ABSTRACT

CARRIKER, ADAM WARREN. Effectiveness of 3D Input on Spatial Abilities. (Under the direction of Dr. Theodore J. Branoff).

The study was an attempt to determine if using a 3D input device is a beneficial way to improve the spatial visualization ability of students. The study was ran during a single semester at North Carolina State University using two independent sections in a foundations course in engineering graphics. The treatment, a 3D input device, was given to the experimental section, and their results on pretest and post-test examinations were compared to the results of a control section. The results were compared using a Wilcoxon method of ranking sums. The data was found to suggest that there was no observable significant difference between the two groups, and that the null hypothesis was unable to be rejected. The treatment did not seem to create any advantage or disadvantage during a single semester in the area of spatial visualization ability for the students. Students reported on a survey that they did not particularly enjoy the device, and many chose to quit using the device partway through the semester. Unfortunately, this knowledge hinders the data because it is difficult to say the device had any potential effects if many of the students in the experimental group chose not to use it.
Effectiveness of 3D Input on Spatial Abilities

by
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DEDICATION

I dedicate this work to my family and my friends.

Congratulations to all of them for their successes and accomplishments.
BIOGRAPHY

Adam Warren Carriker was born in Union County, North Carolina in 1984. He completed his undergraduate degree in Technology Education in May 2007 and entered the graduate program in August 2007. While working on his graduate degree he worked as a research assistant. Before completing the degree he had also been a teaching assistant for an introductory engineering graphics course.
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Chapter 1: Introduction

Background

From the beginning of graphics there has been dissension between what people actually see and what people can reproduce. The majority of mediums that have been used over time to represent the three dimensional (3D) world have been two dimensional (2D) surfaces. The world of computer graphics is no different. For decades 2D images have been produced to depict the natural environment. Recently, new 3D software has come onto the scene creating a new problem. Instead of needing a way to represent three dimensions on a 2D surface, now the recurring problem has been to manipulate a 3D environment with a 2D input (Oh and Stuerzlinger, 2005).

As early as 1986, a group began the attempt to find a more accurate way to navigate 3D space using a 2D input. Nielson and Olsen Jr. (1986) explained the circumstance where they created an axis in which the 2D input is projected on the axis in any two directions at once. The best way they found to manipulate the 3D object or camera was to make the movement relative to the view on the screen. Sometimes a horizontal motion would move an object along the x-axis, while, from another view, the object would be moved along the y or z-axes.

In general, this same tactic is used today to move, rotate, and scale objects. The mouse consistently reacts to the object on the screen to give the illusion of 3D manipulation even though only two dimensions are truly altered at once.
One of the problems that have arisen from this type of manipulation is that of designers getting lost in space. Often they may not know which axis they are attempting to manipulate until after they begin to change the object. Many times this is followed by undoing the operation, rotating the model, and trying again. Though most expert users do not encounter this problem, novice users often have difficulty finding their way through 3D space. This problem is created by using a 2D mouse in a 3D world.

Currently, a new tool has been created to navigate 3D space. A new 'mouse' that is capable of x, y, and z movement has been invented to offer a full range of motion to the user. With the 3D input device, the user can navigate the object on screen as if it were in the user’s hand. Being able to access all three dimensions, as well as rotate and zoom, gives the user the sensation of manipulating the object being in 3D space, not just working in 3D space (3dconnexion, 2008).

**Purpose**

Spatial ability is considered to be an extremely important skill in mathematics, engineering, chemistry, computer science, and physical sciences (Sorby, 2005). Considering the benefits of spatial ability across these disciplines and others it is important to find new ways to try and enhance spatial ability.

Gorska and Sorby (2008) explained that one primary objective of teaching spatial subjects is to introduce new techniques that will aid students in the visualization of objects in a 3D world. The purpose of this study was to determine if using a 3D input device and 2D
mouse with a 3D computer aided design (CAD) program over an entire semester would improve students’ spatial visualization ability more than just using a 2D mouse with a 3D CAD program. The main focus of this study was to analyze differences in scores on the Purdue Spatial Visualization Test – Visualization of Rotations (PSVT) between an experimental group (the group that used a 3D input device during the semester) and a control group (the group that used only a 2D input device). Qualitative measures were also examined to answer additional questions about the data.

Students were assigned to an experimental or control group. Both groups were given the PSVT at the beginning of the semester as a pretest measure of spatial visualization ability. Students in the experimental group were asked to use the 3D input device for the entire semester during their solid modeling activities. At the end of the semester both groups completed the PSVT as a post-test measure. Gain scores were then examined to determine if the 3D input device improved spatial visualization ability.

**Justification and Rationale**

Spatial ability is considered to be extremely important in engineering, mathematics, and science. Field (2007) addressed the importance of abilities other than memory and general academic skills when specifically working with engineering design. Bodner and Guay (1997) found that spatial abilities were a good representation of a student's actual ability in specific chemistry operations. In a study focused on mathematics and adult learning disabilities, Osmon, Smerz, Braun and Plambeck (2006) suggested that spatial abilities are
one of the two underlying cognitive abilities that affect mathematical skills. In the study Osmon et al. found that spatial ability does affect mathematical skills even when general intelligence is taken out of the calculations. Smallman and Hegarty (2007) examined spatial ability as related to scientific conditions, specifically weather conditions using naval forecasters. They found that spatial ability did have an effect on an individual's ability to perform certain tasks dealing with reading naval weather maps. Jing, Spence, and Pratt (2007) found that generally students who are drawn to scientific majors would outperform those drawn toward artistic majors when tested on spatial ability. They found that spatial ability does not cause superior ability in scientific skills but that both are fueled by a deeper cognitive capacity. However, they also suggest that improving one ability may improve the other simultaneously, meaning that improving spatial ability could improve mathematical and scientific abilities and vice versa.

Considering the benefits of spatial ability across these disciplines and others, it is important to find new ways to try and enhance the learning of spatial ability. Engineering educators address spatial ability in most curricula, focusing on spatial tasks and visualization as fundamental skills (Branoff & Connoly, 2008, Leake, 2000, Sorby, 2005). When redesigning a first year engineering graphics course, Leake (2000) put a great deal of focus on spatial tasks and visualization in the curriculum. According to Strong and Smith (2001), some professionals believe that spatial visualization cannot be taught, but most engineers agree that the skill can be positively affected through experience and education.

The reason for the attempt to find an external solution to what would seem to be an
internal problem with individuals or the computer systems they use is primarily because technology is malleable. Dillon (2000) explains the digital environment has been created as if all users are the same. Novice users may not have the same approach as experienced users, and Dillon suggests that it is necessary not to change the user, but to personalize the hardware to an individual’s preferences.

In 1993, a group acknowledged that 3D interfaces on a 2D surface or screen are really just illusions of 3D since one cannot input on 3 axes. They suggested devices be created to work in 3 axes before addressing the 3D interface (Robertson, Card, and Mackinley, 1993). It is important, therefore, to investigate the effectiveness of newly developed 3D devices for manipulating 3D interfaces.

Spatial ability has been shown to correlate with skill in many different disciplines. Since the purpose of this study is to examine the effects of a 3D input device on spatial visualization ability, this study will add to the body of knowledge in the areas of mathematics, science, and engineering.

**Research Question and Hypothesis**

Piburn, Reynolds, Leedy, McAuliff, Birf, & Johnson (2002) found that differences in spatial ability are often explained by lack of experience in the realm of 3D space. This research is designed to examine if the increase in spatial ability will be greater if the experience is coupled with a more intuitive external device. The primary question addressed by this study is “Does the use of a 3D input device in conjunction with a 3D CAD program
over the course of a semester increase spatial visualization ability?”

The question has been addressed by developing the following hypothesis:

\[ H_0 \] There will be no difference in spatial visualization ability (as measured by the PSVT) between students given access to use a 3D input device with a 3D CAD program for a semester and students who use a 2D mouse with a 3D CAD program for the entire semester.

If this hypothesis is not rejected then it will meet the expectation that the 3D input device did not have any observable effect on the experimental group in comparison to the control group.

A second research question that was addressed in this study was to learn how students used the device during the semester and how they felt about the 3D input device. If students respond positively about the device then it could be encouraged for students to purchase the device when entering a course using spatial visualization abilities even if the hypothesis was not rejected. If students enjoy the device and believe it helps them to understand the material then it may cause them to learn more, even if their actual spatial visualization ability does not increase.
**Assumptions**

The experimental group and control group are presented the exact same material, by the same instructor over the same time period in the same setting. Therefore, it is assumed that all factors between the two groups are similar with the exception being the treatment. Any difference found between the groups should be contributed to the treatment tool (the 3D input device). There are many other factors that affect spatial visualization, but due to the nature of the pretest and post-test, it is assumed that these factors are equal between the groups and their effects minimized on the final calculations.

Students are expected to take both the pretest and the post-test as well as participate in every course assignment and the final project. It is also assumed that students will put forth their best effort on both the pretest and post-test and that the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT) is an accurate tool for measuring spatial ability (Bodner and Guay, 1997).

**Limitations**

The study has some limitations based on the small sample size and the decision to use a convenience sample. Ideally, a study of this sort would consist of four equal groups, two of which are control and two of which are experimental. One set of control and experimental groups would be given a pretest and a post-test, while the other group would only be given the post-test. Due to time, accessibility, and other constraints, this study will be a quasi-experimental study that will only focus on the first set of groups, both given the pretest and
Due to the small sample size, it is difficult to address a number of variables that are assumed to be equal, but may not be. Variables included in this assumption are not limited to: prior experience, individuals repeating the course, progress toward a degree, gender, and ethnicity.

It would be preferable to calculate the effect of the 3D input device on each demographic group, but this study did not have the size or time to address these differences. The variables targeted by this study are those that are calculable given the available resources, including the PSVT results and the survey responses.

