statistically significant difference in the block orthographic evaluation scores based on the different instructional methods of the augmented reality and real blocks, for either learning style. Analyzing each individual block helped the researcher come to the conclusion that scores were very high overall on the simpler blocks, indicating that these simple blocks were too easy to visualize and students were not having to really apply their spatial abilities to the problem. The blocks that had more complex features, such as inclined and oblique surfaces were more challenging, concluded from the scores received on these types of blocks. The tables and figures for the analysis of each individual block can be found in Appendix C.

4.2.2. Nested Univariate Repeated Measures ANOVA

A nested univariate repeated measures ANOVA test was used to determine if there are any interactions between the instructional methods and learning style. This model was used, because there are two factors being tested; learning style (haptic and visual) against instructional methods (augmented and real block). However, the model is univariate because there is only one response variable of score. The ANOVA model is called repeated measures because eight different blocks were tested for each subject; the eight different blocks were repeated measures of each subject (Montgomery, 2009).

A nested model was used because there is a need to account for subject-to-subject variation. Since each student was only asked to sketch with either real blocks or augmented blocks, but not both, there is room for subject variance.

This infers one student might inheritably perform better on the test than another, due to past experiences, or any other factor. The nested ANOVA takes these differences in the students into account (NIST-SEMATECH, 2003; Montgomery, 2009). The ANOVA model provides a confidence interval of 95% and P-values are tested for significance against an alpha level of 0.05.

The nested ANOVA yielded many statistical results that were significant. The chart below shows the statistical results of the nested ANOVA given from SPSS, the statistical computer program used to analyze the data. All eight interactions learning styles and instructional methods were tested in the nested model. This section outlines the different interactions and explains if the ANOVA test found the interactions statistically significant. This outline skips learning style by instructional methods nested in subject, and this is addressed in 4.3 Hypothesis Results.

Table 4.5: *Nested Univariate Repeated Measures ANOVA Results*

Dependent Variable: Score on Blocks

Source/contrast	**df**	**Mean Squares**	**F-value**	**P-value**
Learning Style	1	3279.147	10.494	0.002*
Instructional Method	1	31.164	0.1	0.753
Learning Style x Instructional Method	1	709.436	2.27	0.137
Subject-to Subject Variance	69	312.479	6.114	0.000*
Block	7	1816.142	35.533	0.000*
Learning Style x Block	7	197.691	3.868	0.000*
Instructional Method x Block	7	34.981	0.684	0.685
Learning Style x Instructional Method x Block	7	142.185	2.782	0.008*

***p<.05**

4.2.2.1. Learning Style

Learning style refers to whether a student belongs to the haptic group or the visual group. The P-value for learning style was 0.002 which is less than the alpha level of 0.05, meaning learning style is statistically significant in this study.

Table 4.6: *Learning Style Results (All Blocks)*

		N	Min	Max	Mean	Std Dev
Haptic	Both	232	39.00	100.00	90.06	12.79
	Real Block	112	39.00	100.00	88.60	13.73
	Augmented Reality	120	47.00	100.00	91.43	11.75
Visual	Both	304	45.00	100.00	95.06	8.02
	Real Block	160	59.00	100.00	95.92	6.45
	Augmented Reality	144	45.00	100.00	94.10	9.41
Total		536	39.00	100.00	92.89	10.64

By Table 4.6 it can be inferred that visual students performed better than haptic students overall by about 5 points, looking at the mean scores of both. It can also be measured that visual students who tested with real blocks scored an average score of 7 points higher than haptic students who tested with real blocks. Likewise visual students who tested with augmented reality blocks scored an average score of about 3 points higher than haptic students who tested with augmented reality blocks.

Figure 4.6 illustrates the difference in mean scores of real blocks and augmented reality blocks from visual to haptic students. The crossing of the two lines indicates that there is a significant interaction with learning style.

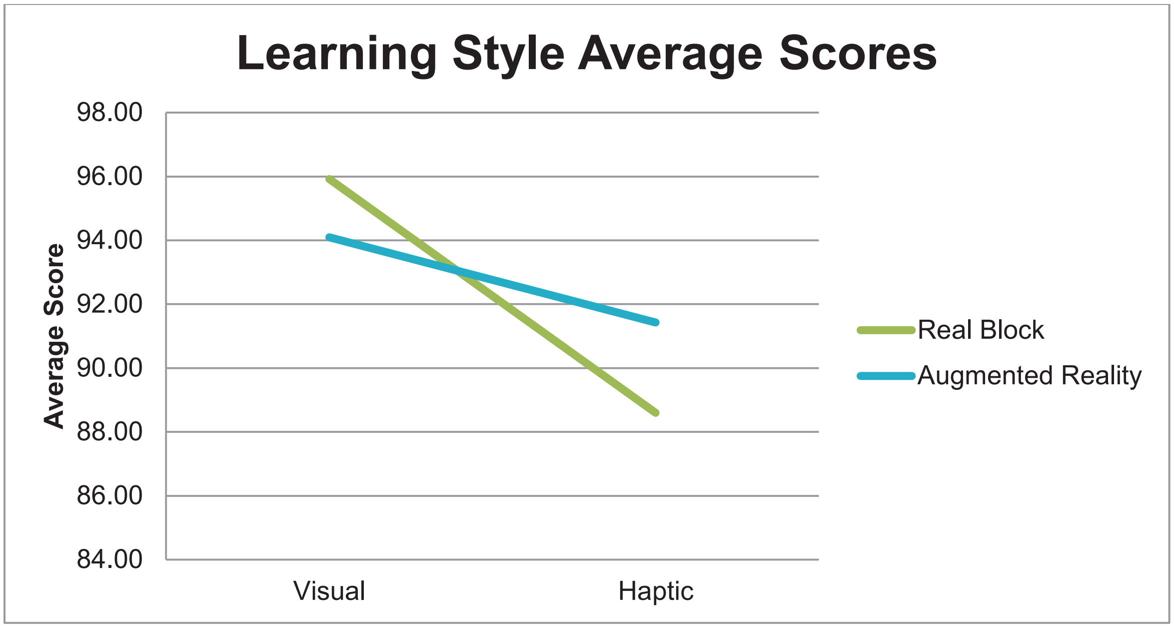


Figure 4.3: Learning Style Average Scores

4.2.2.2. Instructional Method

Instructional method refers to whether a student used augmented reality blocks or real blocks. The P-value for instructional method was 0.753 which is greater than the alpha level of 0.05, meaning instructional method is not statistically significant in this study. Instructional method of augmented reality or real block method was randomly assigned to each participant. Each instructional method may have equally allowed the students to visualize the blocks.

4.2.2.3. Block

Block refers to the eight different blocks that the students graphically represented by sketches. The P-value for block was 0.000 which is less than the alpha level of 0.05, meaning the different blocks are statistically significant in this study. Table 4.7 displays which blocks are statistically significantly different from each other. The comparison with a star (*) in the sig. column denote a statistically significant difference.

The block comparison explains that the complexity of the visualization of each block is significant. The blocks with less complex features seem easier to visualize and thus represent on the worksheets. Each block is different because of its features and types of planes. The more complex blocks contained features and planes, such as inclined and oblique planes, that made theses blocks more complex, than blocks that contained only horizontal and vertical planes that were less complex. It seems rational that the higher the complexity of the block the harder it would be to visualize. The complexity of each block is significant because it affects how well a student may score.

The complexity of the block is relevant to this study because it is important to understand how visual learning style students' spatial reasoning changes as the cut-block becomes harder to visualize compared to the students with haptic learning style. All students, visual and haptic, did well on the very simple cut-blocks, the differences were found in the more complex, harder to visualize blocks. Visual students excelled independent of instructional method, as the cut blocks became harder to visualize whereas, haptic students independent of instructional method, struggled as the cut blocks became harder to visualize.

Table 4.7: *Block Comparison*

Block A		Block B	Mean Difference	P-value	Sig.
1	Compared to	3	13.25	0.000	*
		5	3.43	0.159	
		7	0.33	1.000	
		11	4.54	0.000	*
		12	8.66	0.000	*
		14	0.34	1.000	
		15	9.33	0.000	*
3		5	9.82	0.000	*
		7	12.93	0.000	*
		11	5.72	0.000	*
		12	4.60	0.001	*
		14	12.91	0.000	*
		15	3.93	0.044	*
5		7	3.10	0.345	
		11	4.10	0.027	*
		12	5.22	0.001	*
		14	3.09	0.357	
		15	5.90	0.000	*
7		11	7.21	0.000	*
		12	8.33	0.000	*
		14	0.01	1.000	
		15	9.00	0.000	*
11		12	1.12	1.000	
		14	7.19	0.000	*
		15	1.79	1.000	
12		14	8.31	0.000	*
		15	0.67	1.000	
14		15	8.99	0.000	*

4.2.2.4. Learning Style by Block

Learning style by block refers to the interaction of the two different learning styles (haptic or visual) with the different blocks. The P-value for this interaction was 0.000 which is less than the alpha level of 0.05, meaning this interaction is statistically significant in this study. From Figure 4.7 it can be inferred that the average score of all the blocks for haptic students is about 4 points lower than visual students.

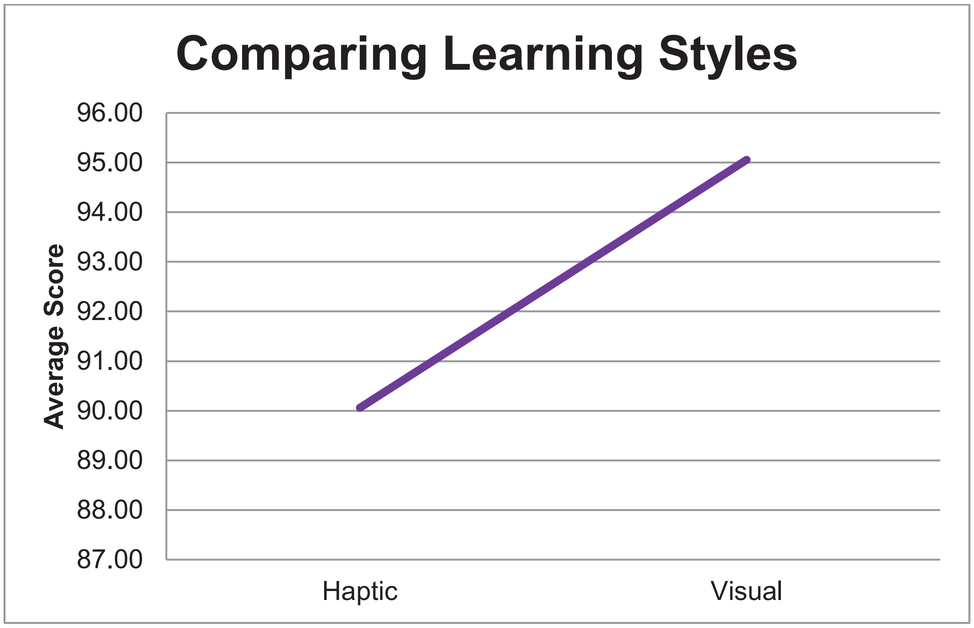


Figure 4.4: Comparing Learning Styles

The data suggests that there is significant difference between haptic and visual students when comparing the overall mean score of all the blocks. The learning style of visual or haptic, compared to the different block complexity levels was significant, in this study. Visual students, on average, scored better than haptic students, independent of the instructional method. The literature supports this result because visual students possess higher visualization abilities and should score higher on visualization tests than haptic subjects (Lowenfeld, 1945; Miller, 1992; Study, 2001).

