

ASSESSING THE EFFECTS OF AUGMENTED REALITY ON THE SPATIAL
SKILLS OF POSTSECONDARY CONSTRUCTION MANAGEMENT STUDENTS IN
THE U.S.

A Thesis
Presented to
The Academic Faculty

By

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In Partial Fulfillment
Of the Requirements for the Degree
Master of Science in Building Construction and Facility Management

Georgia Institute of Technology

May 2016

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ACKNOWLEDGEMENTS

I am sincerely thankful to the many people that have helped me complete this research. The learning experience has been an adventure and a personal achievement that I am grateful to have undertaken.

Thanks to Dr. Javier Irizarry for coaching and mentoring me into the world of academic writing and research. I have taken so much knowledge from our many conversations that I know will be helpful as I pursue my deeper interests in teaching. Thanks to Dr. Tris Utschig for enlightening me on the intricacies of academic research. Thanks to Dr. Daniel Castro for having confidence in my return to academia after many years away.

I am grateful and indebted to Irish Horsey and Sam Delgado, at Gwinnett Technical College for assisting me in this research. Thanks to the students at Gwinnett Technical College for offering their time and effort to participate in this research.

Thanks to Dr. Khalid Siddiqi at Kennesaw State University, whose mentorship on the accreditation aspect of my research would have been incomplete without his guidance.

Thanks to the Master's students of the Building Construction program at Georgia Tech for assisting me with the development of the assessment tools used in this research.

Thanks to my friends at Holder Construction Company, Brian McConnell, Glen Rohrer, George Patsios, Jarin Whigham, Helen Henley and Sonja Checkwood for provided me valuable feedback on various parts of the assessment tools.

Thanks to my parents Mary Kim and Che Hoon Kim (김제훈) for listening to me, supporting me and doing what parent do best for their children. Thanks also to my

sister Stacy Kim for her excited enthusiasm at my return to school and to my brother Andy Kim for his curious and sometimes accepting interest in my research.

Lastly, I offer my fondest thanks to my dearest friend and companion Dianne Kim. It all started on a morning hike where she encouraged me to follow my heart. My return to school is possible because of her and I can truly say that without her I would not have accomplished this. And to my son, who may be too young right now to fully appreciate this, all of those evenings that you gave me a hug and a kiss before going off to bed all while I remained in my office writing – well, I remember everyone one of them – thanks Matthew.

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LIST OF ABBREVIATIONS

2D - Two-Dimensional

3D - Three-Dimensional

ABET - Accreditation Board for Engineering and Technology

ACCE - American Council for Construction Education

AECFM - Architectural, Engineering, Construction, and Facilities management

AR - Augmented Reality

BIM - Building Information Model

CE - Construction Engineering

CM - Construction Management

DAT:SR - Differential Aptitude Tests: Spatial Relations

FM - Facility Manager

GPS - Global Positioning Systems

HHMD - Hand-Held Mobile Device

HMD - Head Mounted Display

IP - Improvement Percentage (expresses as a percentage)

LG - Learning Gain

MAR - Mobile Augmented Reality

MRT - Mental Rotations Test

NASA TLX - NASA Task Load Index Survey

PS - Pilot Survey (for Pre- and Post-Assessment)

PSVT:R - Purdue Spatial Visualization Tests: Visualization of Rotation

SPSS - Statistical Package for the Social Sciences

STEM - Science, Technology, Engineering, and Mathematics

VR - Virtual Reality

SUMMARY

There is a continual challenge within the construction industry to meet schedule, budget, and quality expectations. At the same time, there is an underlying problem where the older and more experienced workforce is retiring from industry at a faster rate than the newer workforce can replace them. As the more experienced workforce departs from the industry, they are taking with them much-needed skills and experience that fail to get transitioned to the newer and less experienced workforce. Among these skills are spatial skills. The construction industry has already caught on that this is a serious problem that they must contend with, and so, they have looked to the postsecondary institutions to help resolve it. However, the postsecondary institutions have a problem of their own, whereby they commonly default to passive teaching techniques that are not well suited to teaching spatial skills. So, therefore, there is a need to graduate construction management students with better spatial skills in order to meet the necessities of industry. Along with this, is the need for academia to reconsider teaching styles to better train spatial skills. Spatial skills, it has been found, are better retained when active and collaborative teaching engagements are arranged. Therefore, identifying and testing a practical and non-interfering classroom tool that students can easily use, would be the most favorable way to overcome academia's tendency towards passive teaching.

Spatial skills are needed in every part of the construction industry. In fact, everyday simple tasks require spatial skills and while these skills are honed over time, more refined skills, capable of interpreting abstract space, are required to assemble a complex construction project. Construction projects are getting more complex and often the design involves some measure of abstract thinking. Teaching these abstract-based spatial skills in postsecondary institutions has typically been done through drafting and plan reading courses, with some success. However, the need from industry is not being fully met with these skills and so an alternative solution is recommended. While Building Information Modeling (BIM) has become an adequate solution to aid in the understanding and planning of highly abstract designs, successfully using it requires excellent spatial skills. Consequently, it would be advantageous if those spatial skills were developed before students were introduced to BIM.

Augmented reality is a collection of technologies that allows a user to view the “real” world with additional information that is intended to provide a better understanding of what is being observed. Augmented reality already has applications in many industries and is fast becoming a proven technology. With the availability of smaller and more powerful consumer mobile devices, augmented reality has the potential of becoming a more ubiquitous and practical tool. Recognizing that this technology can be practical, non-interfering, and known by the masses makes it an excellent solution for the classroom. Therefore, this research will study the use of an augmented reality tool to determine if there is an improvement of spatial skills in terms of accuracy, time to execute, and the retention of concepts over time. Furthermore, a separate analysis will

be conducted to determine if the teaching tool is a benefit or disruption to the overall learning experience.

CHAPTER 1

INTRODUCTION

1.1 Research Motivation

The success of today's construction process is sensitive to errors, mistakes, omissions, and inexperience that affect safety, cost, schedule, and quality of a construction project (Clough, Sears, Sears, Segner, & Rounds, 2015; Kelleher Jr, Mastin, Robey, Smith, & Hancock, 2014; Pierce Jr, 2013). While some of the problems could be attributed to outside factors such as fluctuating demand of raw materials, changes in the financial markets, and unpredictable weather conditions, one should also appreciate that there is also an ongoing challenge of educating the next generation of construction managers. The newly graduated construction management (CM) student will need to possess basic skills that they can use to solve unique complex problems and visualize a finalized project in an empty three-dimensional (3D) space (McCuen, 2014). This skill is called spatial skill. The spatial skills required to visualize the unfinished product is an important part of construction; it becomes a skill that constituents of the building process use to communicate new ideas and resolve issues. The problem in not possessing this skill is that the CM student is less likely to meet the needs of industry when they join the workforce. Therefore, a focus on improving this skill is essential.

Good spatial skills are needed to be successful in the Architectural, Engineering, Construction Management, and Facilities Management (AECFM) industry to reduce errors, mistakes, and omissions (Maeda, Yoon, & Lafayette, 2011; McCuen, 2014). As early as the mid-90s, researchers have concluded that visualization of abstract objects on paper and on computer screens was required to be a good communicator within the engineering trades (Hsi, Linn, & Bell, 1997). Later on, building information modeling (BIM) would replace paper by constructing the project in a virtual space (Eastman, Teicholz, Sacks, & Liston, 2011), however, this transition did not supplant a need for good spatial skills, in fact, it could be argued that it increased the need for better spatial skills. This technology has made a positive impact on the way that the AECFM industry communicates; however, one still needs to possess good spatial skills in order to create these models. Furthermore, the prevalence of BIM is being heightened through the use of mobile technologies capable of bringing BIM physically closer to the construction site. While making BIM more universal within the AECFM industry is important, there are still many instances where communicating visually is done through two-dimensional (2D) sketches and verbal communication without the aid of BIM. Therefore, spatial skills become fundamental communication skills that the CM professional needs for many facets of his/her work. Research has shown that spatial skills can be improved (John Hopkins Center for Talented Youth, 2015) and although experience is one way in which this can happen, many tests and studies have been conducted to show that spatial skills can also be learned (Maeda et al., 2011).