Due to the lack of funding for the study, there was no incentive for the students to use the 3D input device the entire semester. It was assumed that students would choose to participate, but it is possible that without the incentive, students would opt out of participating for the full semester.

**Definition of Terms**

*3D Space* – the platform, in which objects are created, viewed and manipulated in the software. A virtual representation of real world interaction as it is directed into a two dimensional projection.

*Spatial Ability* - “the ability to correctly visualize three dimensional objects when they are represented in two dimensions” (Towle et al., 2005, S2C-16).

*Spatial Visualization* - “the ability to manipulate an object in an imaginary 3-D space
and create a representation of the object from a new viewpoint” (Strong & Smith, 2001, 2).

*Spatial Orientation* - “the ability to predict the correct scenery given a body’s movement relative to that scenery” (Strong & Smith, 2001, 2).

2D mouse - “A pointing device that is pushed around a desk area with the palm of your hand. Traditionally, mice have used roller balls to detect motion, but newer models feature no moving parts and use integrated circuits that detect movement over the desktop and translate that into motion” (Cheap56k.com).

3D input device - “Pressure sensing technology allows the controller cap to become a virtual extension of you. Push, pull, twist or tilt the cap a fraction of inch to simultaneously pan, zoom and rotate 3D imagery. Increase pressure to go fast or decrease pressure to make intricate adjustments” (3d connexion, 2008, p. 1).

GC120 - “Introductory course providing orientation to language of graphics for students majoring in any field. Designed to help develop ability to use CAD within the context of a concurrent design process to understand how everyday objects are designed, analyzed and created. Emphasis placed on decision-making processes involved with creating geometry and development of modeling strategies that incorporate intentions of designer” (North Carolina State University, 2008).

Control group – For this study we define the control group to be the standard GC 120 course, a basic introduction to engineering graphics as well as a 3D CAD program, using the basic mouse and keyboard navigation to complete the required labs for the course (Branoff, 2000).
Experimental group – For this study we define the experimental group to be the standard GC 120 course, using the 3D input device to complete the required labs for the course (Branoff, 2000).
Chapter 2: Literature Review

Introduction

Over the course of time, many changes have taken place in the world of graphics. Originally, 2D sketches and isometric drawings were used to relay information about what would end up being created in a 3D world. Current trends have built on that system; however, 2D sketches have evolved into 3D models and isometric drawings are evolving to 3D animations. As the world of graphics evolves, it is important to understand the skills necessary to continue to be successful graphic communicators.

One specific skill to address is that of spatial visualization. Previously it was necessary for an individual to be able to convert a 2D drawing into a 3D product. In order to do this, the individual had to be able to take the drawing off paper and mentally rotate it and assemble it. That same skill is extremely important today in the world of graphics, engineering, and science. Understanding how an object maneuvers in 3D space is an intricate way of knowing the object's true design. This holds true for geometric shapes, molecular structures, and many other educational platforms. Sorby (2005) explains that most skills relating to spatial performance can be improved through practice and other techniques. This study has been an attempt to find a new way to improve spatial abilities.

Spatial Ability

Many studies have been performed to critique and analyze spatial ability as well as to
attempt to correlate it with other knowledge and improve it. A great many of these studies
have chosen to use the Purdue Spatial Visualization Test (PSVT) to obtain data. Bodner and
Guay (1997) claimed that “Preliminary research with a battery of spatial tests, including the
Purdue Visualization of Rotations (ROT) test described in this paper, showed a highly
significant correlation between spatial ability and spatially oriented tasks in general
chemistry” (p. 2). The study found that students who have a high spatial ability according to
the PSVT also did well on spatial ability tasks in chemistry. The researchers also make a
claim that spatial ability has a positive correlation with success on questions requiring higher
level problem solving skills.

Based on the results, it was clear to Bodner and Guay (1997) that spatial ability does
play a significant role in the scores on chemistry exams. In general chemistry courses the
study found that spatial ability can account for 12% of the variance; however, when the same
concepts were applied in organic chemistry, up to 15% of the variance could be correlated to
spatial ability.

The findings of this study and others like it suggest the importance of finding ways to
improve spatial ability in all students. If spatial ability is important in chemistry classes as
well as other disciplines then the ease in which students learn could be increased by simply
improving spatial ability.

Sorby and Young (1998) were presented with the dilemma of students being bored in
an introductory graphics course. They designed an exam to test students' spatial abilities and
determine if they should be allowed to place out of the course. This place-out was acceptable
because the course was designed to teach students the fundamentals of graphics important to engineering. Some students enter the university with prior experience, and as such, have the base knowledge to progress beyond the introductory class. Sorby and Young (1998) used questions from the PSVT in their own assessment as well as a number of other types of questions used to assess mental abilities. They found that students who have over two years of drafting in high school are usually prepared mentally to pass the exam on the fundamentals. This is accurate with Strong and Smith's (2001) findings as well as the theory presented by Piburn et al. (2002) that experience is the greatest factor in rating spatial ability.

Another study also used the PSVT to obtain data on students from Purdue and North Carolina State University. “The intent of the study was to examine the effects of coordinate axes on a mental rotations task” (Branoff & Connolly, 2008, p. 1). They found that adding coordinate axes to the PSVT successfully increased the understanding of the rotational assessment; however, not to a significant degree. The main benefit of the study was that “the addition of the coordinate axes seemed to eliminate gender differences for scores on the PSVT in some environments” (p. 7).

Considering it has been suggested that males tend to do better on spatial ability tasks than females, it is a positive find that an alteration is able to equalize some of the differences. This finding is in agreement with Piburn et al. (2002) that experience is a large factor in spatial ability and simply allowing individuals of either gender to work in spatial environments will cause the lesser scores to begin to equalize with the greater scores.

Based on the research, it is evident that the PSVT does test accurately, though it is
possible that the addition of coordinate axes could improve scores. The test itself is a
consistent measure of ability across all students. There are other tests that measure spatial
ability consistently such as the Differential Aptitude Test of Spatial Relation (DAT: SR), the
Mental Cutting Test (MCT), or the Mental Rotations Test (MRT). Sorby (2008) defines the
DAT: SR as a fifty item test focused on folding 2D patterns mentally into 3D boxes. She
reports an experiment using the DAT: SR in middle and high schools across the United
States to test spatial visualization ability. Kovac (1989) and Juhel (1991) also report that the
DAT: SR has successfully been used to accurately measure spatial ability.

According to Nemeth and Hoffman (2006) the MCT has been widely used in all age
groups. Nemeth and Hoffman used the MCT to observe gender differences in spatial ability
of engineering students in Hungary. Tsutsumi, Schrocker, Stachel and Weiss (2005) explain
that the MCT is a subset from a special aptitude test created in 1939. They also define the
MCT as a 25 question test taken over 20 minutes where students are asked to find the cross
section of an object given a perspective drawing and a cutting plane. Tsutsumi et al. used the
test to evaluate the spatial ability of students in a descriptive geometry course. Both Nemeth
and Hoffman, and Tsutsumi et al. used the MCT to determine spatial ability in a pretest/post-
test environment.

The MRT has also been widely used to test spatial ability. Monahan, Harke, and
Shelley (2008) used a paper based version as well as a computer based version in a study to
look at gender differences in spatial ability when compared between paper based and
computer based testing in psychology students. They reported that there was no significant
effect found to support a difference between the two test versions. They also found that students followed consistent trends between the first half and second half of the test in both versions. Gorska and Sorby (2008) explain that the MRT measures spatial ability by giving students an object and four choices where they have to determine which two choices are the same object rotated and which two are different objects. They also report that the MRT is a consistent measure of spatial ability over time and with different samples. The average pre-test score and gain was consistent in their study using students from different universities over several years. Guay (1980) has also described the content validity of the MRT as high in comparison to other tests of spatial abilities. The MRT seems to accurately test an individual’s spatial ability throughout the test, and will consistently report similar results for similar individuals.

It is important to note that a great deal of studies have been done to find differences or improvements in spatial abilities. The PSVT, DAT: SR, MCT, and MRT are all well designed and often used tools to measure spatial ability in these tests. According to Branoff (2000), the MRT and the PSVT are the best measures of spatial visualization ability which is the focus of this study. For the purpose of this study either the MRT or the PSVT would be sufficient, but in the end the PSVT was chosen based on availability and ease of administration.

**Interaction**

Many studies have involved different interfaces to attempt to manipulate a person's
understanding of 3D space. One in particular dealt specifically with spatial memory rather than spatial ability. This study by Cockburn (2004) asked whether or not a person would have a better spatial memory if they were given a 3D representation of the object's location. In this study, the user is not allowed to move; it is only a simple comparison of perspective effects in the displays.

Cockburn (2004) added visual cues that gave the illusion of a 3D object, including shadows, lighting and size, to see if individuals could recall the 3D objects better than their 2D counterparts. He found that there were no significant differences between the averages of the 2D and 3D conditions. He returned mean scores of 13.8 for the 2D and 14.1 for the 3D, with standard deviations of 5.3 and 5.9 respectively.

It is important to note that the study was not an attempt to improve spatial ability, only to critique spatial memory. The study is simply an example how different interfaces can affect spatial abilities.

Another example of an interface designed to test spatial ability was described in an article about 3D virtual navigation tasks. The authors, Tan, Gergle, Scupelli, & Pausch (2004) performed a study that was designed to examine the effects of physical display size on an individual’s cognitive strategy and performance on an interactive 3D navigation task. Similar to the prior study by Cockburn, Tan et al. attempted to analyze 3D spatial ability using different displays. However, they also addressed whether that performance is directly affected by the task being interactive or not. Tan et al. (2004) attempted to examine not only the implications of the display, but the effect on the subject when allowed different means of
interaction with the 3D world.