4.2.2.5. Instructional Method by Block

Instructional method by block refers to the interaction of the two different instructional methods (augmented reality and real) with the different blocks. The P-value for this interaction was 0.685 which is greater than the alpha level of 0.05, meaning this interaction is not statistically significant. Figure 4.8 indicates that there was very little difference in the average scores for students who utilized the augmented reality blocks and students who utilized the real blocks.

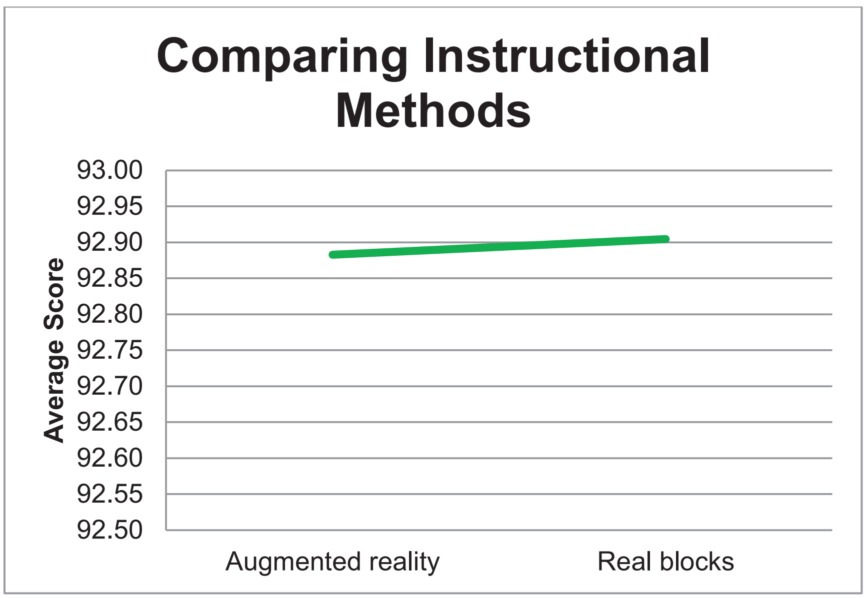


Figure 4.5: Comparing Instructional Methods

The data suggests that there is no significant difference between augmented reality and real block instructional methods when comparing the overall mean scores of all the blocks. This infers that all students performed almost the equivalently using the augmented reality blocks or the real blocks. It can be inferred that augmented reality and real blocks help students to advance their spatial abilities equally, in fact augmented reality blocks has a slightly lower score than real blocks. This suggests that the employment of 3-D technology, such as augmented reality may hinder students from advancing their visualization skills compared with using traditional wooden blocks.

4.2.2.6. Learning Style by Instructional Method by Block

Learning style by instructional method by block refers to the interaction of the two different learning styles (haptic or visual) with of the two different instructional methods (augmented reality and real blocks) with the complexity level of the different blocks. The P-value for this interaction was 0.008 which is less than the alpha level of 0.05, meaning this interaction is statistically significant in this study

Figures 4.9 and 4.10 illustrate the difference in mean scores for each block from augmented reality to real blocks for each learning style. It can be inferred that visual students overall scored consistently higher than haptic students. It can also be inferred that the complexity of the block had an impact on how well students scored. Students scored consistently lower on complex blocks, like block three, and higher on blocks with less complexity than others, such as block one, as illustrated in Figures 4.9 and 4.10.

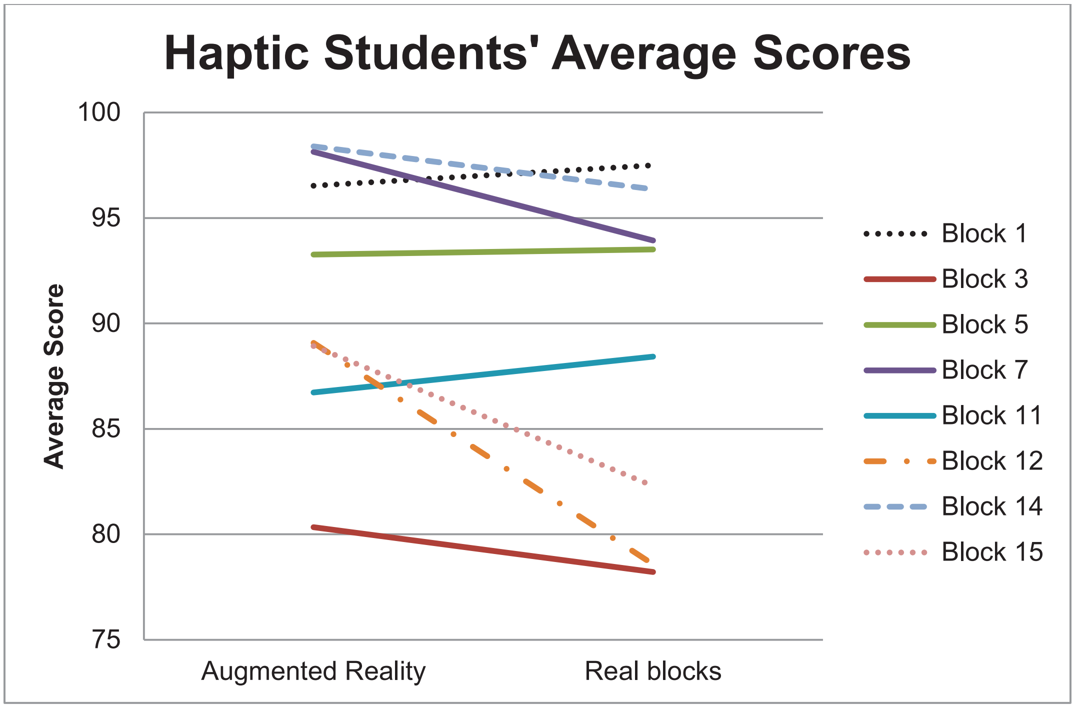


Figure 4.6: Haptic Students' Average Scores

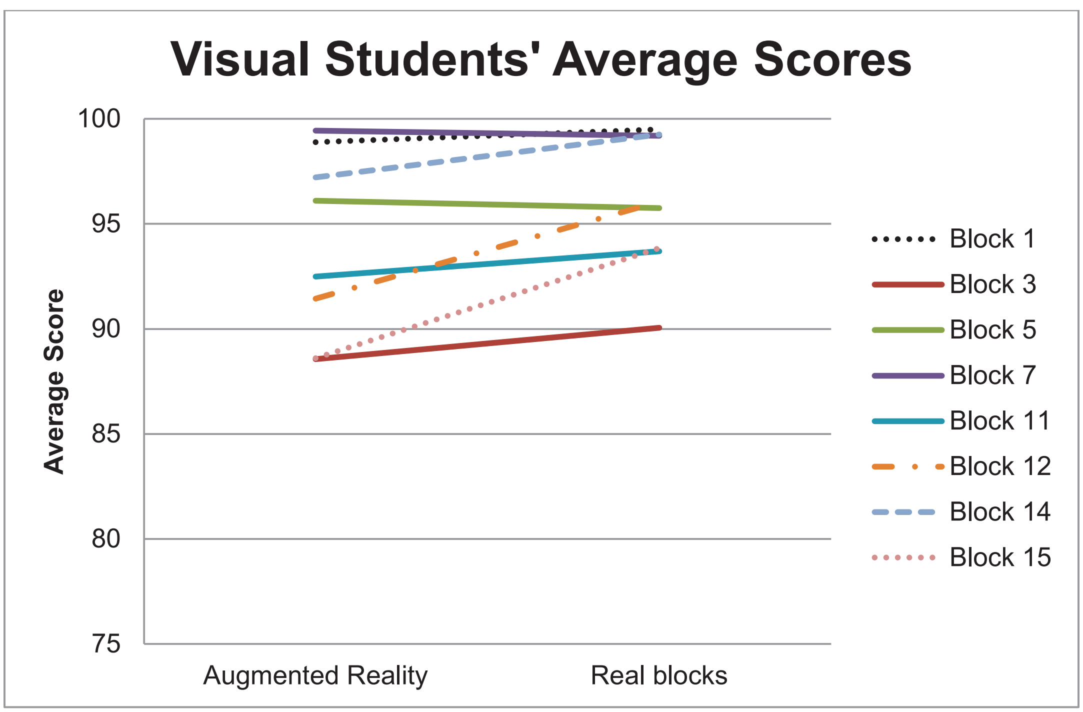


Figure 4.7: Visual Students' Average Scores

4.2.2.7. Subject-to-Subject Variance

Subject-to-subject variance refers to the differences each student might have compared to another student, related to engineering graphics. Each student was classified as either haptic or visual, and the subject received exactly one treatment, otherwise known as the instructional method. The study accounted for subject-to-subject variation by using a nested model with subject nested within learning style by instructional method. The subject-to-subject variance resulted in a P-value of 0.000, which is less than the alpha level of 0.05, meaning this interaction is statistically significant in this study.

4.3. Hypothesis Results

The hypothesis that is the basis for this study is addressed in this section. The nested univariate repeated measures ANOVA gave results of the interaction between learning style and instructional method. The ANOVA model gave a P-value test statistic associated with the interaction of the variables. If the P-value of the test statistic was less than or equal to the alpha level of 0.05 then the null hypothesis was rejected. If the null hypothesis was rejected than there was a statistically significant difference in the interaction of learning style and instructional methods (Miller, 1992). The hypothesis in null form is:

Ho: There is no significant difference between the type of instructional method used and type of learning style of student participants.