Students of CM curricula are introduced to graphics and plan reading courses that are, in part, designed to hone their spatial skills. These courses require students to visualize 2D and 3D objects with and without the aid of illustrations on paper and/or on a computer screen. Spatial skills are taught through lecture along with most course content at the postsecondary level. A lecture is a passive teaching engagement with the students and upwards of 87% of instructors use lecture as their mode of instruction (Livingston, 2001) and Table 1.1). While students can be taught spatial skills through lecture, it is not as effective as other forms of active and visual engagement (Ryu, Kim, Kinnas, & Kang, 2003). The CM student is a visual and active learner (Dong, Behzadan, Chen, & Kamat, 2013; Felder & Silverman, 1988) and today's academic environment for science, technology, engineering, and mathematics (STEM), specific to the construction industry, sees students struggling with visualization tasks (Black & Duff, 1994; Ryu et al., 2003). Therefore, there is an opportunity for meeting teaching style to learning preference that could benefit CM students through the promotion of more active teaching engagements.

Because the market demands higher quality graduates and because having good spatial skills is essential in a growingly abstract and complex design world, improvements in spatial skills could benefit from a new pedagogical tool that supports active learning and engages the students visually. Augmented reality (AR), although not a new technology, has found more applications in today's world, especially with the increasingly widespread use of mobile technologies (smartphones, tablet computers, and ultra-light laptops). Augmented reality presents an enriched world view that includes the use of visualization techniques to better explain how to perform 3D tasks (Feiner, Macintyre, &

Seligmann, 1993). The benefit of using AR in the classroom is that learners can see supplemental digital information (Liarokapis & Anderson, 2010), assisting them in the understanding of highly abstract and complex tasks (Schwald & De Laval, 2003). As a result, students become active participants in their learning by adding visualizations that one can interact with, while encouraging students to ask questions about their learning rather than being told what to learn (Freeman et al., 2014).

1.2 Statement of the Problem (Research Problem)

Successfully executing a construction project is a harmonious orchestration of a number of competing interests, while managing resources, maintaining an agreed schedule and all without overspending a construction budget. There are many opportunities for errors, mistakes, and omissions along the way that can jeopardize any part of the plan (Clough et al., 2015; Kelleher Jr et al., 2014; Pierce Jr, 2013). Various trade journals track raw materials, such as steel, concrete, and wood; and variability in market conditions continually impact the cost and availability of these raw materials. Furthermore, the construction industry is challenged to become more efficient while producing a unique product within a not-so-predictable environment (Thomsen & Sanders, 2011). Central to the management of these complicating factors and to the success of the construction process is its people (Lavender, 2014). However, as older-aged and more experienced individuals leave the construction industry, either through retirement or transition to other industries, they take with them valuable knowledge and experience that does not always get passed along to the next generation of construction professionals (Choi, 2009). In

fact, the aging workforce is departing faster than the newer workers are replacing them (Hildebrandt, 2014; Jain, 2015) In short, the construction industry is faced with a depletion of skill and experience as a result of this imbalance in attrition (McGraw Hill Construction, 2012). As a result, it has become incumbent upon the postsecondary institutions to remediate this situation through adjustments in their curriculum that are being recommended by industry through accreditation organizations (Accreditation Board of Engineering and Technology, 2014; Ahmed, Yaris, Farooqui, & Saqib, 2014; American Council for Construction Education, 2014). Considering all of these factors, the scope of this research has been condensed to focus on a way of improving the spatial skills among postsecondary CM students in an effort to better meet the needs of industry. Specifically, this research will focus on three interconnected areas in order to address the greater problem described above, (1) students continue to struggle with enhancing their spatial skills before they graduate, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions continue to rely on passive teaching techniques that are not well suited to enhance the visual aspects of spatial learning.

1.2.1 Problem Focus 1: Student Spatial Skills

Spatial skills and spatial abilities are two separate concepts and the vocabulary often gets interchanged. Spatial skills are a part of one's spatial ability (McCuen, 2014). There are several factors that can affect the spatial skills of a student, some of which include the student's (1) background and experience, (2) exposure to STEM concentrated studies,

and (3) gender (X. Chen & Soldner, 2013; Jirout & Newcombe, 2015; Linn & Petersen, 1985; McCuen, 2014). These factors cause a variation of proficiency in spatial skills within students, complicating the effort that instructors endure while they adjust course content to meet incoming student needs. Hence, some students will not receive adequate spatial skills training. Furthermore, outside of access to spatial visualization assessment results, students often do not have an accurate perception of their own spatial skills. For instance, this research study included a background survey which students were required to complete prior to participation in the study. When they were asked to rate their own spatial skills they rated their own skill as “high” (“Agree” or “Strongly Agree”, see Figure 1.1), although after completing a pre-assessment instrument, these students were merely able to answer 52.5% of the questions correctly (Table 5.1). This variation among students’ spatial skills proficiency and mismatch in self-perceived spatial skills serve to outline the problem.

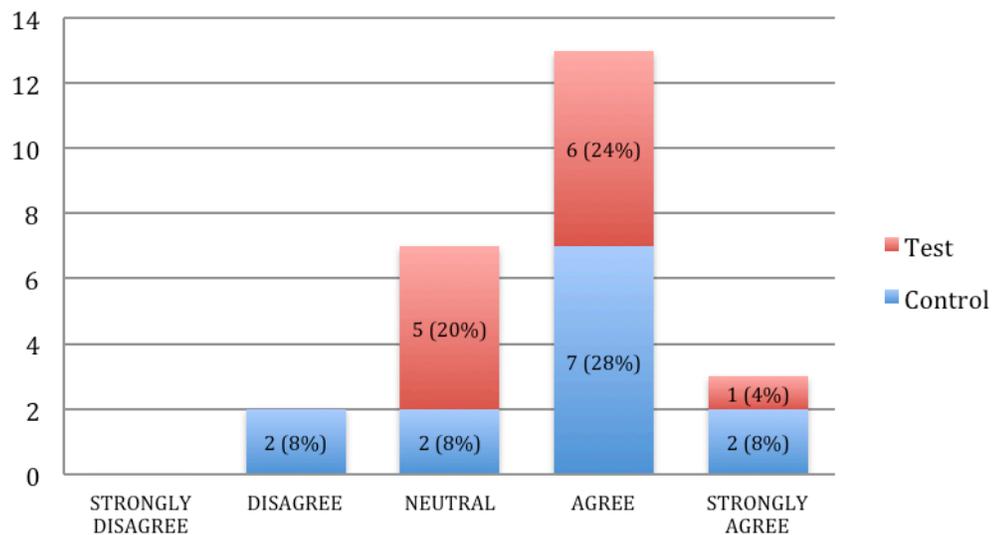


Figure 1.1: Participant Self-Assessment of Spatial Skills. Participant responses to, “I am capable of clearly visualizing, in my mind, objects that are not in front of me and I can manipulate those objects to gain a better understanding of them.”