Instead of a paper based test, Tan et al. (2004) chose a system they referred to as a triangle completion task, where users would be led along two edges or legs of a triangle and then were asked to find their way back to the original point. The purpose was to analyze how the separate manipulations affected path integration. This study was an effective way of measuring spatial memory, as well as spatial visualization and ability, by forcing the participants to recall and manipulate the 3D virtual world. Users were expected to return to the point of origin using only the virtual environment and their own memory, guiding their movement using a joystick.

The study found that both the large display and the use of the interactive device affected individuals in performing the spatial tasks. The data analyzed focused on distances between where the participant was intended to be in 3D space and where they actually were. The large display had a positive influence on the spatial movement of the person. The individuals tested on a large display were 17% more accurate than those tested on the smaller displays, given the same environment and viewing angle (Tan et al., 2004, p. 445). This suggests that people can navigate virtual 3D space better when they feel immersed in the space rather than simply feeling like an onlooker to the environment.

The joystick interaction had a negative impact on the user's performance. Individuals using a passive interaction completed the task with shorter error distances than the other participants actively controlling the movement (Tan et. al., 2004). This result suggests that when users are forced to manipulate the environment with an external tool they may lose the
immersion that seemed to aid in the navigation.

Another way to approach problems encountered with 3D spatial navigation is to alter the software instead of the hardware with which the participants interact. Oh and Stuerzlinger (2005) used standard two dimensional computer mice for their study. They addressed the common problem that using a 2D input device makes it more difficult to predict the exact 3D motion of an object. Using software, they approached the problem of 3D navigation in a number of ways. They believed the simplest approach was adding handles for explicit 3-axis manipulation; this approach forced the user to manipulate only one axis at a time, forcing the user to break down the 3D movement into 2D components.

Another problem Oh and Stuerzlinger (2005) encountered was people often approached the object as if it were part of their body. This caused a break between the way people actually wanted to approach the action and how CAD software allowed them to approach the action of manipulating 3D objects. If the navigation through 3D space could be more intuitive, then the gap would be closed. Using the 2D input, it was difficult to find a successful way to improve navigation. Though Oh and Stuerzlinger (2005) attempted to solve this problem using what they called “Overlap with Foremost-Surface,” (p. 201) a technique where the software measures distance and collision for the user allowing them to manipulate objects based on how they interact with other objects in the scene.

“An ANOVA analysis of the results reveals that the difference between the handles and OFS conditions was significant (F_{9,1}=47, p<0.001). In fact, participants took about twice as long to complete the task with handles” (Oh & Stuerzlinger, 2005, p. 201). The study
compared the Overlap with Foremost-Surface technique to another technique called the axis-handle technique. This study shows that it is possible to aid a person's spatial understanding using different software interaction.

Based on this research, it is clear that changing the software or hardware has a high correlation to a student's understanding of 3D space. This encourages future research to find the most efficient tools to improve 3D spatial visualization ability for all students.

**Navigation**

As previously stated, many techniques have been designed and implemented to assist students in learning and navigating 3D worlds. These include techniques driven by software, hardware, or instruction. In the following pages more software techniques and hardware designs will be discussed that claim to improve spatial ability and navigation in students.

One major problem with 3D software has been the learning curve. Often individuals attempting to move to a 3D CAD program find that they are immediately lost. According to Fitzmaurice, J. Matejka, I. Mordatch, A. Khan & G. Kurtenbach (2008), new 3D users can often find themselves lost in navigation after only 30 seconds. After the user gets lost, they will spend a great deal of time just trying to re-orient the view back to a comfortable angle. Since people use operations involving camera movement more than any other operations in animation and a 3D CAD program, it is understandable why researchers would attempt to find ways to satisfy the need for camera movement in more simple, user friendly ways (Khan, Komalo, Stam, Fitzmaurice & Kurtenbach (2005).
Khan et al. (2005) explained again the common problem that using the two degrees of freedom a mouse allows; it is extremely difficult to maneuver a camera around in a space that requires six degrees of freedom. Oh and Stuerzlinger (2005) acknowledged the problem in their study on moving objects in CAD as well. Researchers seem to agree that camera movement is a primary problem in the industry that needs to be addressed. Fitzmaurice et al. (2008) suggested that more users of 3D navigation are simply attempting to view the model, not edit it or manipulate it. If this is the case, the only operation the user would use is the camera. If this is true, finding a new way to navigate the camera would expectedly improve the ability of users.

HoverCam is one technique, researched for Alias.com, which is intended to assist users in camera navigation. It is a software package that assumes the user is novice, but can be implemented for experts as well. Most users have trouble keeping their model properly centered on their screen. Often the tools to move the object will force it off screen or force the camera into the object, which may confuse the user. Khan et al (2005) finds that in order to navigate around a single point of interest, “the user must always overshoot, switch tools, correct the view with another tool, overshoot again, and so on” (p. 74). The need to constantly switch tools between rotate, pan and zoom can frustrate the user. Even with simple rotations, the user may be required to take three steps to achieve the appropriate camera position.

HoverCam is software that can alleviate many of the problems encountered by new users and claims to expedite the process for experienced users as well. The secret to
alleviating the problem is finding ways to combine operations that are most often used, mainly zooming, panning, and tumbling. This ability makes viewing models much quicker since it cuts a three step process into a single step (Khan et al., 2005). HoverCam also uses collision detection to keep users from ending up inside an object. Expert users can usually navigate their way out of an object, but novice users may get disoriented. For this reason, the collision detection can be expected to help novice users be more successful in their navigation, since the software prohibits them from getting “trapped” inside the object.

Another software package designed specifically to aid users in the use of rotate, pan, and zoom is “Safe 3D navigation.” The makers of this product claim that a small collection of tools is all that is necessary to navigate in virtual space, though many users do not understand that concept (Fitzmaurice et al, 2008, p. 8). This means that users do not actually understand the tools they are supposed to be using. The software package approaches the solution differently than HoverCam. Instead of guiding movement (and therefore restricting it), Safe 3D navigation is intended to instruct the user in exactly what tools should be necessary for certain movements and when one tool would be preferred over another. Safe 3D navigation designed their software to meet the needs of different level designers. Beginners are restricted to certain specific movements and other options, while experts are given a wider range of options because they are less likely to get lost in the sea of icons. Also, this lessens the initial load of learning. The user may only have to learn 6 motions, instead of 30, which is much less intimidating for a new user.

Safe 3D Navigation also uses text labels as opposed to image labels to tell the user
what the tool does (Fitzmaurice et al, 2008). Often image based tools are very easy for an expert to learn because the images give him a good explanation. For a novice user, the images do not mean as much. Fitzmaurice et al. (2008) claimed that this created problems when users tried a new icon to test what it did and lost orientation. Since a user may not have learned an icon’s function, they have a difficult time re-orienting themselves. One simple way Safe 3D has helped this problem was to add a ‘rewind’ button that moves an object to its previous location as well as a ‘ViewCube’ widget that can be selected to change orientation. Basically, the cube is an icon that gives a visual and text representation as to what side of the model the user is viewing. “Once a component of the ViewCube is selected, the system smoothly animates to the new view to allow the user to stay oriented” (Fitzmaurice et al, p. 12). This allows a user to learn how the object is manipulated to obtain the final position, helping them understand where they actually are in relation to the object.

Part of understanding how to help students improve their spatial visualization is to understand what commonly confuses students. Much of the confusion in 3D software comes from camera motion; however, some students have a hard time with other concepts, even if the camera did not hinder them. A study by Towle, Mann, and Kinsey (2005) addressed this concept explaining two other problems students may have understanding 3D spatial environments and objects as related to the Purdue Spatial Visualization Test. Towle et al. (2005) believe that students performing poorly on spatial visualization tests could have problems visualizing the 3D model as portrayed by visible lines and hidden lines, or they may have trouble rotating the model in their head.
To try and remedy these problems, Towle et al. designed software along with hardware to help train students' spatial visualization abilities. The hardware was primarily designed to help students understand how the model on screen rotates in real time. The Physical Model Rotator (PMR) simultaneously rotates an actual model of an object that directly correlates to a virtual model being observed in CAD software. This allows the student to examine the object they are rotating from different views as it is being rotated. This is very similar to the camera control techniques that have attempted to keep students from being disoriented as instituted in HoverCam and the Safe 3D navigation. The difference is that instead of a camera, the student can actually see in the real world what is happening on the screen. This double view helps to train users to perceive the objects on screen more accurately.

The software designed by this team also used a double view system. It used an add in that permitted a student to receive multiple representations of a single object, allowing them to observe a solid model directly alongside the exact same model in a wireframe view (Towle et al, 2005, p. 2). This is very similar to the 3D model representation of what is on screen, but instead, it gives the student a line representation of the model on screen. This helps the student to be able to relate the line drawings to an actual 3D model with more ease as they train.

Many of the problems that arise when students are navigating 3D space can be overcome by practice and increased familiarity with the software. This practice stimulates the understanding of the 3D space, by familiarizing the student with how to navigate an object in
virtual space. All of these improvements are based on a person's spatial ability. As ability improves, it is expected that the navigation and interaction with the 3D software and space will become more efficient and effective.

**Differences in Gender and Experiences**

Many studies tend to address two points when describing their sample. The first point is gender of the participants. Research has often found that males outperform females when tested on skills involving spatial abilities (Sorby, 2005). Branoff and Connolly (1999) agree with the research and perform a study addressing a number of hypotheses to determine the reason for the lower female scores. Branoff and Connolly’s study claimed that adding axes to the images in the PSVT removed the gender gap on that test. This suggests that certain testing techniques may not show the predicted gender differences. Sorby (2008) supports this idea by explaining that gender differences are often not reported on the Differential Aptitude Test of Spatial Relation.