The nested univariate repeated measures ANOVA resulted in a P-value of 0.137, which is greater than the alpha level of 0.05, meaning the hypothesis was not rejected. The interaction between learning style and instructional method was not statistically significant.

Figure 4.11 illustrates learning style compared to instructional method using the mean scores of the haptic and visual students testing with real blocks and augmented reality blocks. The line graph lines did not cross thus indicating there was no interaction between learning style and instructional method. This suggests that of the instructional methods used in the study, augmented and real blocks, either would function equivalently as a learning aid for students of different learning style (visual or haptic) with engineering graphic problems.

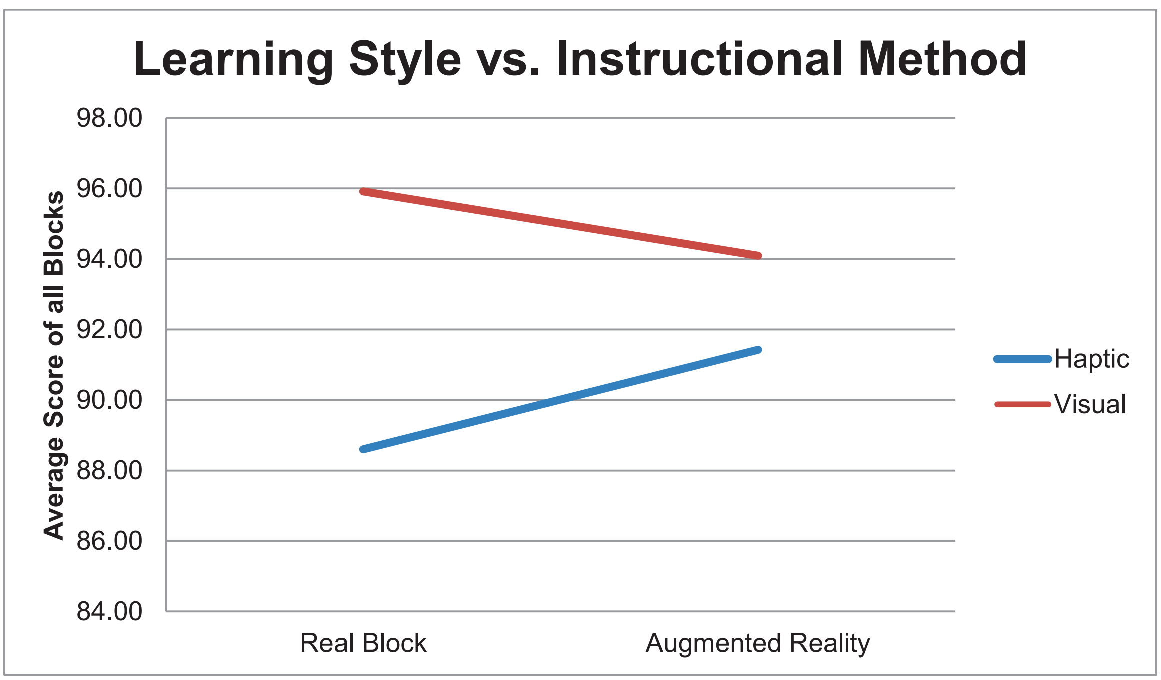


Figure 4.8: Learning Style vs. Instructional Method

4.3.1. Learning Style

Students who participated in the study were designated as either visual or haptic learners using the PSVT and the HVDT, as discussed earlier in this chapter. The literature theorizes that visual learners perform better on spatial tasks such as visualization than haptic learners (Lowenfeld, 1945; Miller, 1992; Study, 2001). The results study found this statement validated the earlier research. Independent of instructional method, visual students did perform better on visualizing every block compared to the haptic students. Overall, visual learners scored higher than haptic learners on each of the eight blocks. This indicates that spatial tasks such as visualization are easier for visual learners than haptic learners.

4.3.2. Instructional Method

This study explores whether the visualization advantage that visual learners have over haptic learners can be leveled for the haptic learners through the use of two different instructional methods (augmented reality or real blocks). The statistical results of the study imply that the different instructional methods did not allow haptic subjects to advance their visualization abilities compared with the visual subjects. It seems that augmented reality blocks and real blocks cannot make up the inherit differences in the learn styles of visual and haptic subjects. This is discussed more in Chapter 5.

4.4. Summary

This chapter discussed the results from all the testing done for the study. The chapter started with discussing the demographics of the participants. Different demographics that were gathered were age, gender, major, and class standing. Next, the chapter discussed the results of each test given to the participants. This section started with the PSVT, then the HVDT, and finally the block test. The block test was analyzed in depth. First, the selection of the blocks was explained, and then a brief summary of the block test. The scoring of the block worksheets was also explained. Finally, the data of the block test was analyzed. The eight blocks were then analyzed individually.

After the blocks were explained, the overall block test was evaluated by a nested univariate repeated measures ANOVA. This statistical model compared different variables in the block test, including learning style, instructional method, the blocks, and subject-to-subject variation. These interactions were then analyzed using graphs and tables to interpret the data. Learning style, the blocks, and subject-to-subject variation were found to be statistically significant. Instructional method was not found to be statistically significant.

Finally, the hypothesis was tested using the nested univariate repeated measures ANOVA model. It was determined to not reject the null hypothesis, meaning the data from the block test showed a non-significant interaction between the learning style of the students, haptic or visual, and the instructional method of augmented reality or real blocks. This suggested that of the instructional methods tested (augmented reality or real blocks); either would help aid a student of learning style (visual or haptic) equivalently when developing engineering graphics skills such as visualization and spatial ability.

This study is another example of visual students outperforming haptic students in spatial tasks, even with different aids. The research has shown that visual learners visualize easier than haptic students, and this study is no exception (Lowenfeld, 1945; Miller, 1992; Study, 2001).

The hypothesis was not significant, but this study has shed light on how the cutting edge innovative technologies, such as augmented reality, may not allow for the advancement of spatial abilities more successfully than traditional instructional methods such as real models.

CHAPTER 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter discusses a brief summary of the study; explaining the problem statement the study and the methodology used to complete it. Next, this chapter explains the conclusions of the study and discusses the relevance of these findings. Finally, recommendations for future research in the areas of learning style and instructional method are made.

5.1. Summary

This study focused on advancing spatial abilities for entry-level engineering students, related to engineering graphics. The problem of the study was to determine if the use of augmented reality blocks or real blocks (different instructional methods) would advance spatial ability in students who possess different learning styles of visual or haptic.

The literature indicated that not all students possess the same learning styles or spatial abilities; this study focused on the learning style of visual/haptic (Lowenfeld, 1945; Miller, 1992; Study, 2001). Employing an instructional method of augmented reality or real blocks, the study asked which instructional method helped advance the spatial abilities of subjects who possess either visual or haptic learning style. The research was done in the context of an engineering graphics course that relies heavily on visualization abilities.

The literature review discussed topics from spatial ability, engineering graphics, learning styles, and augmented reality used for the advancement of spatial abilities of engineering students. Spatial ability is discussed reviewing the history of spatial research, spatial cognition, developmental theories, gender differences, learning and training, and spatial tests.

This study implemented the use of cutting edge, innovative technologies, such as augmented reality, to aid students in spatial ability advancement. The study was being utilized to test these new innovative approaches to understand if the technology really is helpful in aiding students in advancing spatial skills. This study divided the students into two different learning styles to understand how different learning styles can have an impact on spatial skill advancement depending on different instructional methods.

5.2. Methodology

This section describes the methodology used for the study, including the instrumentation. The study was performed at Purdue University at the West Lafayette, Indiana campus, in the fall semester of 2011. The course utilized to recruit participants from was CGT 163, Introduction to Engineering Graphics. This course covers topics that require visualization abilities such as, multi-view orthographic sketching, pictorial isometric sketching, and 3-D modeling in computer-aided design (CAD) programs. The course is required for Mechanical Engineering (ME) and Aeronautical and Astrological Engineering (AAE) students and majority of them fulfill this requirement in their first two years of their curriculum at Purdue University.

The methodology of the study employed a sample of participants that was split into two groups determined by the Purdue Spatial Visualization Test (PSVT) and the Haptic/Visual Discrimination Test (HVDT). These two tests divided the participants into students that learned with visual tendencies and students that learned with haptic tendencies. Participants in each group were randomly selected to use either the augmented reality or the real blocks instructional method.

First the PSVT was administered in the CGT 163 lecture during the first week of classes, to all the students who were present in lecture on that day. The PSVT is a visual test used to measure spatial ability. It consists of three parts: developments, rotations, and views (Guay, 1976). Developments are the folding of shapes into three-dimensional objects (Guay, 1976). Rotations are designed to “help visualize the rotation of a three-dimensional object” (Guay, 1976, p.6). Views are what the three-dimensional object looks like from different views (Guay, 1976). The participants took the whole test, as all parts of the test are related to engineering graphics. 370 students took the PSVT on this day. Students who scored a 95% or better on the PSVT were considered visual students. These students were asked to sign up for the block test as participants in the visual group.

Students who scored lower that 95% were asked to sign up to take the HVDT during the second week of classes. 71 students took the HVDT during this week. The HVDT is an individual test that determines if a participant's learning style is haptic; that is, learning with tactile and touch as opposed to visually. The test consists of a participant reaching through a screened frame (where they cannot see what is through the screen) and holding an object. Next, the participant is asked to identify the object in their hand, without looking at it, from an identification chart. There are four criteria: shape, size, texture, and configuration. The student receives a score depending on how well they identify these characteristics of the object (Study, 2001). Students who scored a normal score of above 100 (average) were considered to possess haptic tendencies and they were asked to sign up for the haptic group for the block testing.

The students were then split into the two learning style groups of visual and haptic students determined by the PSVT and HVDT respectively. Next, the instructional treatment was started and continued for the next three weeks. 67 students were tested, 29 haptic and 38 visual. During the block testing, each student received eight different cut-blocks ranging in difficulty from simple to complex. The subject constructed these blocks as multi-view sketches. Every student received the same eight cut-blocks, in the same order. Each student received eight worksheets. On each worksheet the isometric or pictorial view of the cut-block was illustrated along with an orthographic grid to sketch the multi-view of the cut-block. These worksheets can be found in Appendix A. The students were randomly assigned into one of two instructional methods; real or augmented reality blocks. The worksheets were then gathered and scored for accuracy. Each cut-block had a corresponding score sheet, located in Appendix B. Students received a set amount of points for sketching the different features of each cut-block correctly in all three views.