1.2.2 Problem Focus 2: Industry Need

Training and education is a continuous process in the construction industry (McGraw Hill Construction, 2012) and begins as soon as a new worker enters the industry. Oftentimes, older and more experienced workers will pass on a way of doing things that are a product of their many years of work and experience (Hildebrandt, 2014; McGraw Hill Construction, 2012). Unfortunately, these older and more experienced workers are leaving the industry faster than the newer workers can replace them (Jain, 2015). More specifically, as has been stated by (Hildebrandt, 2014)

“Losing older experienced workers means losing those workers’ knowledge as well. For a construction worker new to the industry, there is only so much knowledge that he or she can bring to the first day of work. For these new employees—and for companies—experienced workers who can share their expertise are tremendous assets.”

Therefore, it could be reasoned that among the “knowledge” and “expertise” that is being lost is also artful spatial skills training. Instruction on how to interpret complex and abstract 2D drawings or creating digital 3D content in a building information model happens at a much slower pace without the trainers to support it. This lack of personnel to continue the training and education serves to outline the problem.

1.2.3 Problem Focus 3: Passive Teaching in Postsecondary Education

In postsecondary engineering education, upwards of 87% of all means of instruction is delivered as lectures (Livingston, 2001) as is illustrated in Table 1.1.

Table 1.1
Lecture within Postsecondary Education

Teaching Discipline	Primary Instructional Method				
	Lecture	Seminar	Lab/ Clinic	Fieldwork	Other
Total	82.7	14.7	21.8	5.3	7.4
Agriculture	84.3	10.2	31.8	9.6	3.9
Business	90.6	10.4	16.6	3.0	6.1
Education	77.1	20.7	16.2	12.7	7.8
Engineering	87.7	8.9	21.5	3.1	5.0
Fine Arts	69.4	14.8	34.0	5.2	20.4
Health Sciences	75.7	14.9	38.0	10.2	5.0
Humanities	88.0	16.5	10.8	3.0	6.9
Natural Sciences	86.3	10.3	24.7	2.3	5.3
Social Sciences	89.5	22.9	8.9	3.7	4.7

Note. This table is adapted from the National Center for Education Statistics, *The Condition of Education 2001*, Section 5: The Context of Postsecondary Education, 2001, page 79 (Livingston, 2001).

While lecture has a purpose in academia, it is often found to be inadequate at truly engaging students (Carter, 2006; Haque, 2001) and constrains their learning (Bonwell & Eison, 1991). Moreover, students of STEM curricula, that go on to become students at postsecondary CM institutions, have been found to prefer visual and active learning techniques (Dong et al., 2013; Felder & Silverman, 1988). In order to appreciate how visual, active, and collaborative teaching techniques can improve spatial skills, consider the increasingly widespread use of BIM in the construction industry (Eastman et al., 2011). CM students have to be taught the concepts and technical skills to successfully implement and use BIM related concepts on a construction project. Because the

elements of BIM are highly visual, a good course structure should allow for high levels of interaction with the software, where students should be allowed to test, manipulate, and form their own conclusions while they work with the technology (Maria Bernardete Barison, 2010). These are techniques that should also be employed in the teaching of spatial skills. Therefore, addressing a disconnect between teaching students in a manner that they prefer while also teaching in a way that best achieves results, on a subject such as spatial skill, serves to outline the problem. However, the fact that 87% of instruction is delivered in the form of lecture does not solely define the overarching problem. There is also a need to focus proper teaching technique to the concepts being imparted. For instance, success in plan reading is best achieved when the student can interact with the content in a bi-directional manner whereby the information received from the instructor can be immediately used to experiment and solve problems (Goodrum, Asce, Miller, Sweany, & Alruwaythi, 2016).

As noted, the success of a construction project is predicated upon the skills of the people involved. As CM students enter the workforce, they obtain work-skills training that prepares them for the rigors often associated with completing a project successfully. This level of on-the-job training becomes problematic because more skilled workers are departing faster than ones that can replace them; consequently, they are taking their know-how with them. All the while, the industry is continuing to design and build more complex projects that require honed spatial skills in order to resolve problems, coordinate work, and communicate with constituents of the building process. As a result, the training obligation passes to the postsecondary institutions. However, they too must

overcome an over-reliance on passive teaching techniques and focus more on alternative ways of engaging students with the skill sets that can promote better spatial skills.

1.3 Background and Need

As has been mentioned, critical to working in the construction industry is a need to have good spatial skills. In most cases, these skills are improved through training in the industry, but they can also be improved through formal academic education (John Hopkins Center for Talented Youth, 2015). On-the-job training for these skills is problematic because the industry is faced with a year-by-year decline in its experience base. Older aged, well-experienced workers are departing faster than the newer workforce can replace them and these newly graduating entrants often lack adequate spatial skills (Alias, Black, & Gray, 2002; Black & Duff, 1994; Ryu et al., 2003) so, therefore, there is an immediate need to improve them. As the obligation to shore up the educational gap falls to the postsecondary institutions, they too must reevaluate their tendency for passive teaching techniques and accommodate more visual and active teaching principles that are the foundation of spatial learning (Halpern & Hakel, 2002). In summary, the needs are threefold, (1) students need to improve their spatial skills, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions need to reevaluate their default tendency toward passive teaching techniques.

As a matter of clarification, this Thesis is distinctly focused on the CM student whose academic curriculum is a blend of STEM-related studies, practical business principles, and development of management skills (Hauck, 1998). Not unlike students of the construction engineering (CE) disciplines, the CM student must complete courses in applied structures and have a basic understanding of the strengths of materials (American Council for Construction Education, 2014). Moreover, the two disciplines need to understand spatial concepts and be able to communicate using spatial skills and abilities. As a result, students from both of these disciplines require heightened spatial skills to be successful in STEM occupations. Throughout this Thesis, the researcher will draw comparisons between CM students and CE students only to the extent of the similarity in their need to possess the spatial skills described here.

1.3.1 Need Focus 1: Student Spatial Skills

Spatial ability is an innate competency, whereas spatial skills are developed spatial abilities that gain improvement through practice and application (McCuen, 2014). Educating and training of the type of spatial skills necessary in CM is already being done within the postsecondary education system. However, as research has demonstrated, students have reported that they still struggle with abstract and complex spatial tasks (Alias et al., 2002; Black & Duff, 1994; Ryu et al., 2003). Therefore, the need for this research will be to address the inadequate spatial skills proficiency of current postsecondary CM students.

1.3.2 Need Focus 2: Industry Need

Reading plans for a construction project requires spatial skills that are usually taught at the entry-level years of the postsecondary CM education curriculum. CM students are required to interpret 2D images to their associated 3D counterparts. The skills necessary to translate these images, whether 2D or 3D, involve spatial skills (Baartmans & Sorby, 1996; Sorby & Baartmans, 2000). Moreover, with the introduction of BIM, students have to virtually orient themselves in a non-existent space as they mentally envision the 3D images on a computer screen or a mobile device. The abundance of new types of BIM jobs in the construction industry has also increased demand for good spatial skills (McGraw Hill Construction, 2012). Furthermore, building designs are becoming more complex and with the introduction of BIM, fantastically complex structures are being imagined that require acute spatial skills to coordinate and build. In addition, constituents on a construction project use their spatial skills to communicate, requiring the use of solid spatial skills that often do not involve supplemental images to support a mental image that must be created and communicated between people. Therefore, the CM professional must possess solid spatial skills in order to be successful (Maeda et al., 2011; McCuen, 2014). The need here is to increase the spatial skills proficiency of graduating CM students so they are more capable of addressing the ever-increasing visualization challenges that they will be exposed to in the industry.