Stafford (1972) suggests that the gender difference can be explained by a recessive trait found on the X-chromosome while Hier and Crowley (1982) suggest that gender differences can be attributed to hormones found in larger doses in males. Both of these are a common interpretation that gender differences are mostly genetic.

Bodner and Mcmillen (1986) found that in upper level chemistry courses the expected gender difference in spatial ability is much less than that found in lower level courses. This suggests that the gap may be bridged with experience in a subject developing spatial ability.
Sorby (2001) found that with training in a single course on spatial ability females gained a much higher retention rate over six years than those females who did not take the course.

The thought that experience can bridge the gap between gender bias leads to a second factor analyzed in research, experience. Tan et al. (2004) and Cockburn (2004) both express testing subjects with little 3D gaming experience. Individuals who spend a great deal of time navigating a virtual 3D world may be expected to have greater 3D spatial understanding than an individual who does not. Sorby (2005) suggests that childhood entertainment may play a role in giving individuals the experience they need to excel in spatial abilities. She suggests that playing with Legos, playing 3D virtual games, or engaging in team sports may lead to higher spatial ability as an adult. Because many of these activities are often male dominated, it could be suggested that experience, not gender is the primary factor.

Piburn et al (2002) as well as Strong and Smith (2001) agreed that most individual differences can be explained away by experience. Allowing individuals to work and practice spatial abilities should even out the differences between specific groups or persons.

For this reason, this study has chosen to ignore individual differences and assume that as found in other studies any differences will be addressed by exposure to the software and hardware.

**Sketching**

Contrary to the notion that new technology must be designed to help students better understand and train 3D spatial visualization abilities, Contero, Company, Saorín, & Naya,
(2007) suggested that sketching tools are still the best way to train a student in visualization. They do agree that 3D games as well as CAD systems can assist the learning, but they argue, “Sketch-based applications can provide an effective way of improving spatial abilities and capturing students’ attention. They stimulate students and create a positive attitude to the sketching tasks” (p. 11). Zachary (2008) emphasized that individuals actually need the hands on experiences in order to successfully comprehend engineering design practices. He believed that if students only manipulate a computer mouse and are not involved in hands on activities they lose important elements of the design process.

Sorby (1999) also suggested that sketching is a better way to train visualization than computer modeling. Sketching has always been used to successfully train engineers to read and create drawings. Although this study argued that as new tools enter the field, new means of training should also be designed to keep up with technology. This is why the current study focuses on the technology available rather than the traditional approach.

**Experiential Learning**

The original education system can be traced back to apprenticeships where every pupil learned simply by watching and re-creating the actions of their trainer or teacher. In the current school system the focus is much more on the watching than the learning. A revival of the old approach has been suggested by a newer learning theory. “The theory is called Experiential Learning [ELT] to emphasize the central role that experience plays in the learning process, an emphasis that distinguishes ELT from other learning theories” (Kolb,
Boyatzis & Mainemelis, 1999, p. 1). Experiential learning claims that knowledge is created out of experiences and that it is enhanced by observations and reflections.

Kolb, Boyatzis & Mainemelis also suggested that learners are constantly forced into a decision between polar opposite abilities in each task they approach. Obviously certain abilities are better for certain individuals and tasks. The researchers define these opposite approaches as 'abstract' and 'concrete' methods to learning. Concrete focuses learning through action and reality while abstract learners focus on observations and reflections to gain knowledge. In certain situations individuals are forced to choose one way or the other. An example is the concept of driving a car. It is impossible to both learn through a concrete method (driving) and an abstract method (reading the manual) so the individual is forced to choose (Kolb, Boyatzis & Mainemelis, 1999).

Experiential learning is further broken down into four distinct styles: Diverging, Assimilating, Converging, and Accommodating. These learning styles are focused on how an individual approaches a problem. For diverging, a person would focus in concrete experience and reflective observation, while for assimilating a person would be focused in abstract conceptualization and reflective observation. Similarly, converging is focused in abstract conceptualization while accommodating is focused in concrete experience; both of these two styles use active experimentation (Kolb, Boyatzis & Mainemelis, 1999).

Miller (2000) made a comparison between experiences in learning and content in learning. Most of what teachers present to their students can be considered content learning where they present material in a predictable, linear environment. Miller suggested that
Experiential Learning actually puts the student into a situation where learning becomes spontaneous, proactive, and flexible. He believed this learning method prepares the learner for the way things really get done outside of the learning environment.

In an interview with Robert I. Sutton (2000), Beth Scofield recorded Sutton's responses when dealing with on-line learning, Sutton explained that on-line learning is directed for failure because it lacks the portion of education that is active. Instead of allowing for random scenarios, everything is extremely linear and informational. Sutton's response included the idea that he does not believe anyone can be considered fully educated in anything by hearing or reading about it. Reading content can help the learning process, but it is necessary to actually engage in the action and reach the expected outcome to fully understand the topic.

One problem with learning to navigate 3D space and enhance spatial ability is that people have so much trouble with the initial experience dealing with the space that it takes time for them to begin to apply useful experiences to gaining knowledge. Strong and Smith (2001) found that sufficient experience in manipulating 3D space can actually compensate for any deficiencies between individuals. If there were a way to approach 3D space with a more natural experience, then individuals may be able to begin applying the experience to knowledge much more quickly.
Summary

The literature shows that many different approaches have been taken to address the need for 3D spatial understanding. It is apparent that researchers understand the necessity of encouraging students to train their 3D awareness. New problems have arisen with the introduction of 3D software. One notably expressed by Oh and Stuerzlinger (1995) was attempting to navigate a 3D world with 2D tools. This causes great stress to any user, especially new users, though even the most esteemed expert can encounter problems with manipulating 3D space. A great deal of research has been done to attempt to remedy this dilemma.

Referencing the Experiential Learning Theory, any tool that can create natural, hands on learning environments would stimulate learning at a higher rate than the traditional way. A number of individuals have attempted to investigate creating these environments. The current study is an attempt to follow the method of Experiential Learning using the most up to date technology to allow users to be completely involved in the learning process.

Overall the research suggests that 3D spatial visualization ability is an important tool to have in learning and problem solving. As it is so important, many tools have been created to attempt to improve spatial ability and understanding. These studies have shown the possibility of enhancing spatial understanding using tools, but they also have flaws that could be addressed by a new tool in 3D navigation. Following this research, is extremely important to continue to do research to find ways to improve the instruction and education dealing with any spatial visualization, navigation, or manipulation. Whether it be through software such as
the HoverCam and the Safe 3D navigation or hardware such as the Physical Model Rotator and larger displays, it is important to find a way for all students to be able to quickly and effectively learn how to visualize and maneuver in 3D space.
Chapter 3: Methodology

Introduction

Based on the literature, it is understood that different input devices and techniques can have an actual impact on the spatial ability of an individual. It is also expressed that spatial ability has a direct impact on a number of different disciplines. Based on this, it is important to continue to find ways to train and improve spatial visualization ability more efficiently.

Different assessments have been implemented across the disciplines to test spatial visualization ability. One specific test that has been found to be reliable and valid is the Purdue Spatial Visualization Test-Visualization of Rotations. Based on the results of this test, it is possible to explain a person's spatial visualization ability as well as their increased ability by using a pretest – post-test control group research design. The pretest – post-test approach has been adapted from a study conducted by Branoff (1998). Based on the assumption of validity, the Purdue Spatial Visualization Test has been chosen to examine students' actual spatial visualization ability.

Purpose

The purpose of this study was to determine if using a 3D input device and 2D mouse with a 3D CAD program over an entire semester would improve students’ spatial visualization ability more than just using a 2D mouse with a 3D CAD program. The main
focus of this study was to analyze differences in scores on the PSVT between an experimental group (the group that used a 3D input device during the semester) and a control group (the group that used only a 2D input device). Qualitative measures were also examined to answer additional questions about the data.

The data will be recorded from students enrolled in a Foundations of Graphics course (GC120) at North Carolina State University. The data will be analyzed to determine if students using the 3D input device score higher on a test of spatial visualization ability than those who use a traditional mouse. Based on the information gained, it will be possible to determine if a 3D input device should be encouraged to students entering graphics programs and potentially other disciplines.

**Research Question and Hypothesis**

The primary research question for this study is ‘Does using a 3D input device in conjunction with a 3D CAD program over the course of a semester increase spatial visualization ability?’ The following hypothesis will be analyzed to attempt to find a solution to the research question:

\[ H_0 \] There will be no difference in spatial visualization ability (as measured by the PSVT) between students given access to use a 3D input device with a 3D CAD program for a semester and students who use a 2D mouse with a 3D CAD program for the entire semester.
If this hypothesis is not rejected then it will meet the expectation that the 3D input device did not have any observable effect on the experimental group in comparison to the control group.

A second research question that was addressed in this study was to learn how students used the device during the semester and how they felt about the 3D input device. If students respond positively about the device then it could be encouraged for students to purchase the device when entering courses using spatial visualization abilities even if the hypothesis was not rejected. If students enjoy the device and believe it helps them to understand the material then it may cause them to learn more, even if their actual spatial visualization ability does not increase.

**Research Design**

The focus of this study is to be a comparative analysis of the effect of using a 3D input device on 3D spatial visualization ability. A sample of convenience was used to select two intact laptop sections of GC 120 from the sixteen total sections during the 2009 spring semester at North Carolina State University. Giving a pretest at the beginning of the study, followed by a post-test at the end of the study is one way to examine students’ improvement. This is a method used by Hamlin, Boersma, and Sorby (2006) and Branoff (1998) in other studies analyzing spatial visualization ability. The research design for this study is represented in Table 3.1.
Table 3.1 - Research Design

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Treatment</th>
<th>Post-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Experimental</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The treatment is defined as access to a 3D input device that was provided for the students to use. The only access the students had to the software and the 3D input device prior to the pretest was to install the necessary files. These installations took place during the first class period. During the second class period, both groups in both sections were administered the Purdue Spatial Visualization Test – Visualization of Rotations. Students then completed a sixteen week course on the foundations of graphics. The PSVT was administered again during the sixteenth and final week of class.