The main objective of this study was to determine the effect of real versus augmented models on spatial ability based on haptic or visual learning style of entry-level engineering graphic students. A nested univariate repeated measures ANOVA test was used to determine if there was an interaction between learning style and instructional method.

5.3. Findings

The findings of this study were based on the research hypothesis stated initially in Chapter 1. The hypothesis was tested at 0.05 level of probability using a nested univariate repeated measures ANOVA test. The hypothesis that was investigated in this study focused on how entry-level engineering students, divided into visual and haptic learners, advanced their visualization abilities in engineering graphics using either augmented reality or real blocks. The hypothesis focused on the interaction between learning style (visual or haptic) and instructional method (augmented reality or real blocks). Which method aided which type of learning style best? The statistical findings gave a result higher than the alpha level of 0.05, indicating that the interaction between learning style and instructional method was not significant. Meaning either instructional method would aid either learning style equivalently.

However, there were other factors included in the statistical analysis that the hypotheses did not directly address. These factors include learning style, instructional method, block, learning style by block, instructional method by block, learning style by instructional method by block, and subject-to-subject variance. It was important to include these statistical findings of these other factors because the findings support the hypothesis results and enlighten some areas for future study. From the ANOVA model it was found that learning style, block, learning style by block, learning style by instructional method by block, and subject-to-subject variance were statistically significant.

Learning style significance can be supported from the literature of prior research in this area. Visual students generally performed better at spatial tasks including visualization than haptic students (Lowenfeld, 1945; Miller, 1992; Study, 2001). This is shown from the literature and was supported from the results of this study. In the study, visual students outperformed haptic students on every block.

The complexity level of the blocks was also statistically significant. It was determined that more complex blocks, determined by inclined and oblique features or type of planes, were harder to visualize than a block that did not have these abstract features. A less complex a block was defined as possessing features or planes that were horizontal of vertical.

The ANOVA model classified the interaction between learning style and complexity level of block as statistically significant. Visual students tend to score higher than haptic students while comparing the overall mean scores of all the blocks. This is true even when the instructional method was not taken into account.

The interaction between learning style, instructional method, and complexity of the blocks was also found to be statistically significant with the ANOVA model. Again, it can be inferred that visual students generally outscored haptic students independent of the block complexity and the instructional method. However, this interaction being statistically significant infers that the learning style, block complexity, and instructional method develop an influence on how well a student scored.

Subject-to-subject variance is the last factor that was found statistically significant in the ANOVA model. Basically, each student was not identical with the next student, because each student possessed different internal factors that have developed their spatial abilities and visualization skills over their lives. Some students might have played with more spatial sensing toys as children such as Legos, some students might have taken a drafting class in high school, some students might just be inheritably better at these skills than others. Subject-to-subject variance accounts for these potential differences in the statistical model. This factor was significant in the study because any one of these differences and the combination of them made each student unique in their spatial abilities of the sample of students chosen to participate.

5.4. Discussion of the Findings

The data does not support the research hypothesis that the two different instructional methods (real or augmented blocks) should be employed depending on the learning style (visual or haptic). The data supports that either instructional method that was used, would help students of either learning style advance their spatial abilities.

5.4.1. Learning Style

One might have thought that real blocks would aid haptic students more so than the augmented reality blocks. The research contends that haptic students learn through tactile interaction with an object. Since the real blocks could be held and felt as opposed to the augmented reality blocks that cannot; this fact lead the researcher to believe that the real blocks might be more beneficial than augmented reality blocks for haptic students. This however, was not the case. Haptic students did equally as well with augmented reality and real blocks, in this study. Future research should be repeated to confirm these results.

Students who are identified as visual are likely to be better at visualization skills than haptic students according to the results of prior research studies (Lowenfeld, 1945; Miller, 1992; Study, 2001). Both the augmented reality and real blocks aided visual students in an equivalent way. This result might be what is expected to happen since visual students are better with spatial skills in general. It might be beneficial to test visual students again, with more challenging blocks.

The statistical result of learning style being significant in this study follows what the literature has theorized about visual or haptic students possessing spatial abilities (Lowenfeld, 1945; Miller, 1992; Study, 2001). The results indicate that visual students seem to have a higher capacity to understand spatial problems and tasks than haptic students, no matter what the aid is. Students who used real blocks or augmented blocks that were designated visual students did better overall than haptic students. This signifies that learning style does make a difference in student's spatial abilities, which also follows the statistical evidence from this study.

Visual learners may possess the required spatial abilities required to visualize, making the augmented reality or real block aid irrelevant. The visual learner may not need an aid to help visualize the cut-block. The literature suggests that no matter the instructional method, haptic learners may still struggle with visualization because their learning style does not complement visual tasks such as block exercises (Lowenfeld, 1945; Miller, 1992; Study, 2001).

5.4.2. Subject-to-Subject Variation

Subject-to-subject variance refers to the differences each student might have compared to another student, related to engineering graphics. For example, some students might have taken an engineering graphics course in high school, or might be genetically better at spatial ability and visualization than the next student. Subject-to-subject variance takes these possible differences into account in the statistical model (Montgomery, 2009).

These differences in the students could have impacted the overall study. Some students may have taken a previous course in engineering graphics or are inheritably better at spatial cognition. It is impossible to use identical participants because of background experiences and other factors make them different from each other. Accounting for these individual subject differences using subject-to-subject variance in the statistical model increased the validly of the study.

5.4.3. Augmented Reality Technology versus Real Blocks

The study suggests, from the conclusion of the hypothesis that the two different instructional methods did not seem to help or hurt either the visual or haptic learners. The statistical conclusion of the hypothesis also suggests that either the augmented reality blocks or the real blocks could have equal potential in helping students learn visualization skills. The results of the study suggests that augmented reality blocks have a greater potential of getting students interested in learning visualization skill from the expressions of a majority of the students who used the augmented reality blocks.

The augmented reality blocks used some of the newest technologies to help students develop spatial abilities. However, this study implies that real wooden blocks helped students of both visual and haptic learning styles equally as the augmented reality blocks. Additional research in this area is suggested to understand the cost effectiveness versus learning benefit of each instructional method. It is also noted, that the augmented reality Vizard system that was used in this study, was not practical for a large class. Research should also be investigated in using more practical devices such as smartphones and tablets to receive the same results.

The technology of augmented reality might sound very appealing to most educators and students. Using this innovative technology to convey learning and skills needed for the classroom and beyond is one way to get students interested and eager to learn. However, if a less motivating, less expensive method is thought to be equally as successful in advancing the visualization abilities of students then which method does an educator choose? This decision should be made by considering the costs of augmented reality versus the cost of producing real models and how successful each method is in advancing students' spatial abilities. There needs to be more research done in this area, and as the costs decrease and availability of new augmented reality systems become more available than the use of this technology could be considered for implementation. There are many new developments that can be made with tablets and smartphones that may be far less expensive than the Vizard augmented reality system that was used in this study and might benefit students in developing spatial skills. Engineering education could potentially benefit greatly by exploring the uses of new and old technology in developing spatial skills in future engineers. Further research should be done to understand the uses of technology such as smartphones and tablets to develop visualization skills in engineering education.

5.5. Conclusions

The conclusions of this study were based on its research hypothesis. The following conclusions were drawn based upon the statistical analysis and findings found in Chapter Four. It can be concluded that:

- The learning style of either visual or haptic impacted on how well students advanced spatial skills based on the orthographic cut block evaluation. Visual students developed and performed better on spatial tests than haptic students.
- The instructional method of augmented reality blocks or real blocks had no effect on students of different learning styles of visual/haptic in aiding in their development of spatial skills.

5.6. Recommendations

The review of literature, experiences of the researcher during the study, and the statistical results of it serve as a basis for several recommendations. These recommendations are directed to educators and future researchers in spatial ability advancement, learning styles, and instructional methods.

- Repeat the study using more challenging blocks. In this study some blocks were very challenging while some were very simple. If this study was to be repeated the very simple blocks should be replaced with more challenging ones. Repeating the study with more challenging blocks may give a more accurate analysis of this thesis.
- Even though augmented reality blocks were proven to help students equally as real blocks, several students were excited about the 3-D glasses and using an augmented reality system. This eagerness to learn might make augmented reality blocks worth the investment in this technology in the future. However, it is believed, with more research, applications for smartphones and tablets could be developed to receive a similar effect as the Vizard system. The Vizard system that was used in this study would not be cost effective for a large multi-lab section course. These different technologies might be both cost effective in implementation and motivational for the students to want to use.
- Comparing the cost effectiveness of mass producing the real blocks and developing new applications for smartphones and tablets. This is

important to understand, from a standpoint of being cost effective. Instructional methods for advancing spatial skills in students need to be both effective and affordable.

- Exploring in depth the fundamental differences between visual and haptic learners to understand how they learn. This could help academia better understand how to teach these different learning styles of students. This study adds to the many previous studies that acknowledge visual learners as students who possess well-developed spatial abilities while haptic students seem to struggle with spatial abilities. Exploring the fundamental differences in these learning styles could potentially help develop creative methods of teaching to help students of both learning styles.

These recommendations could potentially find a new creative way of learning in the classroom in the realm of engineering graphics and spatial abilities coupled with the implementation of new technologies.

LIST OF REFEERNCES

LIST OF REFERENCES

Anderson, G., Fruchter, B. Manuel, H. T., & Worchel, P. (1954). *Survey of research on spatial factors*. Lackland, TX: Air Force Personal Training Research Center.

ANSI: Historical Overview. (n.d.). . Retrieved April 10, 2011, from http://www.ansi.org/about_ansi/introduction/history.aspx?menuid=1

Azuma, R. T. (1997). A survey of augmented reality. *Teleoperators and Virtual Environments, 6,* 355-385.

Berry, M. & Genskow, J. (1986). Haptic visual discrimination and cognitive functioning. *Vocational Evaluation and Work Adjustment Bulletin, Spring,* 15-17.

Beroline, G. R. & Weibe, E. N. (2005). *Fundamentals of Graphics Communications Fifth Edition*. New York, New York: McGraw-Hill.

Branoff, T. J. (2000). Spatial visualization measurement: a modification of the Purdue spatial visualization test- visualization rotations. *Engineering Design Graphics Journal. volume 64, number 2*, 14-22.