1.3.3 Need Focus 3: Passive Teaching in Postsecondary Education

As previously mentioned, today's classroom instruction typically consists of 87% lecture (Livingston, 2001). Lecturing is considered a passive form of teaching and while it seems to be an efficient mode of teaching it does not truly engage CM students in a manner by which they prefer to learn (Bonwell & Eison, 1991). In order to address the inadequacy of spatial skills of graduating CM students, we must first address the manner through which they receive their training, so it is important to understand that CM students prefer visual learning techniques (Dong et al., 2013; Felder & Silverman, 1988). Coincidentally, teaching spatial skills is best done using visual, active, and collaborative techniques (Maeda et al., 2011).

Beyond the common CM lecture, it has been suggested that providing students 3D models with which they can manipulate at their own pace allows students to discover their own strengths and weaknesses in their own learning experiences, which facilitates self-improvement (Zolfagharian, Gheisari, Irizarry, & Meadati, 2013). However, one of the ironies of teaching is that the more complex and abstract a concept being taught, the more compelled the instructor feels to lecture (Stearns, 1994). Therefore, the need would be to encourage visual stimulation and allow students to participate in their own learning while improving their spatial skills.

Because the success of working in the construction industry is heavily tied to the skills of the workforce executing the work (Lavender, 2014), it becomes necessary to make sure

that they are adequately educated and trained to do the work. However, since the pace of attrition of the aging workforce is faster than the gain of new workers entering the workforce, the industry finds itself in a position where those skills and experiences are not getting transferred at all (Hildebrandt, 2014; McGraw Hill Construction, 2012). Consequently, postsecondary institutions are now being relied on more heavily to educate the new workforce. But, the postsecondary institution must address an ongoing challenge to meet teaching style to the learning style of the students and to overcome an over-reliance on passive teaching techniques. To this end, this research will aim to design, implement, and assess a new pedagogical tool focused on improving spatial skills in postsecondary CM students.

1.4 Purpose of the Research

The purpose of this research was to examine the outcome of applying a mobile augmented reality (MAR) tool into a construction management course at a postsecondary institute and determine if there was an improvement in the spatial skills of the students.

1.4.1 Rationale for Research

To understand the basis for this research, one needs to appreciate that the construction industry is in the midst of a departure of its most experienced workforce. The explosion of the U.S. population after World War II created a bubble in the construction industry workforce, the repercussions of which are being experienced now as they begin to retire

(Hildebrandt, 2014; Jain, 2015) and leave the workforce. Furthermore, the construction industry functions on the need of its workforce to think spatially and to have spatial skills in order to solve complex abstract problems (Maeda et al., 2011). All the while, postsecondary institutions are being relied upon more heavily to fill the growing needs of industry in training the new workforce (Ahmed et al., 2014). Lastly, the postsecondary institutions are struggling to engage students in a more visual and active learning environment, one more suited to educate and train budding spatial skills (Livingston, 2001). Therefore, the overarching rationale for this research is to examine a new way of teaching the skills necessary to strengthen the spatial ability of CM students in postsecondary institutions in an effort to meet the needs of an industry that is facing an experience shortfall.

1.4.2 Description of Research

To improve the spatial skills of CM students at a postsecondary institution, a between-group double-blind experiment was conducted. The subject pool consisted of twenty-five ($n=25$) postsecondary construction management students at Gwinnett Technical College in Atlanta, Georgia. Upon consenting to the experiment, the subjects were administered a background survey (Appendix A). Immediately following the survey a pre-assessment (Appendix B) was administered to discern a baseline of the student's spatial skills. Following the pre-assessment, all students participated in a lecture (Appendix C) given by the researcher that included an electronic presentation of the techniques used to understand basic spatial concepts. Upon completion of the

presentation, the subjects were randomly divided into two groups, with the purpose of the groups unidentified to the subjects. Each group was placed in a separate room. Each of those groups further split into pairs of individuals to complete a lab assignment (Appendix D). The lab assignment consisted of six spatial skills exercises that the students had to work through. The Control Group worked in pairs to complete the six assignments. Within the Test Group, each pair of students received a mobile device that was configured to run Augment software (<http://www.augment.com>). Augment is a software application that reads a marker and displays a pre-determined 3D image on the mobile device. A marker is a machine-readable optical label that contains information which can be decoded to produce an image on the mobile device running the software capable of reading the label. In this experiment, the lab assignment is the marker (Figure 1.2 and Appendix D). The 3D image is set to render above the given lab assignment whereby subjects can move around the lab assignment and view a 3D object as if it were truly there (Figure 1.3). Furthermore, the lab assignment contains a 2D image of the 3D image that displays on the mobile device so that subjects can compare the two images and learn better ways to translate 2D images into their associated 3D counterparts.

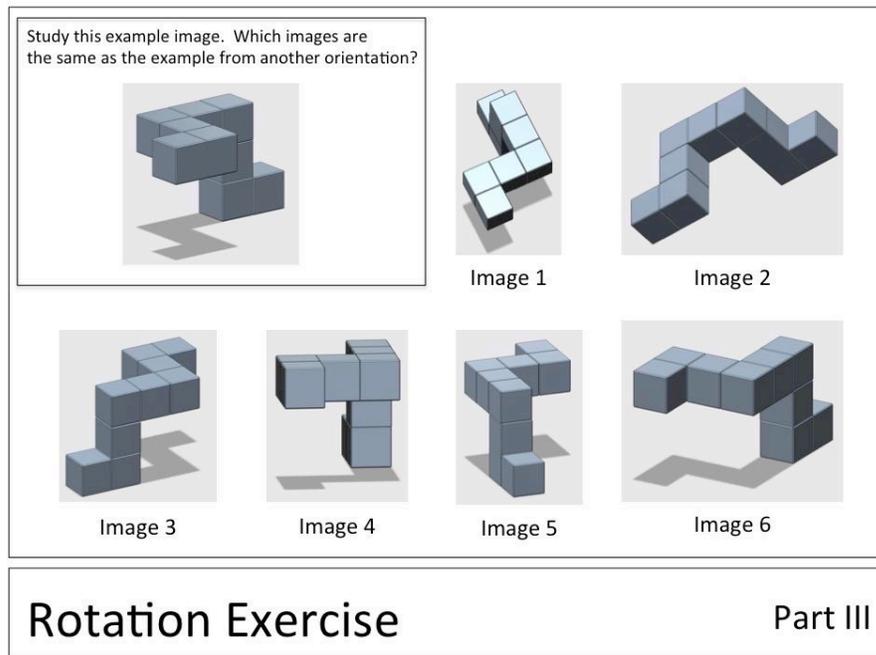


Figure 1.2: Lab Assignment Marker. This figure illustrates one of the lab assignment exercises performed by both Control and Test Groups.