After the course students in the experimental group were given the surveys that would report any opinions they had about the usability and benefits of the 3D input device.

Variables

The only independent variable was access to the 3D input device. The study assumes all other variables are equal or controlled. The dependent variable was the post-test score. The post-test results were compared to the pretest results to see if the experimental group increased significantly more than the control group.
There are potentially other variables that were unable to be controlled or examined. It is the assumption of the study that any other variables were equal among all groups, including but not restricted to: prior experience, individuals repeating the course, progress toward a degree, gender, and ethnicity.

**Instrumentation**

Fields (2007) discussed a number of different instruments used to assess an individual's spatial ability. These include tests that are often given in engineering disciplines including, the Mental Rotations Test, the Mental Cutting Test, and Purdue Spatial Visualization Test and the Differential Aptitude Test: Spatial Relations. He concluded that each of these tests is an accurate and reliable way to examine spatial skills.

The instrument chosen for this study is the Purdue Spatial Visualization Test – Visualization of Rotations. (PSVT). This test is designed to measure a student's ability to mentally rotate a 3D object. The test uses 30 questions of varying difficulty where the student must take the initial position of the object and choose the final resting place if the object were to be rotated 90 or 180 degrees in different directions (Guay, 1980). Bodner and Guay (2007) claimed that it is “the one rotational test that has been shown to be among the spatial ability tests whose results are least likely to be complicated by analytical processing” (p. 1).

Although Bodner and Guay applied the PSVT to general chemistry courses, it is possible to apply it across all disciplines considering it is a test of spatial visualization ability and not course material. Branoff and Connolly (1999) used the PSVT to examine students' spatial
visualization ability in foundational graphics courses, while Towle et. al. (2005) applied a derivation of the PSVT specifically to engineering students.

According to Onyancha and Kinsey (2007) spatial ability as recorded by the PSVT does in fact improve over time for an engineering student. Onyancha and Kinsey used the PSVT on a group of mechanical, electrical, civil and computer engineers from the University of New Hampshire. They found that it recorded accurate ability; however, they addressed that due to the mechanical nature of the models on the test, mechanical engineers seemed to be more confident in their responses.

Sorby (2003) presented documentation for seven years of using the PSVT in different scenarios involving spatial visualization ability. Overall the students' scores seemed to increase by about seven or eight over the course of her studies. This increase was significantly different where $p < .05$ in every occurrence. Over the seven years, the average pretest and post-test scores of students were similar within 1.5 points of one another. Branoff (1998, 1999, & 2000) also found similar mean scores in all groups taking the PSVT. Over the course of seven years the test was accurate and reliable in the examination of engineering students.

In reference to the PSVT, many internal consistency (KR-20) calculations have been done. Guay, Sorby and Baartmans, and Battista, Wheatley, and Talsma reported high consistency coefficient results. Guay (1980) returns results of .87, .92 and .89 on studies that involve two groups of university students and one group of skilled machinists. Sorby and Baartmans (1996) reported a KR-20 of .82 in another study involving university engineering
students, while a KR-20 of .80 was calculated by Battista, Wheatley and Talsma (1982) using pre-service elementary teachers taking a geometry course. For this study the calculated KR-20 internal consistency coefficients were lower than that of previous studies. For the pretest a KR-20 was found to be .71 with the control group being .78 and the experimental group being .64. For the post-test the KR-20 was found to be .74 with a .77 and .71 for the control and experimental groups respectively.

A second instrument was given to all students in the treatment group. This instrument was a survey based on a five level Likert scale where students were asked a set of questions designed to understand their reactions to the treatment. Sorby (2006) used a similar Likert scale survey to assess how students rated their own abilities as well as rating the ease with which they accomplished certain tasks. This study's survey addresses how often students used the 3D device, as well as how they felt it aided them in their own spatial abilities. Onyancha and Kinsey (2007) also followed up on a PSVT test with a survey that addressed self efficacy. This study intends to clarify how students respond to the device based on usability and effectiveness more so than the user’s personal opinion of themselves. This data will then be processed along with the PSVT scores to find how the use of the 3D device correlated with the PSVT scores.

**Summary**

This study was an attempt to determine if using a 3D input device is a beneficial way to improve the spatial visualization ability of students. There are many tools designed to test
spatial visualization ability. For this study the PSVT was selected for both the pretest and post-test. Using the control and experimental groups with both measures, it was the researcher's intent to analyze the results and present information on whether future research needs to be pursued as well as whether or not students should be encouraged to purchase a 3D input device for courses involving any manipulation within 3D space.

This study attempted to minimize the external variables and assumed that any external variables would be equivalent between groups. The dependent variable (the post-test results) were examined and compared between groups to determine the effect of the treatment.
Chapter 4: Findings

Introduction

The purpose of this study was to determine if using a 3D input device and 2D mouse with a 3D CAD program over an entire semester would improve students’ spatial visualization ability more than just using a 2D mouse with a 3D CAD program. The main focus of this study was to analyze differences in scores on the PSVT between an experimental group (the group that used a 3D input device during the semester) and a control group (the group that used only a 2D input device). Qualitative measures were also examined to answer additional questions about the data.

Students in the experimental group were given a 3D input device to use along with their normal mouse and keyboard during the semester in a course examining the fundamentals of engineering graphics. The experimental group was encouraged to use the device for the duration of the course on each and every one of their labs as well as their final project. The control group approached the course the standard way using only a normal mouse and keyboard to complete labs and the final project. A pretest and a post-test were given to both the experimental and control groups to attempt to determine if the 3D input device had an effect on the students’ spatial abilities. The experimental group also completed a survey covering their personal perceptions of the input device.
Population

The study was conducted at North Carolina State University to examine a possible course improvement in an early engineering course that focuses on engineering graphics. Two sections of this course sharing the same instructor were chosen to participate in this study, one being the control and the other the experimental group.

This was a convenience sample chosen to see if a full scale study would be beneficial to the students and researchers. Overall, forty-one students participated in the study, however; a small number of students failed to complete either the pretest or the post-test. Of the forty-one students, only thirty-four completed both the pretest and post-test. Table 4.1 depicts the organization by gender in each group.

<table>
<thead>
<tr>
<th>Table 4.1 – Gender by Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Males</td>
</tr>
<tr>
<td>Females</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Of the thirty-four students who participated in the study, only six were female; all of which were in the experimental group. The rest of the students in the experimental group (15) as well as all the students in the control group (13) were male. All but one of the experimental group students filled out a survey that addressed their perceptions in relation to
how the 3D input device affected their understanding of virtual space and the course material.

Almost all of the students were enrolled in some version of engineering. Table 4.2 registers the overall breakdown of the number of each major represented in both the control and experimental groups.

<table>
<thead>
<tr>
<th>Table 4.2 – Major by Group</th>
<th>Control</th>
<th>Experimental</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Engineering</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>4</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Nuclear Engineering</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Computer Science</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Textile Engineering</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Engineering - Undecided</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>English</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>21</td>
<td>34</td>
</tr>
</tbody>
</table>

The majority of students in both groups were split between Civil (11) and Mechanical (14) Engineering. The table shows that in the control group, almost one third (4) of students were Civil Engineering students, and almost half (6) were Mechanical. Also, exactly one third (7) of the students in the experimental group were Civil where just over one third (8)
were Mechanical. The rest of the students were distributed between Nuclear Engineering, Computer Science, Textile Engineering, Engineering Undecided and English.

All of the students enrolled were freshmen and sophomores in the first two years of their respective programs. All of the students were between the ages of eighteen and twenty. This is acceptable because the target population of the study is geared towards students taking an introductory level Engineering Graphics courses.

**Analysis – Quantitative**

Students were asked to complete a pretest and a post-test of a spatial visualization before and after the semester. A randomly assigned four digit number documented their scores confidentially and the pretest was calculated against the post-test. Using statistical analysis software, Jump (jmp), the data was analyzed using a Wilcoxon method of ranking sums. The statistics returned were then analyzed to determine the affect of the alternate 3D input device.

The statistics address the mean of the pretest and post-test for both groups and well as the overall change in scores. The statistics were calculated with the number of students who took both the pretest and post-test (thirty-four), and the researcher has observed and compared the change in scores from the pretest to the post-test. Table 4.3 shows the pretest, post-test, and gain score values for both the control and experimental groups.
<table>
<thead>
<tr>
<th>Group</th>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>pretest</td>
<td>13</td>
<td>23.77</td>
<td>4.43</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>Control</td>
<td>post-test</td>
<td>13</td>
<td>23.46</td>
<td>4.46</td>
<td>17</td>
<td>29</td>
</tr>
<tr>
<td>Control</td>
<td>delta</td>
<td>13</td>
<td>-0.31</td>
<td>3.83</td>
<td>-11</td>
<td>5</td>
</tr>
<tr>
<td>Experimental</td>
<td>pretest</td>
<td>21</td>
<td>25.1</td>
<td>2.28</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>Experimental</td>
<td>post-test</td>
<td>21</td>
<td>25</td>
<td>3.61</td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>Experimental</td>
<td>delta</td>
<td>21</td>
<td>-0.1</td>
<td>3.99</td>
<td>-7</td>
<td>8</td>
</tr>
</tbody>
</table>

The mean of scores in the pretest were higher in the experimental group than in the control group by 1.23 and again higher in the experimental group for the post-test by 1.54. The standard deviation was smaller in the experimental group for both the pretest and post-test. The overall change in scores from the pretest to the post-test for the control group was a delta of -0.31, while in the experimental group the delta was -0.1.