Carroll, J. B. (1993*). Human cognitive abilities*. New York: Cambridge University Press (pp.30-72/Chapter 2).

Connolly, P. E. (2009). Spatial ability improvement and curriculum content. *Engineering Design Graphics Journal. volume 73 number 1,* 1-5.

Devore, J. L. (2008). Multifactor analysis of variance. In C. Crockett (Ed.), Probability and Statistics for Engineers and the Sciences 7th Edition (pp.397-445). Belmont, CA: Thompson Brooks/Cole.

Eals, M., & Silverman, I. (1994). The hunter-gatherer theory of spatial sex differences: proximate factors mediating the female advantage in recall of object arrays. *Ethnology and Sociobiology 15*, 95-105.

Earl, J. H. (1987). *Engineering design graphics*. Reading, MA: Addison-Wesley.

Eliot, J., & Smith, I. M. (1983). *An international directory of spatial tests*. Windsor, Berkshire: NFER-NELSON.

El Koussy, A. A. H. (1935). The visual perception of space. *The British Journal Of Psychology*, Monograph supplements, 1-80.

Envision Center at Purdue University website (n.d.). Retrieved August 1, 2011, from www.envision.purdue.edu/about.html.

Fisher-Thompson, D. (1990). Adult sex typing of children’s toys. *Sex Roles*, *23*(5), 291–303.

Griffith, A. L. (2010). Persistence of women and minorities in STEM field majors: is it the school that matters?. *Economics of Educational Review, 29*, 911-922.

Guay, R. (1976). *Purdue Spatial Visualization Test.*

Guay, R. B. (1980, April). *Spatial ability measurement: A critique and an alternative.* Paper presented at the Annual Meeting of the American Educational Research Association, Boston, MA.

Harris, L. J. (1978). Sex differences in spatial ability: possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.), *Asymmetrical Function of the Brain*. Cambridge: Cambridge University Press.

Hartman, N. W., Connolly, P. E., Gilger, J. W., Bertoline, G. R., & Heisler, J. (2006). Virtual reality-based spatial skills assessment and its role in computer graphics education. *ACM SIGGRAPH 2006 Educators program* (p. 46–54).

Kelley, T. L. (1928). *Crossroads in the mind of man*. Stanford, CA: Stanford University Press (pp.1-23/chapter 1)

Kaufmann, H., & Meyer, B. (2008). Simulating educational physical experiments in augmented reality. *ACM SIGGRAPH ASIA 2008 educators program* (p. 1–8).

Lohman, D. F. (1988). Spatial abilities as traits, processes, and knowledge. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 4, pp. 181-428). Hillsdale, NJ: Lawrence Erlbaum Associates.

Lohman, D. F., & Kyllonen, P. C. (1983). Individual differences on solution strategy on spatial tasks. In Dillon & Schmede (Eds.), *Individual differences in cognition* (Vol 1, pp. 105-132). New York:Academic Press

Lowenfeld, V. (1945). Tests for visual and haptical aptitudes. *American Journal of Psycholog*y (58, pp. 100-112).

Luzadder, W. J., & Duff, J. M. (1989). *Introduction to engineering drawing*. Prentice-Hall: Englewood Cliffs, NJ.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences*. Stanford, CA: Stanford University Press (pp. 63-133/chapter 3).

McCarron, L. T., & Dial, J. G. (1988). *Sensory Integration: The Haptic Visual Processes.* McCarron-Dial Systems Inc.

McGee, M. G. (1979). Human spatial abilities: *Sources of sex differences*. New York: Praeger Publishers.

Miller, C. L. (1992). *The effectiveness of real- and computer-generated models to avance the spatial abilities of visual/haptic engineering students* (Doctoral dissertation, The Ohio State University). Retrieved from Proquest.com

Mohler, J. (2011). [Notes from CGT 600 at Purdue University]. Unpublished raw data.

Mohler J. L., & Miller, C. L. (2008). Improving spatial ability with mentored sketching. *Engineering Design Graphics Journal, volume. 72 number 1*, 19-27.

Montgomery, D. C. (2009). Nested and split-plot designs. In J. Welter & J. Foxman (Eds.), *Design and analysis of experiments* (pp. 542-556). Hoboken, NJ: John Wiley & Sons, Inc.

Newcombe, N. S., & Learmonth, A. E. (2005). Development of spatial competence. In P. Shah & A. Miyake (Eds.), The Cambridge Handbook of Visuospatial Thinking. New York: Cambridge University Press.

NIST/SEMATECH. (June 6, 2003). Two-Way Nested ANOVA. In *NIST/SEMATECH e-Handbook of Statistical Methods* (3.2.3.3.). Retrieved from http://www.itl.nist.gov/div898/handbook/ppc/section2/ppc233.htm.

Nordvik, H., & Amponsah, B. (1988). Gender differences in spatial abilites and spatial activity among university students in an egalitarian educational system. *Sex Roles*, 38(11/12), 1009-1023.

Olson, D. R., & Bialystok, E. (1983). *Spatial cognition: the structure and development of mental representation of spatial relations*. London: Lawerence Erlbaum Associates.

Sekaran, U., & Bougie, R. (Eds.). (2010). *Research methods for business 5th edition.* West Sussex, United Kingdom: John Wiley & Sons Ltd.

Sorby, S. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students. *International Journal of Science Education*, *31*(3), 459-480. doi:10.1080/09500690802595839

Study, N E. (2003). Haptic abilities of freshman engineers as measured by the haptic visual discrimination test. *Engineering Design Graphics Journal*, vol. 67 number 3, 29-34.

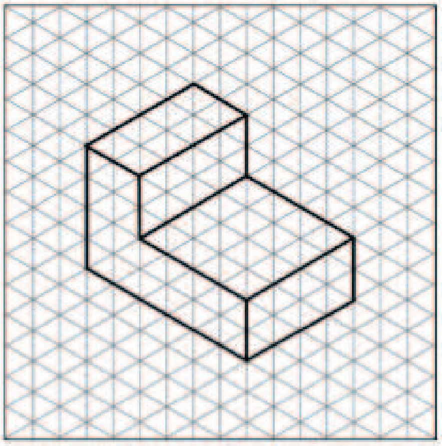
Study, N. E. (2001). The effectiveness of using the successive perception test I to measure visual-haptic ability in engineering students (Doctoral Dissertation, Purdue University). Retrieved from Proquest.com

Thurstone, L. L. (1950). Some primary abilities in visual thinking. *Proceedings of the American Philosophical Society*, 94(6), 517-521.

Veurink, N. L., Hamlin, A. J., & Kampe, J. C. M. (2009). Enhancing Visualization Skills-Improving Options aNd Success (EnViSIONS) of Engineering and Technology Students. *Engineering Design Graphics Journal, volume. 73 number 1-17.*

APPENDICES

Appendix A: Worksheets



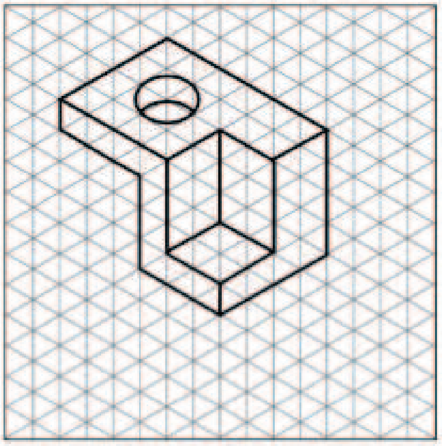
Model 1

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME________________________________

TYPE_________ SCORE_____



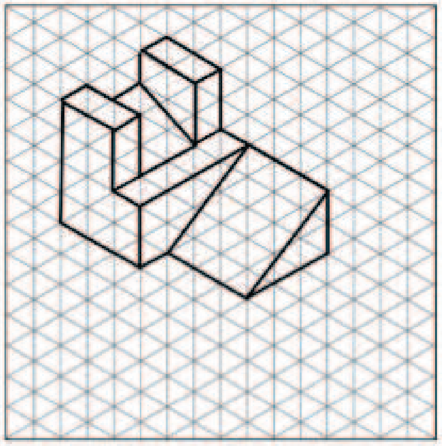
Model 3

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME___________________________________

TYPE_________ SCORE_____



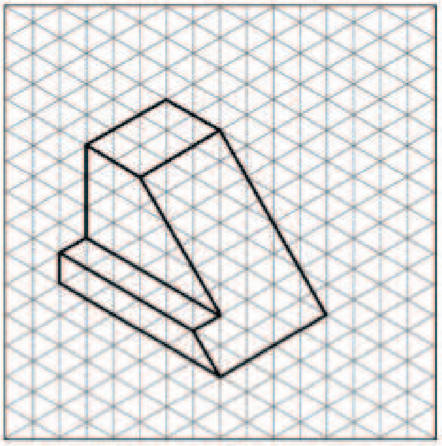
Model 5

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME________________________________

TYPE_________ SCORE_____



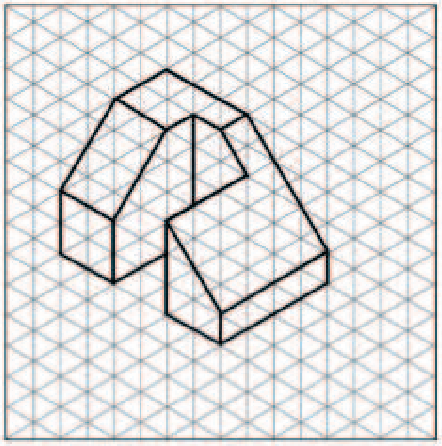
Model 7

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME__________________________________

TYPE_________ SCORE_____



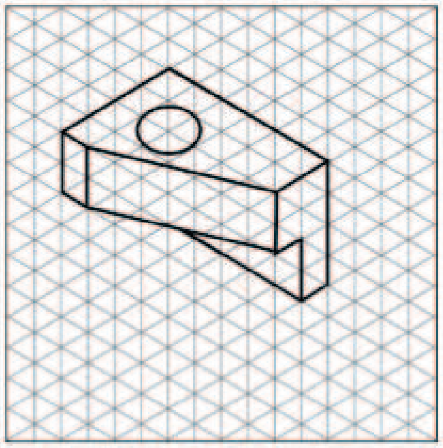
Model 11

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME__________________________________

TYPE_________ SCORE_____



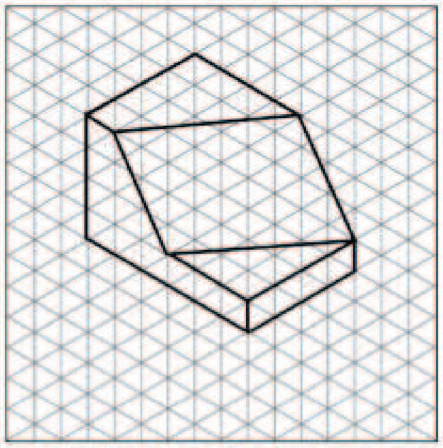
Model 12

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME_______________________________

TYPE_________ SCORE_____



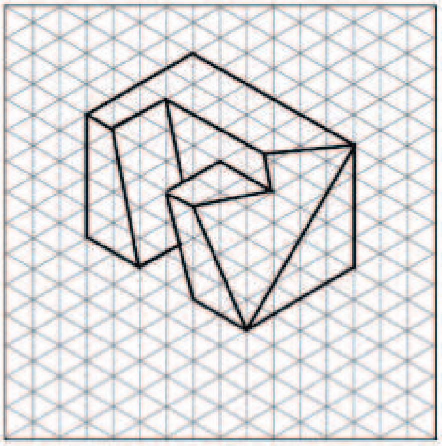
Model 14

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

SCALE 1:1

NAME___________________________________

TYPE_________ SCORE_____



Model 15

Sketch this object on the orthographic grid below, sketching the front, top, and right side views. Include all hidden features with dashed lines and all axis and center lines as needed.