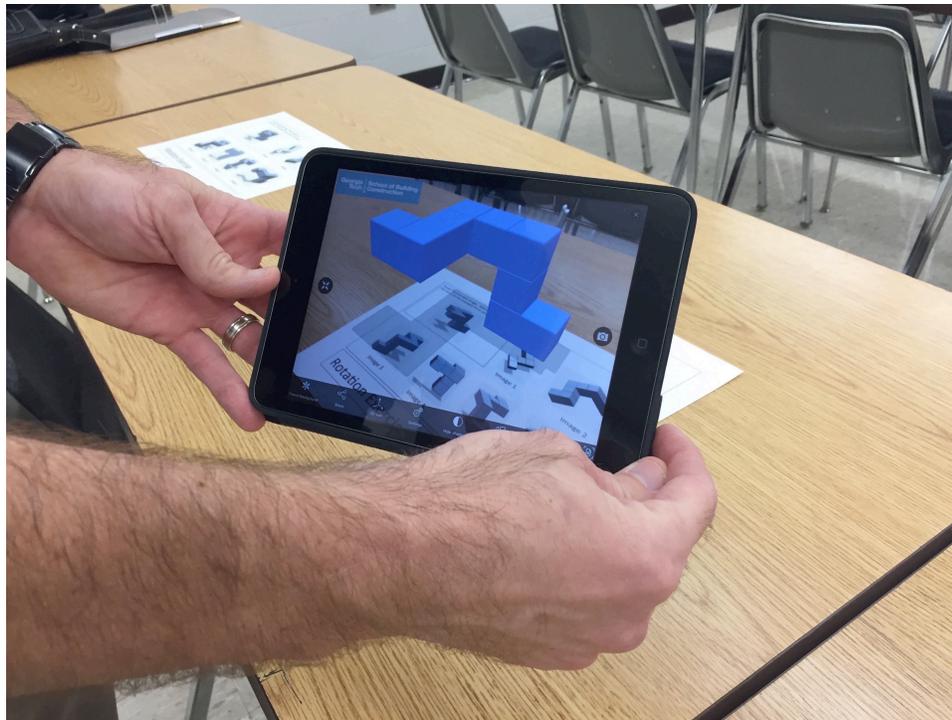


Figure 1.3: Lab Assignment Marker and Mobile Augmented Reality Tool. 3D model is shown on the mobile device screen in blue.

With the students still separated, and once all students in both groups completed the lab assignment, they were administered a post-assessment (Appendix E) and a NASA Task Load Index (NASA TLX) survey (Human Performance Research Group, 1986) (Appendix F).

1.5 Research Questions

The objective of this research was to understand if the intervention of a mobile augmented reality application, and thereby a visual active learning pedagogical tool, would improve the spatial skills of CM students at the postsecondary level. Fundamentally, this research is set to respond to the following three problems facing the construction industry, (1) students continue to struggle with enhancing their spatial skills before they graduate, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions continue to rely on passive teaching techniques that are not well suited to enhance the visual aspects of spatial learning.

In addition to the focused research problems, stated above, the following research questions were established to provide guidance to the research study and to become measurable data points by which conclusions could be drawn from this research.

Question 1

Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?

Question 2

Can a mobile augmented reality pedagogical tool be used to improve the speed of executing spatial tasks in CM students at the postsecondary level?

Question 3

Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skills in CM students at the postsecondary level over time?

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A successful construction project requires skillful people to implement an often complex and abstractly designed project (Clough et al., 2015; Kelleher Jr et al., 2014; Pierce Jr, 2013). Modern day construction projects call for a more advanced use of mathematical models, data analysis, and 3D modeling software, which in turn needs to be converted to a plan of execution by a construction manager. In order to interpret this kind of data, a CM employee needs to possess good spatial skills that will allow him/her to visually predict where and how components of the project will be assembled. These spatial skills, therefore, are in high demand on a construction project; without them, the construction project is in jeopardy in terms of coordination, problem solving, scheduling, and overall harmony. The industry is also faced with a growing shortage of experienced and skilled workers, predominantly contained within the older and aging workforce. This older and aging workforce is departing from the industry at a faster rate than the newer, younger, and less experienced workforce can replace them (Hildebrandt, 2014; Jain, 2015). The industry is faced with a depletion of skill and experience as a result of this imbalance in attrition (McGraw Hill Construction, 2012). Therefore, it becomes incumbent upon the postsecondary institutions to slow this siphon of knowledge. This burden comes at a time when postsecondary institutions are working through ways to

better meet the educational needs of students. Currently, these institutions prefer passive means of educational engagement (Livingston, 2001), which is not highly effective in teaching the visual and active elements of spatial skills. So, therefore, it is necessary to reevaluate alternative ways of engaging students that can promote better spatial skills.

The literature review will address the primary three problems stated in this research, (1) students continue to struggle with enhancing their spatial skills before they graduate, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions continue to rely on passive teaching techniques that are not well suited to enhance the visual aspects of spatial learning. In the first section, research studies related to spatial skills will be examined and correlated to how the CM student learns. In the second section, an overview of the aging construction workforce and its implications for experience and skills as they depart from it will be examined. In the third section, the current state of postsecondary passive teaching methods will be compared to active teaching methods. Lastly, a complementary study of the current technology available to meet the needs of a pedagogical tool that can teach spatial skills while engaging students visually and actively to promote better spatial skills will be examined.

2.2 Spatial Skills and How the CM Student Learns

To begin an understanding of spatial skills, an appreciation needs to be made for utilizing those skills in spatial thinking. According to the (The National Academies Press, 2006) spatial thinking is a universal way of thinking that is present in everyone in different amounts and is derived from different life experiences and it contains three elements: (1) space, (2) interpretation, and (3) reasoning. Space involves the area or dimension that can be measured and coordinated to contain objects. Interpretation involves discerning relationships between boundaries of objects. Reasoning involves using one's own knowledge to draw conclusions about how objects should appear within a framework of physical sciences known to a person. Spatial thinking is the act of engaging the mind by using one's spatial abilities and spatial skills to develop a visualization of the physical world around them (McCuen, 2014). Spatial ability is innate to the individual and is developed over time through experiences and an overall interaction with the physical world around them (Martin-Gutierrez, Saorin, Martin-Dorta, & Contero, 2009; McCuen, 2014). Common tasks such as packing a car trunk or organizing a cupboard involve spatial ability. When packing a trunk, one must know what available space there is to insert an overnight bag. The bag must be lifted through space and maneuvered, rotated, and inserted into an appropriate open space in the trunk. Likewise, in a cupboard, bottles of spices may need to be moved to alternate locations to make more space for a newer and larger bottle of spices. The act of moving the existing bottles involves a complex series of lifting with rotations to make sure that one does not topple over existing bottles while making room for the newer bottle. The examples detailed here

when actually performed describe a spatial task while thinking about the task before actually performing it involves spatial thinking. Spatial thinking can be thought of as a series of steps or stages, one building upon the previous stage to complete a spatial task, the stages are: (1) spatial thinking, (2) mental modeling, and (3) spatial reasoning (Lohman, 1996; McCuen, 2014). Again, in our example, spatial thinking involves understanding where the cupboard is, what is contained within it, and where we are in relation to it. Mental modeling involves visualizing the spice bottles, the open spaces, and where we think a new bottle can be placed. Lastly, spatial reasoning is understanding, based on our perception of how the physical world operates, what it will take to move the bottles around to place a new bottle in the cupboard. As (McCuen, 2014) states, success at each stage is imperative if an individual is to have success at subsequent stages.

2.2.1 The Vocabulary of Spatial Skills

The vocabulary for spatial “skills” in the research literature is often used interchangeably with spatial “abilities”. Spatial skills are identifiable attributes that one is capable of performing at a measurable rate and many different skills combined make up one’ s spatial ability (McCuen, 2014); the skill is part of the ability. Therefore, as will be examined, spatial skills can be improved and likewise, the ability will improve because it is the sum of one’ s spatial skills proficiency. The attention of this research will be directed at the spatial skills level of an individual.