Both groups concluded the semester by scoring lower on the post-test than the pretest. In comparison to similar studies, the reported means are close to the expected result for the pretest. Sorby (1999) reported to have means of 23.1, 22.7, and 23.8 on the same version of the PSVT. Branoff and Connolly (1998) represent the same PSVT having means of 23.46 and 22.77. In comparison to this study, where the means are 23.77 and 25.1, there is approximately a 5% difference between the previously recorded means and the means.
recorded for this study. Bodner (1997) recorded lower percentage scores on a different version of the PSVT, with fewer questions. Bodner’s average standard deviation (3.91) was very close to the average deviation for this study (3.35). Overall the pretest scores and standard deviations are within normal expectations for the PSVT.

Sorby (1999) also used a pretest/post-test method recording mean gains of 7.5, 4.1 and .7. Sorby (2001) reported average gains for a number of different studies, ranging from 6.5 to 9.6 on the 30 point test. In this study, the reported changes in scores were both negative at -.3 and -.1. This is inconsistent from previous experiments using the same PSVT where scores generally increase. There is a possibility that other factors affected student performance that were not expected or calculated. However, as both groups reacted in a similar way the statistics can still calculate the possible effect the 3D input device had on the students’ performance.

Running the Wilcoxon model in Jump using the pretest and post-test scores from the experimental group against the control group shown in table 4.4, returned the data in table 4.5 based on a 2-sample test with a normal approximation.

<table>
<thead>
<tr>
<th>Level</th>
<th>Count</th>
<th>Score Sum</th>
<th>Score Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>13</td>
<td>234.5</td>
<td>18.04</td>
</tr>
<tr>
<td>Experimental</td>
<td>21</td>
<td>360.5</td>
<td>17.17</td>
</tr>
</tbody>
</table>
The Wilcoxon test is a nonparametric test that converts data to a ranking system, which is not affected by normal dilemmas in research, such as normal distribution, outliers, or random sampling (Scales, 2004). The Wilcoxon test is used with comparison of two independent samples, regardless of equal sample sizes. This was a good choice for this particular study because of the different sample sizes between the control and experimental groups. In this study it ranked and summed the scores on the PSVT for both groups and calculated the probability that any change on the post-test scores were generated by the treatment in the study. Table 4.4 shows that the p value was not significant on a two-tailed test at .82.

| S    | Z  | Prob>|Z| |
|---|---|---|
| 234.5 | 0.23 | 0.82 |

Based on this data it is not possible to reject the null hypothesis. There is not a statistically significant level of difference within an appropriate confidence level between the delta scores of the two groups to suggest that the treatment was effective in creating an observable deviation.
Analysis - Qualitative

A survey was given to the experimental group to determine what the general perception of the 3D input device was at the end of the semester after the post-test. Sorby (2006) used a number of surveys to test student perceptions in a spatial visualization study performed in an introductory English course. Many of the questions were set up on a Likert scale from 1 to 5, where 1 was very poor and 5 was very good. This study’s survey has taken a similar approach where all of the questions are on a 1 to 5 Likert scale or are Yes/No responses. Nineteen of the students chose to respond to the survey at the end of the semester. These students were asked a number of questions about their own abilities as well as how they believed the 3D input device affected their abilities. Table 4.6 shows the questions, the number of responses per Likert Rank, and the average of the responses.

<table>
<thead>
<tr>
<th>Likert Rankings</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do you rate your experience with 3D virtual Space?</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>3.15</td>
</tr>
<tr>
<td>How do you rate the usability of the 3D Input device?</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>6</td>
<td>2</td>
<td>3.3</td>
</tr>
<tr>
<td>How do you rate the effectiveness of the 3D mouse at navigation?</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td>How do you rate your understanding of 3D navigation?</td>
<td>0</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>3.45</td>
</tr>
<tr>
<td>How do you rate your skill with the 3D mouse?</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>2.8</td>
</tr>
</tbody>
</table>
The opening question was designed to analyze if the students utilized the 3D input device for their projects and labs or not. Over half (11) of the students returned data that they did not use the mouse the entire semester. The effect this observation has on the validity of this study will be addressed later in this chapter.

The next question addressed the students’ perception of their experience with spatial abilities. The average score students gave was 3.15. Five students rated themselves either good or very good while five students reported either poor or very poor while the rest reported neutral. The mean response for their understanding of 3D navigation was 3.45. Nine students ranked themselves as good or very good while only two ranked themselves as poor. None of the students labeled themselves as very poor on this question. The rest of the students (8) returned that they were neutral on this response.

Three other questions dealt with the usability, effectiveness, and the students’ skill in relation to the 3D input device. In the case of usability, students’ average return was 3.3. Three students said the usability of the device was poor or very poor while eight students reported that it was good or very good. The effectiveness of the device was rated nearly the same by the students at 3.4. Similarly four students rated that it was poor or very poor while ten rated it as good or very good.

The last Likert Scale question addressed the students’ skills in using the 3D input device. Students were less confident in their abilities with the mouse. The average score for this question was a 2.8. Eight students rated themselves as poor or very poor in this category while only four students considered themselves good or very good.
Six of the nineteen students believed that the 3D input device actually aided them in the understanding of the material presented in the course, but only three of the students said they would choose to use the device again in future courses.

In a number of informal interviews with the students, the general consensus was that the device was too difficult to get used to in such a short time and with as infrequent use as the class required. Many of the students who said they did not use the mouse the entire semester stated that the reason for this was the inconvenience of carrying around the extra device.

**Research Question and Hypothesis**

The primary question addressed by this study was “Does the use of a 3D input device in conjunction with a 3D CAD program over the course of a semester increase spatial visualization ability?” This question was addressed using the hypothesis:

\[ H_0 \] There will be no difference in spatial visualization ability (as measured by the PSVT) between students given access to use a 3D input device with a 3D CAD program for a semester and students who use a 2D mouse with a 3D CAD program for the entire semester.

If this hypothesis is not rejected, then it will meet the expectation that the 3D input device did not have any observable effect on the experimental group in comparison to the
control group. The analysis of the data revealed no significant difference between the PSVT scores for the control and experimental groups. The surveys suggest that the majority of students (16 of 19) do not believe that the device would be beneficial to use again.

Summary

The study was run during a single semester at North Carolina State University using two independent sections in a foundations course in engineering graphics. The treatment, a 3D input device, was given to the experimental section, and their results on a pretest and post-test examinations were compared to the results of a control section. The results were compared using a Wilcoxon method of ranking sums. The data was found to suggest that there was no observable significant difference in the two groups and that the null hypothesis was unable to be rejected. The treatment did not seem to create any advantage or disadvantage over the course of a single semester in the area of spatial visualization ability for the students.

It is necessary to recognize that the findings for this study are potentially invalid due to the fact that many students did not perceive any benefits to the 3D input device and chose to quit using the device on their assignments. This would suggest that the data collected for the experimental group was not greatly affected by the treatment. Assuming enough students chose not to incorporate the treatment into their learning, it would be expected that no difference would occur between the groups.
Chapter 5: Conclusions and Recommendations

Introduction

Over the course of time, many changes have taken place in the world of graphics. Originally, 2D sketches and isometric drawings were used to relay information about what would end up being created in a 3D world. Current trends have built on that system; however, 2D sketches have evolved into 3D models and isometric drawings are evolving to 3D animations. As the world of graphics evolves, it is important to understand the skills necessary to continue to be successful graphic communicators.

This study was an attempt at harnessing a way to improve the comprehension of 3D spatial visualization ability. Three-dimensional navigation runs into problems virtually due to the lack of a proper input device. Oh and Stuerzlinger (2005) explain that a recurring problem is manipulating a 3D environment using a 2D input. (Khan, Komalo, Stam, Fitzmaurice & Kurtenbach (2005) agree with Oh and Stuerzlinger that it is difficult to navigate around six degrees of freedom using only two degrees of freedom that a normal mouse allows. The problem with navigation is detrimental to spatial ability because it can cause a user to get disoriented and lost in space, forcing them to spend a large portion of time finding the correct view for their particular task.

Background

One reason so much time has been spent developing a better navigational system for
3D software is to train spatial abilities more efficiently. Training spatial abilities is important because it is considered to be extremely important in engineering, mathematics, and science. Bodner and Guay (1997) claimed that “Preliminary research with a battery of spatial tests, including the Purdue Visualization of Rotations (ROT) test described in this paper, showed a highly significant correlation between spatial ability and spatially oriented tasks in general chemistry.” Field (2007) addressed the importance of abilities other than memory and general academic skills when specifically working with engineering design. Osmon, Smerz, Braun and Plambeck (2006) suggested that spatial abilities are one of the two underlying cognitive abilities that affect mathematical skills. Jing, Spence, and Pratt (2007) found that generally students who are drawn to scientific majors would outperform those drawn toward artistic majors when tested on spatial ability. Jing et al. (2007) suggested that spatial ability is not directly related to scientific performance, but agreed that finding a way to improve spatial ability may also improve ability in other areas.

Research suggests that improving spatial ability may have an impact on a wide range of skills, including, but not limited to, mathematics, physical sciences and engineering disciplines. It is important to find new ways to improve spatial ability in order to continue to advance the education system. This study addressed the potential of finding a suitable navigational technique that will hopefully increase the rate at which students develop spatial visualization ability.

This study also investigated whether or not an external tool, in this case a 3D input device, could accelerate the rate at which a student's spatial visualization ability improves
when compared to improvement through normal experiences. Sorby (2005) explains that most skills related to spatial performance can be improved through practice and other techniques. This study has been an attempt to find a new way to improve spatial abilities. Sorby and Young (1998) found that students who have over two years of drafting in high school are usually prepared mentally to pass the exam on the fundamentals. This is accurate with Strong and Smith's (2001) findings that experience is the greatest factor in rating spatial ability. Due to the normal improvement through experience it was necessary to compare a control and experimental group to determine if the 3D input device actually enhanced the experience, or was a detriment.