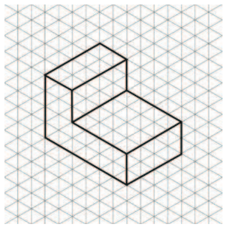
SCALE 1:1

NAME________________________________

TYPE_________ SCORE_____

Appendix B: Score Sheets

Rubric Model 1:

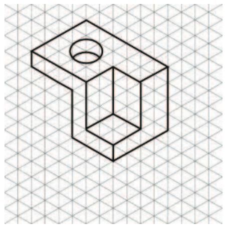


Student Name ___________________________
Student ID number________________________

	Rectangular prism (bottom)	rectangular prism (top)	TOTAL
Top View	___/15	___/15	___/30
Front View	___/20	___/20	___/40
Side View	___/15	___/15	___/30

Extra Lines (dashed or solid)	___/-1 each
Missing Lines (dashed or solid)	___/-1 each
View in incorrect orientation	___/-5 each
TOTAL SCORE	___/100

Rubric Model 3:

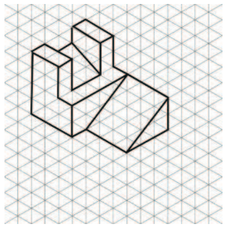


Student Name ________________________
Student ID number______________________

	Rectangular prism (bottom)	rectangular prism (top)	negative rectangular prism (bottom)	negative cylinder (top)	TOTAL
Top View	___/5	___/10	___/5	___/10	___/30
Front View	___/10	___/10	___/10	___/10	___/40
Side View	___/10	___/5	___/5	___/10	___/30

Extra Lines (dashed, center or solid)	___/-1 each
Missing Lines (dashed, center or solid)	___/-1 each
Incorrect Line Precedence	___/-1 each
View in incorrect orientation	___/-5 each
TOTAL SCORE	___/100

Rubric Model 5:



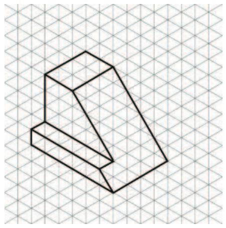
Student Name ___________________________

Student ID number________________________

	Rectangular prism (left)	triangular prism (right)	rectangular prism (top)	triangular prism (top)	TOTAL
Top View	___/5	___/10	___/5	___/10	___/30
Front View	___/10	___/10	___/10	___/10	___/40
Side View	___/10	___/5	___/5	___/10	___/30

Extra Lines (dashed, center or solid)	___/-1 each
Missing Lines (dashed, center or solid)	___/-1 each
Incorrect Line Precedence	___/-1 each
View in incorrect orientation	___/-5 each
TOTAL SCORE	___/100

Rubric Model 7:



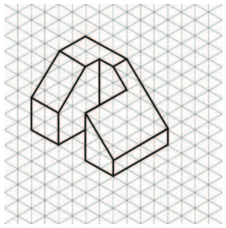
Student Name ___________________________

Student ID number________________________

	Triangular prism (bottom)	Triangular prism (top)	TOTAL
Top View	___/15	___/15	___/30
Front View	___/20	___/20	___/40
Side View	___/15	___/15	___/30

Extra Lines (dashed or solid)		___/-1 each
Missing Lines (dashed or solid)		___/-1 each
View in incorrect orientation		___/-5 each
	TOTAL SCORE	___/100

Rubric Model 11:

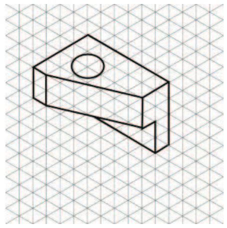


Student Name ________________________
Student ID number_____________________

	Triangular prism (left)	triangular prism (right)	negative rectangular prism (front)	rectangular prism (bottom)	TOTAL
Top View	___/10	___/5	___/10	___/5	___/30
Front View	___/10	___/10	___/10	___/5	___/35
Side View	___/10	___/10	___/10	___/5	___/35

Extra Lines (dashed, center or solid)	___/-1 each
Missing Lines (dashed, center or solid)	___/-1 each
Incorrect Line Precedence	___/-1 each
View in incorrect orientation	___/-5 each
TOTAL SCORE	___/100

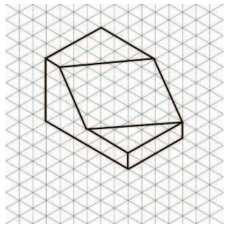
Rubric Model 12:



Student Name ____________________________
Student ID number________________________

	Triangular prism (top)	rectangular prism (back)	negative cylinder	TOTAL
Top View	___/10	___/10	___/10	___/30
Front View	___/15	___/10	___/10	___/35
Side View	___/15	___/10	___/10	___/35
Extra Lines (dashed, center or solid)				___/-1 each
Missing Lines (dashed, center or solid)				___/-1 each
Incorrect Line Precedence				___/-1 each
View in incorrect orientation				___/-5 each
			TOTAL SCORE	___/100

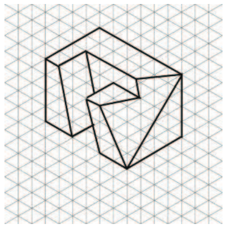
Rubric Model 14:



Student Name ________________________
Student ID number______________________

	Rectangular prism (bottom)	oblique surface	rectangular prism (left)	TOTAL
Top View	___/10	___/10	___/10	___/30
Front View	___/10	___/15	___/10	___/35
Side View	___/10	___/15	___/10	___/35
Extra Lines (dashed, center or solid)				___/-1 each
Missing Lines (dashed, center or solid)				___/-1 each
Incorrect Line Precedence				___/-1 each
View in incorrect orientation				___/-5 each
		TOTAL SCORE		___/100

Rubric Model 15:



Student Name ________________________
Student ID number_____________________

	Inclined surface (left)	negative rectangular prism (front)	oblique surface (left)	rectangular prism (back)	TOTAL
Top View	___/5	___/10	___/10	___/5	___/30
Front View	___/5	___/10	___/10	___/10	___/35
Side View	___/5	___/10	___/10	___/10	___/35

Extra Lines (dashed, center or solid)	___/-1 each
Missing Lines (dashed, center or solid)	___/-1 each
Incorrect Line Precedence	___/-1 each
View in incorrect orientation	___/-5 each
TOTAL SCORE	___/100

Appendix C: Individual Block Scores

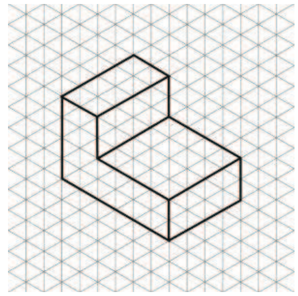


Figure C.1: Isometric View of Block 1

Table C.1: *Results of Block 1 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	83.00	100.00	97.00	5.91
Visual	38.00	85.00	100.00	99.21	2.73
Augmented	33.00	83.00	100.00	97.82	5.17
Real Block	34.00	85.00	100.00	98.68	3.76
Total	67.00	83.00	100.00	98.25	4.50

Table C.2: *Results of Block 1 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	83.00	100.00	96.53	6.46
	Real Block	14.00	85.00	100.00	97.50	5.46
Visual	**Augmented**	18.00	85.00	100.00	98.89	3.66
	Real Block	20.00	95.00	100.00	99.50	1.54

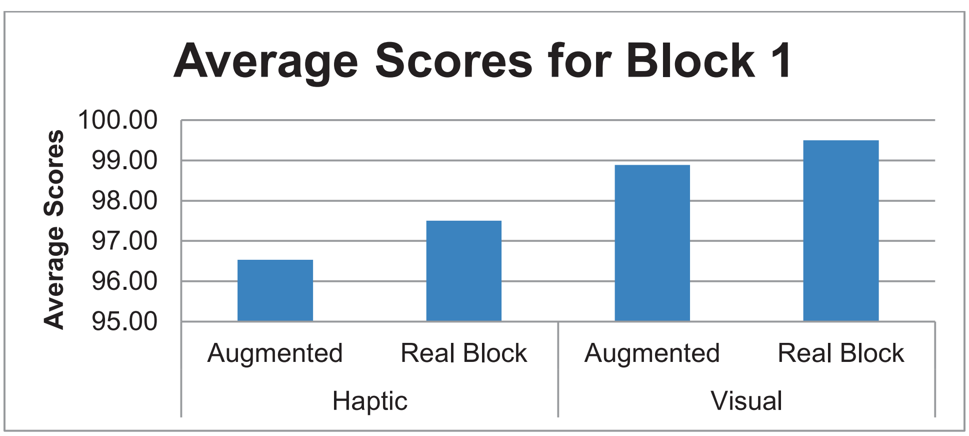


Figure C.2: Average Scores of Block 1

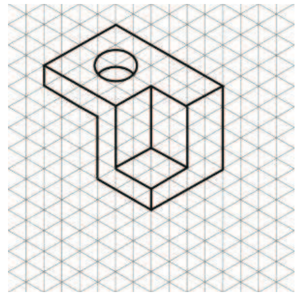


Figure C.3: Isometric View of Block 3

Table C.3: *Results of Block 3 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	47.00	100.00	79.31	14.08
Visual	38.00	64.00	100.00	89.34	9.80
Augmented	33.00	47.00	100.00	84.82	13.45
Real Block	34.00	49.00	100.00	85.18	12.26
Total	67.00	47.00	100.00	85.00	12.77