2.2.2 Spatial Skills and CM Students

There appears to be no unitary definition of spatial ability; it has been argued to contain many components (Michael, Guilford, Fruchter, & Zimmerman, 1957), which makes it a difficult proficiency to assess. Despite this fact, there have been various spatial skills assessments that have been developed in other research studies and over the years, seem to be tightly connected to the engineering profession (Caissie, Vigneau, & Bors, 2009). In terms of assessing engineering students, and as clarified in the previous chapter, there is a similarity between CE students (future entrants to the engineering profession) and CM students. The CM student's academic curriculum is a blend of STEM-related studies, practical business principles, and development of management skills (Hauck, 1998). Not unlike students of the CE disciplines, the CM student must complete courses in applied structures and have a basic understanding of the strengths of materials (American Council for Construction Education, 2014). Moreover, the two disciplines need to understand spatial concepts and be able to communicate using spatial skills and abilities. As a result, students from both of these disciplines require heightened spatial skills to be successful in STEM occupations (Wai, Lubinski, & Benbow, 2009). Therefore, since past research has demonstrated a positive impact for CE students, in terms of their spatial ability, it is being reasoned that this research could also be used to benefit CM students. The benefit to the CM student becomes a benefit to the construction industry because these students become a working member of that industry. Good spatial skills are needed in the construction industry because its constituents will be required to visualize and represent their ideas in abstract and complex ways, often using

paper and the computer to assist in conveying their thoughts graphically (Maeda et al., 2011). Spatial skills then become a tool that the constituents of the construction industry use to complete their tasks. Likewise, they will also use this tool to communicate with others in the greater AECFM space. But can spatial skills be improved for CM students?

2.2.3 Can Spatial Skills Improve?

A review of the literature has shown that spatial skills can be improved (John Hopkins Center for Talented Youth, 2015; Lohman & Nichols, 1990; McCuen, 2014; Sattineni & Williams, 2008; Wai et al., 2009) so, therefore, the question remains, can the effect of specifically teaching postsecondary CM students have a positive outcome on their spatial skills? According to (The National Academies Press, 2006) the skills required for spatial thinking can be developed within a specific setting, supported by tools and technology. For instance, in a mathematics discipline, students use a calculator, in geography, students use graphical information systems and in design and construction, students use computer-aided design systems. Consequently, the tools used to teach should be designed to accommodate the tools and technologies pertinent to the discipline being trained. Therefore, it can be concluded from past research that the CM students' spatial skills can be improved by education and training, given that the correct composition of tools and technology are employed in the correct setting.

2.2.4 CM Student Learning Preferences

In line with attempting to match the tools and technologies in the teaching and learning experience, the preferences of the student must also be considered (Bernold, 2005). Overall, research shows that engineering and CM students prefer visual and active learning engagements (Bernold, 2005; Felder & Silverman, 1988). Additionally, as cited by (Felder & Silverman, 1988), most people of college age are visual and auditory learners. The key, therefore, is to match a teaching style that complements this need. Referring to Figure 2.1, because most college students are visual and auditory learners, the corresponding teaching style should be based on “presentation” that includes both visual and verbal elements. Consequently, the aforementioned need to have good spatial skills along with the understanding that spatial skills can be improved, along with matching the correct teaching style to the students’ preferred learning style, provides validation for a reliable research effort.

Preferred Learning Style		Corresponding Teaching Style	
Sensory	} Perception	Concrete	} Content
Intuitive		Abstract	
Visual	} Input	Visual	} Presentation
Auditory		Verbal	
Inductive	} Organization	Inductive	} Organization
Deductive		Deductive	
Active	} Processing	Active	} Participation
Reflective		Passive	
Sequential	} Understanding	Sequential	} Perspective
Global		Global	

Figure 2.1: Dimensions of Learning and Teaching Styles. This model has been adapted from Learning and Teaching Styles in Engineering Education, 1988, Page 675 (Felder & Silverman, 1988).

2.3 Industry Needs, the CM Curriculum, and the CM Student

2.3.1 Industry Influence

There are a number of ways that industry can participate in the education of future graduates from postsecondary institutions, such as, scholarships, fellowships, research funding, and guest speaking engagements to name a few. In addition, the establishment of accreditation organizations ensures that the skills demanded by the construction industry become a part of the postsecondary institution's curriculum. Organizations, such as, the American Council for Construction Education (ACCE) and the Accreditation Board for Engineering and Technology (ABET) have similar missions and purposes that

are structured in such a way to shape the future of construction education through close collaboration with the industry (Accreditation Board of Engineering and Technology, 2014; American Council for Construction Education, 2014). Each organization holds multiple yearly events where industry and academia conduct day-long strategic planning sessions. Accreditation is also ensured through quality review inspections of the academic programs along a predefined set of standards. Through all of this collaboration and co-mingling, the industry has opportunities to share ideas about future trends within the business that can affect course content while academia can share research trends and opportunities that industry can benefit from. Hence, there are mechanisms in place to transfer knowledge between industry and academia. However, research has shown that there is a gap in spatial skills between what industry expects and what students have (John Hopkins Center for Talented Youth, 2015; Lohman & Nichols, 1990; McCuen, 2014; Sattineni & Williams, 2008; Wai et al., 2009).

2.3.2 The CM Student's Struggle

The civil engineering curriculum, similar to the construction management curriculum, is typically a blend of STEM-related studies along with practical business principles (Hauck, 1998). Students of these curricula are often required to interpret complex and abstract images into 3D images in order to solve engineering problems (Martin-Gutierrez et al., 2009; McCuen, 2014). However, research conducted by (Alias et al., 2002; Black & Duff, 1994; Ryu et al., 2003), indicates that students still struggle with visualization tasks. (Black & Duff, 1994) continues to suggest that educators would not hesitate to

argue that shortcomings still exist. As was examined in Chapter 1, students of this research over-reported their proficiency in spatial skills (Figure 1.1). Upon completion of a pre-assessment, those same students that self-reported “high” proficiency (“Agree” or “Strongly Agree”) in spatial skills only responded correctly on 52.5% of the questions (Table 5.1). This inconsistent self-perception indicates that a problem still exists. Therefore, there is some correlation to the statement that (Black & Duff, 1994) made over 20 years ago that can still be pertinent today about student spatial skills.

2.3.3 Academic Challenge

It is commonly understood that success in the construction industry is sensitive to inexperience and mistakes by the people who work in it (Clough et al., 2015; Kelleher Jr et al., 2014; Pierce Jr, 2013). Therefore, it could be reasoned that the industry would want to make sure that the graduating workforce is capable of solving problems common in today’s construction work environment. There are three factors that affect the challenge faced by academia in making sure that the newly graduated student is qualified for the challenges that await him/her. These challenges are: (1) there is an experience drain as older, more experienced workers depart the industry faster than the newer workers can replace them, (2) building design is becoming more complex, and (3) the use of BIM is becoming more widespread in the industry.

Firstly, the industry has recognized a shift of its workforce as younger, less experienced workers begin to replace an older more experienced workforce. That older and more

experienced workforce is departing quicker than the younger workforce can replace it (Hildebrandt, 2014; Jain, 2015). With the departure of the older generation of workers, so too goes the experience and training that they can offer.

Secondly, there are countless trade articles that extol the successes and failures of some of the most complex structures being built today; each year achieving new heights, faster speeds, and more sustainability. These complexities are achieved, in part, through a good ability to think spatially. The success of engineers comes from being able to visualize and represent ideas involving abstract objects conceived on paper and on a computer screen (Maeda et al., 2011; Wai et al., 2009).