**Purpose**

The purpose of this study was to determine if using a 3D input device and 2D mouse with a 3D CAD program over an entire semester would improve students’ spatial visualization ability more than just using a 2D mouse with a 3D CAD program. The main focus of this study was to analyze differences in scores on the PSVT between an experimental group (the group that used a 3D input device during the semester) and a control group (the group that used only a 2D input device). Qualitative measures were also examined to answer additional questions about the data in reference to usability and perceived benefits of the 3D input device. Based on the information gained, it will be possible to determine if a 3D input device should be encouraged to students entering graphics programs and potentially other disciplines.
Research Question and Hypothesis

The primary research question for this study was whether or not students who are given access and required to use a 3D input device during the projects for GC120 will gain spatial visualization ability at a greater rate than students who are not given access to the 3D input device. The following hypothesis will be analyzed to attempt to find a solution to the research question:

\[ H_0 \) There will be no difference in spatial visualization ability (as measured by the PSVT) between students given access to use a 3D input device with a 3D CAD program for a semester and students who use a 2D mouse with a 3D CAD program for the entire semester.

If this hypothesis is not rejected then it will meet the expectation that the 3D input device did not have any observable effect on the experimental group in comparison to the control group.

A second research question that was addressed in this study was to learn how students used the device during the semester and how they felt about the 3D input device. If students respond positively about the device then it could be encouraged for students to purchase the device when entering a course using spatial visualization ability even if the hypothesis was not rejected. If students enjoy the device and believe it helps them to understand the material then it may cause them to learn more, even if their actual spatial ability does not increase.
Procedures

The focus of this study is to be a comparative analysis of the effect of using a 3D input device on 3D spatial visualization ability. A sample of convenience was used to select two intact laptop sections of GC 120 from the sixteen total sections during the 2009 spring semester at North Carolina State University. Overall, forty-one students participated in the study, however; a small number of students failed to complete either the pretest or the post-test. Of the forty-one students, only thirty-four completed both the pretest and post-test.

One group was the control group, consisting of 13 male students, while the other was the experimental group which consisted of 15 male and 6 female students for a total of 21. The experimental group was given a treatment that was the primary motivator for the experiment. The treatment is defined as access to a 3D input device that was provided for the students to use. The only access the students had to the software and the 3D input device prior to the pretest was to install the necessary files. These installations took place during the first class period. During the second class period, both groups in both sections were administered the Purdue Spatial Visualization Test – Visualization of Rotations. Students then completed a sixteen week course on the foundations of graphics. The PSVT was administered again during the sixteenth and final week of class. After the course, students in the experimental group were given the surveys that would report any opinions they had about the usability and benefits of the 3D input device. All of the students in the experimental group except two chose to fill out the survey.
Results and Conclusions

The data returned that there was no major difference between the control group and the experimental group. Both groups’ means for the difference between the pretest and post-test scores are assumed to be approximately equal according to a Wilcoxon test of ranking sums.

The scores themselves were inconsistent with data collected from other research studies using similar tests, the changes in scores were significantly lower; but within this study the grades were consistent with one another. There are many potential reasons the scores were not consistent with other studies. Many factors can alter test scores on any given day. The post-test was given the week before exams while the pretest was given during the first weeks of the semester. Possibly, students were stressed about their exams and therefore were unfocused when taking the post-test, or perhaps they did not believe the research study was important and did not give the test their full attention. It may also be that the structure of the class the day the post-test was distributed was unclear and students were confused about the purpose or intent of the test. It is also possible that the students understood that the test had no effect on their course grade and chose to treat it as if it were not important. Other factors that have not been recognized or reported may also have had an effect on the scores.

As the research showed, there was little to no effect on the mean score for the PSVT due to the treatment. Even though having the new input device may be a luxury and may have an effect on other situations that deal with 3D navigation, modeling, and other abilities, for the sake of this study it was not beneficial to a student's spatial visualization skills. In
reference to the survey given the overall response suggested that students did not prefer to use the 3D input device, they did not believe it assisted them in their understanding of the material and they did not believe they would choose to use the device again.

**Recommendations**

From this particular study it is understood that the actual 3D input device does not affect the students' comprehension of 3D space. However, it may be possible that it improves efficiency in solid modeling, or shortens the time needed to learn the software, or it may even shorten the time required to learn the material. What the study showed was that at the end of the semester the students in the experimental group were not ahead of students in the control group. It may be beneficial to apply an extra test in the middle of the semester to address the speed at which the students improve.

There were not enough female students in the research study to warrant calculating statistics based on gender. Branoff and Connolly (1999) found that females and males can react differently to the same treatment. In their particular study, females improved at a greater rate than males in both time and score on a pretest and post-test experiment. It is suggested that future experiments develop research to discern if the secondary input device could in fact modify one gender's responses differently than another. Again, this study lacked numbers to do examination based on learning styles; but, it could possibly be beneficial to see how students with different learning styles react to the different input device.

It may also be beneficial to examine not only how the 3D input device affects
capabilities in spatial visualization, but also to run a study to see if students become more efficient when using the device than when they are not using the device. As this is a new tool being introduced into the environment of virtual modeling, it is necessary to do more research on the topic. Students need to be given more time with the device in the studies than just once a week for one semester; they need time to really become familiar with the device in order for researchers to truly comprehend the type of impact it may have on the student or even the classroom.

Also recommended is a study where the device is tested for more than efficiency or spatial skills, but a much larger study on the students' perceptions of the device. In this particular study many of the students chose to quit using the device, or they commented that it was difficult to learn and therefore they were not encouraged to utilize the tool as they could have. Running a larger study where more students are given more time to use the input device would be beneficial to see how it affects a student's desire or confidence in using the actual software.

In future studies students should have more training with the device in order to feel comfortable using it before they are tested to determine its impact. This study lacked sufficient training and many of the students that did not use the device the entire semester chose that path simply because they were not familiar enough with it to perceive any benefit. In order to accomplish a smooth flow between training and the actual coursework, it is necessary that the researcher have a day to day input in the way the course is handled. If the researcher is not consistently involved there is no guarantee the students will get the expected
amount of training and encouragement.

Another recommendation is that it may be good to offer an incentive for the study so that students will take it seriously and focus on it, even amidst the distractions of final exams and classroom schedules. It is understood that anything that will affect a student’s grade will take precedence over other assignments; a possible way to counter that would be some incentive, perhaps monetary or extra credit. It may also be beneficial to schedule the pretest, post-test and surveys to be given on exam days in order to allow as much course time for instruction as possible.

Finally, it would be interesting to perform a research study on expert users. In this study students were learning the software for the first time. It is possible that the extra requirement to learn the intricacies of the 3D input device may have been an overload on the software side. Expert users in the software may react completely differently to the incorporation of a new input device.

**Summary**

Overall the research did not show any advantage to spatial visualization ability caused by using the new input device. The survey returned that students did not particularly enjoy the device, even to the point of choosing to quit using it part way through the semester. Unfortunately, this knowledge hinders the data because it is difficult to say the device had an effect if many of the students in the experimental group chose not to use it. However, the data showed that there was no significant difference between the control and experimental
groups, even though many of the experimental group's students did choose to use the device the entire semester. Larger and more in depth research needs to be done on the topic of the 3D input device in reference to spatial abilities but also in reference to students' confidence and efficiency with software and course material.
REFERENCES


APPENDIX A

North Carolina State University
Institutional Review Board for the Use of Human Subjects in Research
SUBMISSION FOR NEW STUDIES

GENERAL INFORMATION

<p>| | |</p>
<table>
<thead>
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<th></th>
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<tr>
<td>1. Date Submitted:</td>
<td>12/15/08</td>
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<tr>
<td>2. Title of Project:</td>
<td>Effectiveness of 3D Input on Spatial Abilities</td>
</tr>
<tr>
<td>3. Principal Investigator:</td>
<td>Adam Carrico</td>
</tr>
<tr>
<td>4. Department:</td>
<td>Math, Science, and Technology Education</td>
</tr>
<tr>
<td>5. Campus Box Number:</td>
<td>Poe Hall 510G</td>
</tr>
<tr>
<td>6. Email:</td>
<td><a href="mailto:awcarrico@ncsu.edu">awcarrico@ncsu.edu</a></td>
</tr>
<tr>
<td>7. Phone Number:</td>
<td>704-719-0540</td>
</tr>
<tr>
<td>8. Fax Number:</td>
<td></td>
</tr>
<tr>
<td>9. Faculty Sponsor Name and Email Address if Student Submission:</td>
<td>Ted Branoff: <a href="mailto:Ted.Branoff@ncsu.edu">Ted.Branoff@ncsu.edu</a></td>
</tr>
<tr>
<td>10. Source of Funding? (required information)</td>
<td>3rd party</td>
</tr>
<tr>
<td>11. Is this research receiving federal funding?:</td>
<td>No</td>
</tr>
<tr>
<td>12. If externally funded, include sponsor name and university account number:</td>
<td></td>
</tr>
<tr>
<td>13. RANK:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Faculty</td>
</tr>
<tr>
<td></td>
<td>☐ Student</td>
</tr>
<tr>
<td></td>
<td>☑ Undergraduate, ☒ Masters, or ☐ PhD</td>
</tr>
<tr>
<td></td>
<td>☐ Other (specify):</td>
</tr>
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</table>

As the principal investigator, my signature testifies that I have read and understood the University Policy and Procedures for the Use of Human Subjects in Research. I assure the Committee that all procedures performed under this project will be conducted exactly as outlined in the Proposal Narrative and that any modification to this protocol will be submitted to the Committee in the form of an amendment for its approval prior to implementation.