Table C.4: *Results of Block 3 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	47.00	100.00	80.33	14.56
	Real Block	14.00	49.00	95.00	78.21	14.01
Visual	**Augmented**	18.00	64.00	100.00	88.56	11.56
	Real Block	20.00	69.00	100.00	90.05	8.14

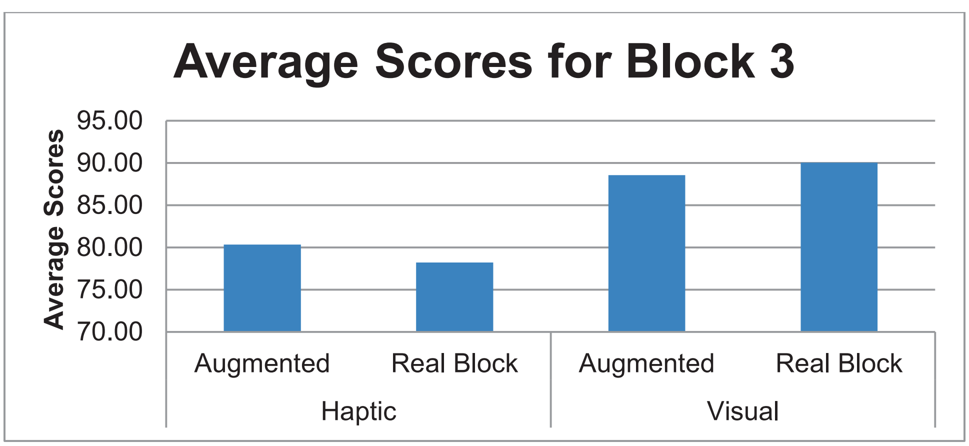


Figure C.4: Average Scores of Block 3

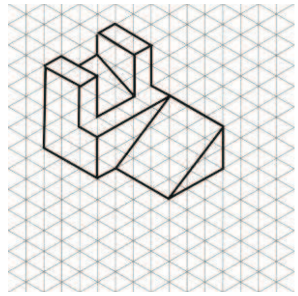


Figure C.5: Isometric View of Block 5

Table C.5: *Results of Block 5 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	59.00	100.00	93.38	8.78
Visual	38.00	70.00	100.00	95.92	6.56
Augmented	33.00	59.00	100.00	94.82	8.38
Real Block	34.00	70.00	100.00	94.82	7.00
Total	67.00	59.00	100.00	94.82	7.65

Table C.6: *Results of Block 5 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	59.00	100.00	93.27	10.69
	Real Block	14.00	80.00	100.00	93.50	6.56
Visual	**Augmented**	18.00	80.00	100.00	96.11	5.83
	Real Block	20.00	70.00	100.00	95.75	7.30

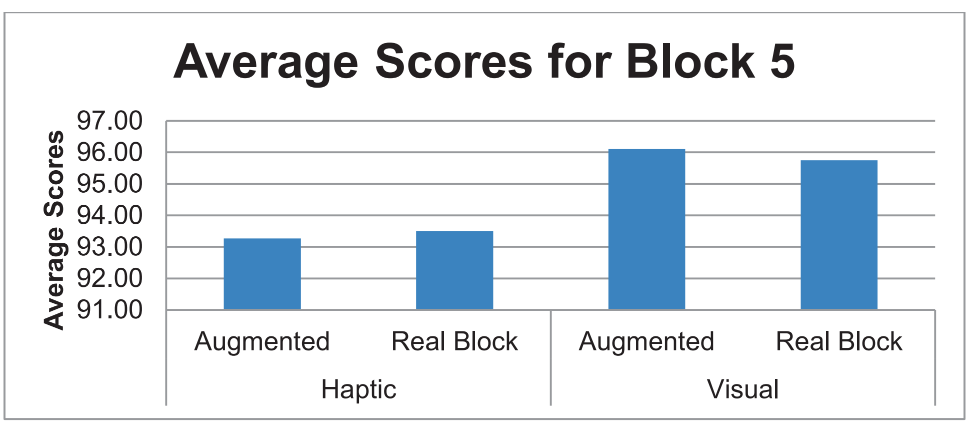


Figure C.6: Average Scores of Block 5

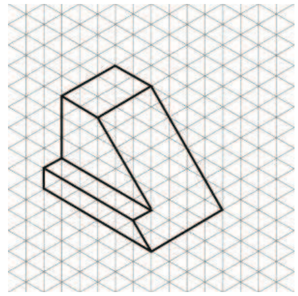


Figure C.7: Isometric View of Block 7

Table C.7: *Results of Block 7 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	65.00	100.00	96.10	8.18
Visual	38.00	85.00	100.00	99.32	2.64
Augmented	33.00	83.00	100.00	98.85	3.29
Real Block	34.00	65.00	100.00	97.03	7.59
Total	67.00	65.00	100.00	97.93	5.91

Table C.8: *Results of Block 7 Split*

Learning style	**Instructional Method**	N	Min	Max	Mean	**Std Dev**
Haptic	**Augmented**	15.00	83.00	100.00	98.13	4.53
	Real Block	14.00	65.00	100.00	93.93	10.59
Visual	**Augmented**	18.00	95.00	100.00	99.44	1.62
	Real Block	20.00	85.00	100.00	99.20	3.35

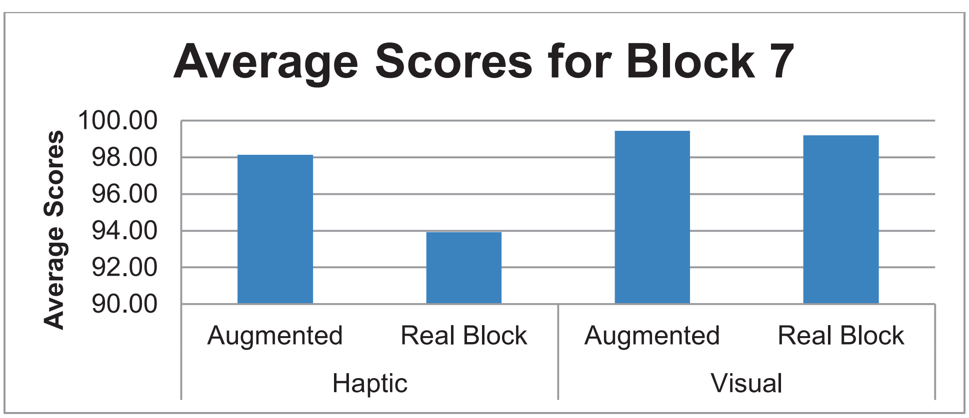


Figure C.8: Average Scores of Block 7

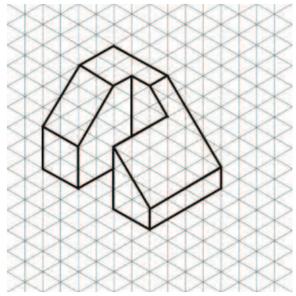


Figure C.9: Isometric View of Block 11

Table C.9: *Results of Block 11 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	61.00	100.00	87.55	11.21
Visual	38.00	60.00	100.00	93.13	7.53
Augmented	33.00	60.00	100.00	89.88	11.41
Real Block	34.00	70.00	100.00	91.53	7.62
Total	67.00	60.00	100.00	90.72	9.64

Table C.10: *Results of Block 11 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	61.00	100.00	86.73	12.48
	Real Block	14.00	70.00	100.00	88.43	10.07
Visual	**Augmented**	18.00	60.00	100.00	92.50	10.04
	Real Block	20.00	79.00	100.00	93.70	4.43

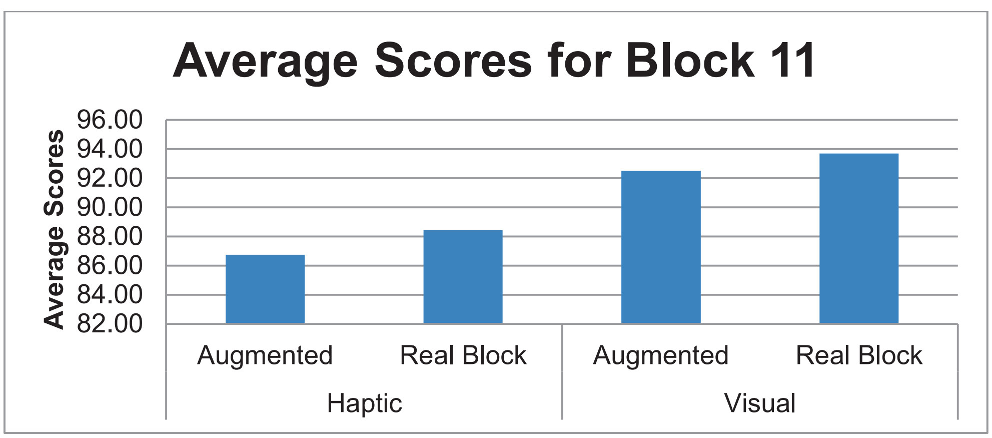


Figure C.10: Average Scores of Block 11

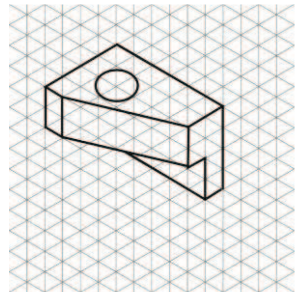


Figure C.11: Isometric View of Block 12

Table C.11: *Results of Block 12 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	39.00	100.00	84.00	17.84
Visual	38.00	59.00	100.00	93.87	10.05
Augmented	33.00	49.00	100.00	90.36	12.41
Real Block	34.00	39.00	100.00	88.85	16.77
Total	67.00	39.00	100.00	89.60	14.69

Table C.12: *Results of Block 12 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	49.00	100.00	89.07	14.67
	Real Block	14.00	39.00	100.00	78.57	19.81
Visual	**Augmented**	18.00	69.00	100.00	91.44	10.49
	Real Block	20.00	59.00	100.00	96.05	9.37