Thirdly, there is no doubt that BIM has become more a part of the construction industry, and there is a steep learning curve that comes in making sure it is used to its highest effectiveness. In “BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors”, 2nd Edition (Eastman et al., 2011), there are over 560 pages dedicated to successfully implementing BIM in all aspects of the AECFM space, and this does not include the software, which may require several days of training to begin using. Reading this handbook and undergoing days of training, still does not prepare one for the spatial skills necessary to render objects and create complex models that can be useful for the coordination of a construction project. While research has shown that BIM can have a positive impact on the quality of learning, there is still the supporting element of visualization that is necessary to support BIM (Wong, Wong, & Nadeem, 2011).

In summary, the industry has an effective and established mechanism for translating needs to academia so that the graduating workforce is capable of facing modern-day challenges. Those challenges are (1) there is an experience drain as older, more experienced workers depart the industry faster than the newer workers can replace them, (2) building design is becoming more complex, and (3) the use of BIM is becoming more widespread in the industry. In light of these challenges, this research will be positioned to address a timely need to improve spatial skills in postsecondary CM students.

2.4 Passive vs. Active Learning

2.4.1 A Reason for Active Learning

(Freeman et al., 2014) completed an exhaustive meta-analysis of current research to come to a consensus comparison description of passive and active learning.

“Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert”.

Additionally, (Freeman et al., 2014) concluded that students were limited to note taking and occasional unprompted questions of the instructor, thereby defining the context for how most lectures are delivered. In postsecondary institutions, it has become commonplace for most if not all, course content to be lecture-based and according to (Bernold, 2005; Livingston, 2001), 87% of all engineering teaching instruction is lecture based. The classroom still remains a passive learning environment (Tatum, 2010).

Others would also agree that lecturing is the predominant form of teaching (King, 1993), mainly because the instructor is able to share information with a larger audience more effectively (W. McKeachie & Svinicki, 2013). In fact, some instructors feel compelled to lecture when the concepts being taught become more complex (Stearns, 1994). Subsequently, some researchers argue that using lecturing alone, no matter how well delivered, is not sufficient (Bonwell & Eison, 1991; Freeman et al., 2014; Haque, 2001).

The antithetical approach to passive learning is active learning, and it is generally more relatable to the CM students' spatial skills (Alias et al., 2002; Dong et al., 2013; Felder & Silverman, 1988). Much like matching the tools and technology pertinent to the discipline being trained, the teaching style also needs to be matched to the concepts being taught. With the need to improve spatial skills, which are taught more successfully using visual and collaborative environments (Maeda et al., 2011), it is being reasoned that the research should focus on active learning as the approach to use. Further support of this can be found in (Freeman et al., 2014) study, which, in their meta-analysis, they concluded that active learning in STEM-related disciplines increased examination performance by just under half a standard deviation, and conversely, lecture alone increased failure rates by 55%. Lastly, in a study endorsed by ABET, it was found that active and collaborative engineering courses were more effective than their lecture-based counterparts (Terenzini et al., 2001).

2.4.2 Active Learning Assessments for Spatial Skills

Active learning works (Anderson & Adams, 1992; Chickering & Gamson, 1987; Johnson, 1991; W. J. McKeachie, 1987). But what role does the instructor then have when they are no longer passively lecturing to their students? As suggested by (Behzadan & Kamat, 2013) a learning environment that incorporates active learning, collaboration, and technology places the instructor in a facilitator mode, which encourages new forms of pedagogy. Therefore, it becomes important to consider pedagogy in terms of improving spatial abilities in CM students when a shift is made from passive to active learning. Exercises have been designed in past research that assesses spatial skills and could also be used as training materials to improve them. In fact, research on spatial skills dates back several decades, and there are some very reliable assessments that could be utilized in this research, some of which include the Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R) (Guay, 1976), Differential Aptitude Tests: Spatial Relations (DAT:SR) (Bennett, Seashore, & Wesman, 1956) and the Mental Rotations Test (MRT) (Vandenberg & Kuse, 1978).

2.4.3 Connecting Active Learning and Spatial Skills

Many postsecondary students in CM related curricula have a background in STEM, either through their current studies or through past academic experiences. A review of the plan of study for any accredited CM program will include Calculus, Physics, Structures and a variety of technology courses pertinent to the CM discipline. Research conducted

by (Freeman et al., 2014) validates that active learning works for STEM disciplines and in (Wai et al., 2009)'s research, it was concluded that spatial skills and STEM were highly interconnected. Given these overlapping relations, it is concluded that spatial skills can be improved through active learning techniques. Based on this statement, it can be concluded that if we intend to improve the spatial skills of CM students we must focus on (1) active learning techniques, (2) encourage collaboration, (3) provide visual content, and (4) utilize appropriate exercise and assessment.

2.5 MAR in CM Education

The review of the literature has included (1) an analysis of spatial skills and how the CM student learns, (2) the needs of industry, and (3) a comparison of passive and active learning. It has been reasoned that the CM student of today is struggling with meeting the standards expected of them in terms of spatial skills. The need from industry has been justified because the older and more experienced workforce is departing at a faster rate than the newer workforce can replace them and as a result, taking all of their valuable skills and experiences with them. In conjunction with this problem, the postsecondary institutions that are being relied upon to fill this skill and experience gap have a struggle of its own with an over-reliance on passive teaching techniques. Furthermore, it has been reasoned that active teaching techniques, collaboration, visual content, and consideration for assessment techniques will better engage the postsecondary CM student in order to improve their spatial skills. Therefore, the purpose for this section is to present a technology that addresses these concerns while

remaining (1) practical, (2) non-interfering, and (3) using technology familiar to postsecondary CM students.

2.5.1 Augmented Reality

The act of using a computer to make a concept easier to understand can be attributed to (P. Brooks, 1996). These days, we do not hesitate to accept this proposition. Likewise, in education, we can also understand that computers have and will, for the foreseeable future, play an important role in the academic success of students (John Hopkins Center for Talented Youth, 2015). For this reason, it is important to evaluate the educational effectiveness of newer technologies when applied to postsecondary CM education. Careful planning and attention need to be assigned in determining the right amount of technology to employ because improperly applied technology can be detrimental to the teaching effort (Cristia, Ibararán, Santiago, Santiago, & Severin, 2012).

Augmented reality (AR) is the addition or subtraction of virtual (computer-generated) images superimposed on a real-world view (Azuma, 1997). (Liarokapis & Anderson, 2010) defines AR as harmonizing the virtual and real environment in order to provide an understandable and meaningful view. Contrastingly, and more commonly known, is virtual reality (VR) where the entire worldview is completely computer generated; no visual element in VR is real. According to (Milgram, Takemura, Utsumi, & Kishino, 1994)'s "Reality-Virtuality Continuum", augmented reality fits somewhere between the

“real environment” and the “virtual environment” through differing amounts of the applied augmented (computer-generated) reality (Figure 2.2).

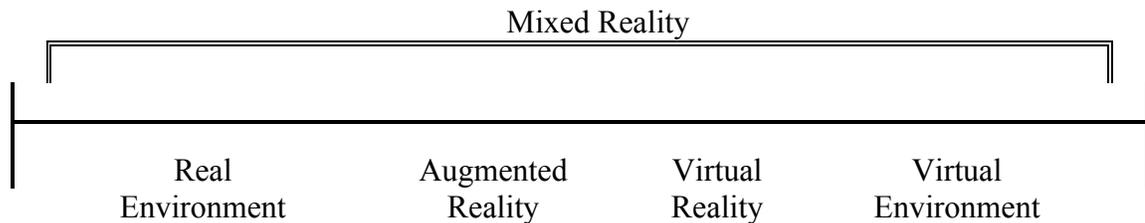


Figure 2.2: The Reality-Virtuality Continuum. Milgram’s Reality-Virtuality Continuum, adapted from page 283 (Milgram et al., 1994).