Principal Investigator:

Adam Carrico *(typed/printed name)*

* (signature) *(date)*

As the faculty sponsor, my signature testifies that I have reviewed this application thoroughly and will oversee the research in its entirety. I hereby acknowledge my role as the principal investigator of record.

Faculty Sponsor:

Ted Branoff *(typed/printed name)*

* (signature) *(date)*

*Electronic submissions to the IRB are considered signed via an electronic signature*

Please complete this application and email as an attachment to: joe_rabigga@ncsu.edu or send by mail to: Institutional Review Board, Box 7514, NCSU Campus (Administrative Services III). Please include consent forms and other study documents with your application and submit as one document.

For SPADES only:

Reviewer Decision (Expedited or Exempt Review)

☐ Exempt ☐ Approved ☐ Approved pending modifications ☐ Table

Expedited Review Category: ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8a ☐ 8b ☐ 8c ☐ 9

Reviewer Name __________________________ Signature __________________________ Date __________________________

North Carolina State University
APPENDIX B

North Carolina State University
Institutional Review Board for the Use of Human Subjects in Research
REQUEST FOR EXEMPTION (Administrative Review)

GENERAL INFORMATION

3. Date Submitted: 12/13/08
4. Title of Project: Effectiveness of 3d Maps on Spatial Abilities
5. Principal Investigator: Adam Carriker
6. Department: Math, Science and Technology Education
7. Campus Box Number: Fox Hall 3102
8. Email: acarriker@ncsu.edu
9. Phone Number: 704-216-0340
10. Fax Number:
11. Faculty Sponsor Name and Email Address if Student Submission: Ted Brunoff - Ted.Brunoff@ncsu.edu
12. Source of Funding? (required information): Adequacy
13. Is this research receiving federal funding?: No
14. If externally funded, include sponsor name and university account number:
15. RANK:
   □ Faculty
   □ Student □ Undergraduate, □ Masters, or □ PhD
   □ Other (specify):

As the principal investigator, my signature testifies that I have read and understood the University Policy and Procedures for the Use of Human Subjects in Research. I assure the Committee that all procedures performed under this project will be conducted exactly as outlined in the Proposal Narrative and that any modification to this protocol will be submitted to the Committee in the form of an amendment for its approval prior to implementation.

Principal Investigator:

Adam Carriker
(typed/printed name) __________________________
(signature) __________
(date)

As the faculty sponsor, my signature testifies that I have reviewed this application thoroughly and will oversee the research in its entirety. I hereby acknowledge my role as the principal investigator of record.

Faculty Sponsor:

Ted Brunoff
(typed/printed name) __________________________
(signature) __________
(date)

*Electronic submissions to the IRB are considered signed via an electronic signature

PLEASE COMPLETE AND DELIVER TO:

joe_rabiega@ncsu.edu or Institutional Review Board, Box 7514, NCSU Campus (Administrative Services III, Room 245)

For SPARCS office use only

Regulatory Compliance Office Disposition

☐ Exemption Granted  ☐ Not Exempt. Submit a full protocol

Exempt Under: ☐ b.1  ☐ b.2  ☐ b.3  ☐ b.4  ☐ b.6
APPENDIX C

From: Joseph Rabiega, IRB Coordinator  
North Carolina State University  
Institutional Review Board

Date: January 13, 2009

Project Title: Effectiveness of 3D Input on Spatial Abilities

IRB#: 14-09-01

Dear Adam:

The project listed above has been reviewed by the NC State Institutional Review Board for the Use of Human Subjects in Research, and is approved for one year. **This protocol was approved on January 9, 2009 and will expire on January 9, 2010, and will need continuing review before that date.**

NOTE:

1. You must use the attached consent forms which have the approval and expiration dates of your study.

2. This board complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU the Assurance Number is: FWA00003429.

3. Any changes to the protocol and supporting documents must be submitted and approved by the IRB prior to implementation.

4. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

5. Your approval for this study lasts for one year from the review date. If your study extends beyond that time, including data analysis, you must obtain continuing review from the IRB.

Please provide a copy of this letter to your faculty sponsor.

Sincerely,

Joseph Rabiega  
NCSU IRB
APPENDIX D

North Carolina State University
INFORMED CONSENT FORM for RESEARCH (Experimental Group)
Title of Study: Effectiveness of 3d Input on Spatial Abilities
Principal Investigator: Adam Carriker
Faculty Sponsor (if applicable): Ted Branoff

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

The purpose of the research is to examine the possibility of enhancing student comprehension of virtual space as it pertains to engineering graphics through the use of a 3-dimensional (3-d) input device.

If you agree to participate in this study, you will be asked to use a 3-dimensional input device, complete an assessment prior to and following this course. You will also be expected to respond to a survey addressing how you felt the technology affected your experiences in the course. No additional time will be required outside of class in excess of normal required assignments. Participation in this study is not a requirement for course credit and will not affect your grade in the course in any way. Should you decide to withdraw from the study you will not be forbidden to continue using the 3-dimensional device, and if you choose not to participate but later decide you would like to use the 3-dimensional device you are welcome to use it for the duration of the semester.

There are no known direct benefits to your participation in this study as this is one of the first studies using the 3-d device.

There is no compensation for participating in this study.

If you have questions at any time about the study or the procedures, you may contact the researcher (Adam Carriker, 510-G Poe Hall or by e-mail at awcarrkie@ncsu.edu).

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514), or Joe Rabiega, IRB Coordinator, Box 7514, NCSU Campus (919/515-7515).

If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed.

Consent To Participate
"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time."

Subject’s signature ___________________________ Date ____________
Print name __________________________________________
Investigator’s signature ___________________________ Date ____________
APPENDIX E

North Carolina State University
INFORMED CONSENT FORM for RESEARCH (Control Group)

Title of Study: Effectiveness of 3d Input on Spatial Abilities
Principal Investigator: Adam Carrker
Faculty Sponsor (if applicable): Ted Branoff

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

The purpose of the research is to examine the possibility of enhancing student comprehension of virtual space as it pertains to engineering graphics through the use of a 3-dimensional (3-d) input device. You have been selected to be in the control group and your participation will be limited to completing an assessment prior to and following this course. No additional time will be required outside of class in excess of normal required assignments. Participation in this study is not a requirement for course credit and will not affect your grade in the course in any way.

There are no known direct benefits to your participation in this study. There are also no known benefits to using the 3-D device mentioned above because this is one of the first studies using this device.

There is no compensation for participating in this study.

If you have questions at any time about the study or the procedures, you may contact the researcher (Adam Carrker, 510-G Poe Hall or by e-mail at awcarrk@ncsu.edu).

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Pacheco, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919)515-4514, or Joe Rabigia, IRB Coordinator, Box 7514, NCSU Campus (919)515-7515.

If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be destroyed.

Consent To Participate
"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time."

Subject’s signature ________________________________ Date ________________

Print name _________________________________________

Investigator’s signature __________________________ Date ________________
Do NOT make any marks in this booklet. Mark your answers on the separate answer card.

Directions

This test consists of 10 questions designed to see how well you can visualize the rotation of three-dimensional objects. Shown below is an example of the type of question included in the second section.

IS ROTATED TO

AS IS ROTATED TO

A B C D E

You are to:
1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?
Answers A, B, C, and E are wrong. Only drawing D looks like the object rotated according to the given rotation. Remember that each question has only one correct answer.

Now look at the next example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied.

```
  IS ROTATED TO
  
A   IS ROTATED TO
  B   C   D   E
```

Notice that the given rotation in this example is more complex. The correct answer for this example is B.

```
Do NOT make any marks in this booklet.
Mark your answers on the separate answer card.
You will be told when to begin.
```
APPENDIX G

1. IS ROTATED TO
   AS IS ROTATED TO
   A B C D E

2. IS ROTATED TO
   AS IS ROTATED TO
   A B C D E
13 IS ROTATED TO

AS IS ROTATED TO

A B C D E

14 IS ROTATED TO

AS IS ROTATED TO

A B C D E
APPENDIX H

Survey for the study: Effectiveness of 3d Input on Spatial Abilities
Principal Investigator Adam Carriker Faculty Sponsor (if applicable) Ted Branoff

For all responses circle ONE answer that best fits your opinion.

How often did you use the 3d connexion mouse during the semester?
1. I used it just about every time I used SolidWorks.
2. I used it about 75% of the time when using SolidWorks.
3. I used it about 50% of the time when using SolidWorks.
4. I used it about 25% of the time when using SolidWorks.
5. I hardly ever used the 3d connexion mouse with SolidWorks.

How do you rate your experience with 3d virtual space?
Very Poor 1 2 3 4 Very Good 5

How do you rate the usability of the 3d connexion mouse?
Very Poor 1 2 3 4 Very Good 5

How do you rate the effectiveness of the 3d connexion mouse at navigation?
Very Poor 1 2 3 4 Very Good 5

How do you rate your understanding of 3d navigation?
Very Poor 1 2 3 4 Very Good 5

How do you rate your skill with the 3d connexion mouse?
Very Poor 1 2 3 4 Very Good 5

Do you believe the 3d connexion mouse aided your ability to understand the software?
YES NO

Will you continue to use the 3d connexion mouse in future 3d softwares?
YES NO

Circle your academic year:
Freshman Sophomore Junior Senior Other ________

What is your academic major? __________
APPENDIX I

E-mail to student's enrolled in the study sections

Principal Investigator:  Adam Carriker
Faculty Sponsor (if applicable):  Ted Bransoff

Subject: GC 120 - Spring Semester – 2009

Student,

You are receiving this e-mail because you are currently enrolled in an experimental section of GC 120. Attached is the consent form you will be given to sign on the first day of the class. Feel free to read the attached form and bring any questions you may have to class on the first day.