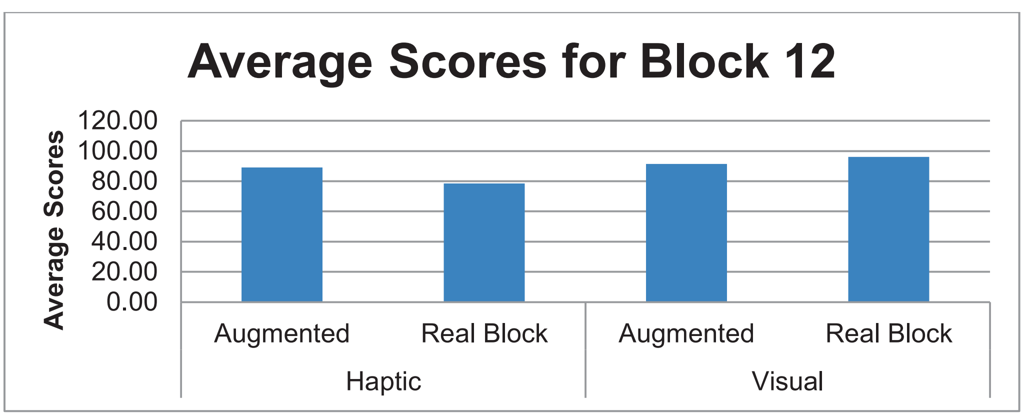


Figure C.12: Average Scores of Block 12

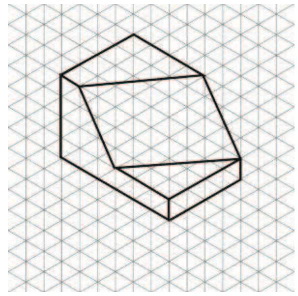


Figure C.13: Isometric View of Block 14

Table C.13: *Results of Block 14 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	64.00	100.00	97.41	7.82
Visual	38.00	75.00	100.00	98.29	4.69
Augmented	33.00	75.00	100.00	97.76	5.65
Real Block	34.00	64.00	100.00	98.06	6.78
Total	67.00	64.00	100.00	97.91	6.20

Table C.14: *Results of Block 14 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	81.00	100.00	98.40	4.98
	Real Block	14.00	64.00	100.00	96.36	10.13
Visual	**Augmented**	18.00	75.00	100.00	97.22	6.24
	Real Block	20.00	90.00	100.00	99.25	2.45

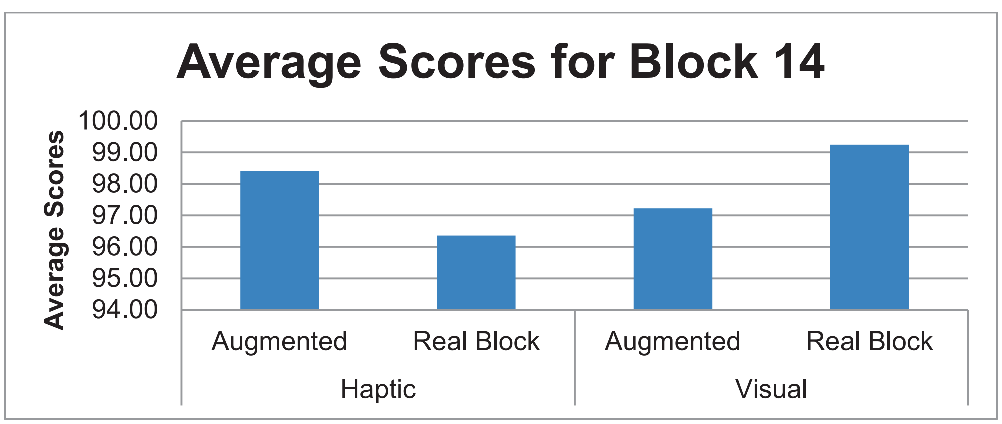


Figure C.14: Average Scores of Block 14

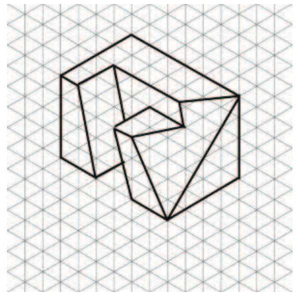


Figure C.15: Isometric View of Block 15

Table C.15: *Results of Block 15 Overall*

	N	Min	Max	Mean	Std Dev
Haptic	29.00	53.00	100.00	85.72	11.35
Visual	38.00	45.00	100.00	91.37	9.67
Augmented	33.00	45.00	100.00	88.76	11.29
Real Block	34.00	53.00	100.00	89.09	10.31
Total	67.00	45.00	100.00	88.93	10.72

Table C.16: *Results of Block 15 Split*

Learning style	**Instructional Method**	**N**	**Min**	**Max**	**Mean**	**Std Dev**
Haptic	**Augmented**	15.00	65.00	100.00	88.93	9.41
	Real Block	14.00	53.00	100.00	82.29	12.55
Visual	**Augmented**	18.00	45.00	100.00	88.61	12.93
	Real Block	20.00	85.00	100.00	93.85	4.34

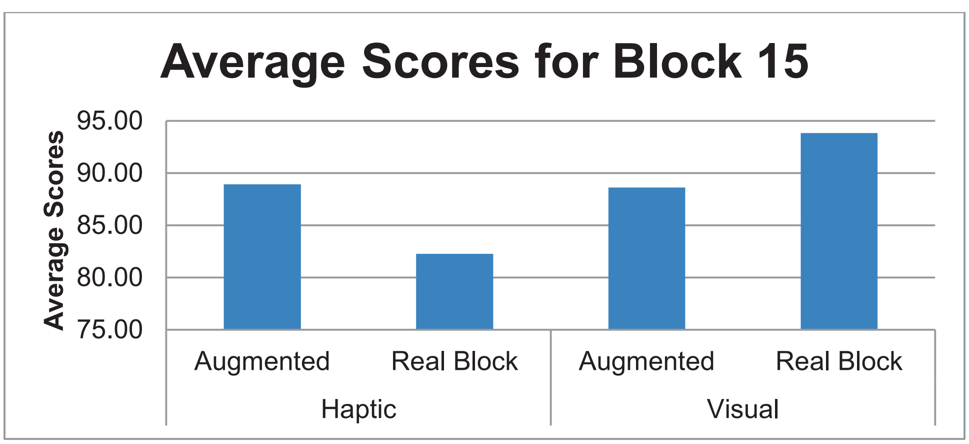


Figure C.16: Average Scores of Block 15

Appendix D: IRB Approval Forms

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	PATRICK CONNOLLY KNOY 323
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	08/17/2011
Committee Action:	**Approval**
IRB Action Date	07/13/2011
IRB Protocol #	1107011012
Study Title	What is the effect of real versus augmented models on spatial ability based on haptic of visual learning style of entry-level engineering graphics students?
Expiration Date	07/21/2012

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

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 used for research purposes including reporting or publishing as research data.

Unanticipated Problems/Adverse Events: Researchers must report unanticipated problems and/or adverse events to the IRB. If the problem/adverse event is serious, or is expected but occurs with unexpected severity or frequency, or the problem/even is unanticipated, it must be reported to the IRB within 48 hours of learning of the event and a written report submitted within five (5) business days. All other problems/events should be reported at the time of Continuing Review.

We wish you good luck with your work. Please retain copy of this letter for your records.

For IRB Office Use Only

APPROVED
JUL 2 2 2011
EXPIRES 07-21-2012
PURDUE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Research Project Number 1107011012

RESEARCH PARTICIPANT CONSENT FORM

What is the effect of real versus augmented models on spatial ability based on haptic or visual learning style of entry-level engineering graphics students?

Dr. Patrick Connolly
Katie Huffman
Purdue University
Computer Graphics Technology

Purpose of Research

The purpose of this research is to investigate the learning styles of students in engineering at Purdue University, and how different instructional techniques can help teach engineering graphics and spatial ability.

Specific Procedures

You will be given the Purdue Spatial Visualization Test. Then you will be given the Haptic Visual Discrimination Test to determine if you have haptic or visual learning tendencies. You will be asked to sketch objects using different techniques. The two techniques are real blocks, and augmented reality blocks. Then you will take the Purdue Spatial Visualization Test again.

Duration of Participation

You will be asked to participate at 2 different meetings, over the first half of the fall 2011 semester. The first meeting the Purdue Spatial Visualization Test and the Visual Haptic Discrimination Test will be taken. This will take approximately one hour. At the second meeting the sketches will be made, the second meeting will be at the Envision Center. At the second meeting the Purdue Spatial Visualization Test will also be given again. The second meeting will take approximately 1.5-2 hours.

Risks

There is minimal to risk in participating in this study. Some people have experienced dizziness or motion sickness from augmented reality glasses. The number of people who have experienced this is very small. Breach of confidentially and the safeguards is a risk, this can be found in the confidentially section

Benefits

There are no direct benefits for the participants. You may receive more instruction on subjects in the CGT 163 course, and therefore may gather a better understanding of the material and may perform better in the course. You may be able to learn in a new and exciting way.

The benefits of the study are that it may help instructors in engineering courses teach students in a way that they receive a better understanding of the material. This study may benefit future students in engineering.

Participant's Initials __________ Date________

Research Project Number 1107011012

Compensation
You will receive no greater than 3% to their overall grade of CGT 163, if you participate throughout the whole study. If they cannot participate in this study, students may do the alternative activity for the extra credit.

Confidentiality
The project's research records may be reviewed by departments at Purdue University responsible for regulatory and research oversight. All the consent forms test scores from the Purdue Spatial Visualization Test, and all the sketches, in a locked storage cabinet in Knoy Hall in the Computer Graphics Department. Participants will be given an identification number for the purposes of this study so they're names are not used in any electronic file. All electronic files of data will be stored on a flash drive that is secure. Data will not be destroyed at any time during the study, and data will be kept for 1 year after the study is complete.

Voluntary Nature of Participation
You do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty. This action will have no effect on your grade in CGT 163, or any other course.

Contact Information:
If you have any questions about this research project, you can contact Dr. Connolly or Katie Huffman at klhuffma@gmail.com. If you have concerns about the treatment of research participants, you can contact the Institutional Review Board at Purdue University, Ernest C. Young Hall, Room 1032, 155 S. Grant St., West Lafayette, IN 47907-2114. The phone number for the Board is (765) 494-5942. The email address is irb@purdue.edu.

Documentation of Informed Consent
I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research project and my questions have been answered. I am prepared to participate in the research project described above. I will receive a copy of this consent form after I sign it.

Participant's Signature — Date

Participant's Name

Researcher's Signature — Date