AR is a vision-based technology that requires markers to create a connectedness between the real environment and the one that is generated by the computer (Feiner et al., 1993). A marker, also known as a fiducial, is a machine-readable optical label that contains information that can be decoded to produce an image on a mobile device running the software capable of reading the label (Azuma, 1997). There are other methods of connecting the real environment to the virtual one that does not involve fiducials. The technology surrounding these more advanced methods of connection defines what is called registration. However, if the AR software is unable to properly connect the real environment to the virtual one, the illusion that the two worlds coexist will be compromised (Azuma, 1997). For this reason, the use of fiducials that can be placed in very specific and controlled locations is a preferred method of rendering the augmented view because it eliminates complexity in setup and the need for high-powered computing currently necessary in non-fiducial rendered AR.

According to (Azuma, 1997) nearly two decades ago, ergonomics and ease of use are of paramount consideration when using AR. Since some of the technology surrounding AR involves head mounted displays (HMD) that can be heavy and impair or completely negate the natural vision of the user, his point on ergonomics is quite valid. An interesting property of AR is that it fosters mobility; it encourages the user to move around (Azuma, 1997), unlike VR where the user's complete field of view is obscured by a virtual world. Lastly, today's student is visually media conscious (Moskal, Lurie, & Cooper, 2004), is generally aware of newer technologies (Bowie, 2010), and has access to mobile technology that is in wide use today (Riedel, 2014; Yu & Conway, 2012). Therefore, arguing that AR is a mobile technology that today's students could make use of would not be unacceptable. For this reason, the use of smaller and more mobile devices would be advantageous because it meets the needs for the tool to be (1) practical, (2) non-interfering and (3) using technology familiar to CM students.

2.5.2 Current Technology, AR, and Education

According to (Liarokapis & Anderson, 2010), an ideal AR solution will need to fulfill the following minimum requirements (1) be simple and robust, (2) provide the learner with clear and concise information, (3) enable the educator to input information in an effective and simple manner, (4) enable an easy interaction between the learner and the educator, (5) make a complex procedure transparent to the learner and educator, (6) be cost effective, and (7) be extensible. Until recently, not all of these requirements could be met at the same time for an AR solution. Through the availability of supporting

technologies such as smaller and faster mobile devices, faster available broadband Internet service, and more accurate global positioning systems (GPS), the fulfillment of the requirements by (Liarokapis & Anderson, 2010) can now be realized.

A case study for augmented reality's use in CM education is included in "Exploring BIM and Mobile Augmented Reality Use in Facilities Management" (Gheisari et al., 2014). In this research, the use of a BIM and a MAR device was used to provide a detail rich environment for building facility managers (FM) on their mobile device. Typically, the facility manager's duties require them to be highly mobile while continually cross checking paper manuals, drawings, and specifications. With BIM and MAR, the FM is able to use AR to get more information about their surroundings through viewing actual building components and equipment with embedded cameras on their mobile devices. Through a web browser that accesses BIM data, and overlays virtual data they can obtain information about building components, systems, and equipment all on their mobile device. From this case study, it is the intent of this research to use a similar design that could be used in a classroom setting for the purposes of providing supplemental explanation during a student spatial skills exercise, all the while, meeting those requirements from (Liarokapis & Anderson, 2010) previously mentioned. In addition, an educational tool employed in this manner should foster an active learning environment, one that is necessary to best improve spatial skills (Maeda et al., 2011).

In a background survey conducted as a part of this research, CM students were asked if they had an understanding of what augmented reality was. Half responded that they had a basic understanding or better of the technology (Figure 2.3).

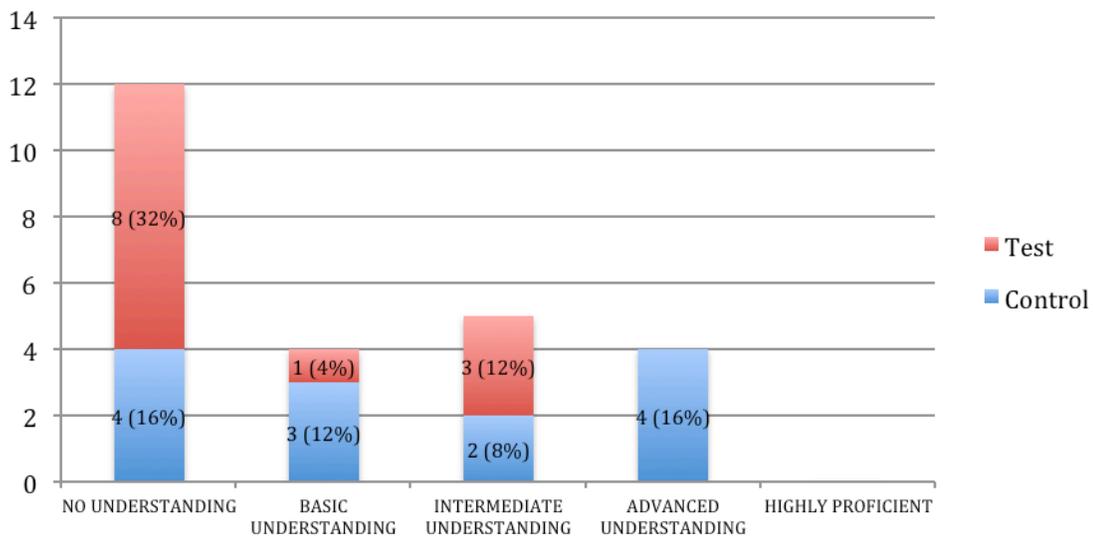


Figure 2.3: Participant Perceived Understanding of Augmented Reality. Participant responses to, “How would you rate your understanding of augmented reality?”

Therefore, from this data we can conclude that some postsecondary CM students are already aware of AR and have good knowledge about the terms surrounding this technology, however, according to (Shirazi & Behzadan, 2014) they are unable to relate the use of these tools to their own learning experience and therefore, will rely on universities and schools to make this connection. Therefore, part of the aim of this research is to increase the level of understanding of spatial concepts in postsecondary CM education. With today’s visually motivated generation of media-conscious students (Moskal et al., 2004), the application of the latest AR technology along with mobile

devices that these students are already familiar with will provide a visually active learning environment that has the greatest potential to improve spatial skills.

2.6 Summary

Success for a construction project is mostly dependent upon the people involved and their skills. Specific to this literature review it was discussed that the industry is faced with a threefold problem, (1) students continue to struggle with enhancing their spatial skills before they graduate, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions continue to rely on passive teaching techniques that are not well suited to enhance the visual aspects of spatial learning.

Firstly, it was determined that students do exhibit a lack of certain spatial skills and that those skills could be improved. The opportunity in doing so is evident in matching the correct tools and technology to the discipline being developed. However, the learning styles of the postsecondary CM student should not be ignored and therefore, matching correct teaching style to the learning preferences of the student is also necessary. These supporting, but separate research studies, were analyzed for their benefit to improve spatial skills in postsecondary CM students.

Secondly, this research was validated through the literature by outlining a way in which industry influences the CM educational curriculum. An industry need for good spatial

skills was defined that currently lacks any literature supporting a solution. Ultimately, academia will bear the burden of closing this skills gap. However, academia also has a pervasive problem in passive instruction that is not well suited to improve spatial skills.

Thirdly, it was determined that passive teaching techniques was not the best way to teach spatial skills. The literature supported active learning as a better way to address visualization concepts. The review of the literature supports active learning in STEM disciplines and it also validated that STEM curricula could support spatial skills, so it was therefore concluded that active learning could support spatial skills.

Lastly, since it was reasoned that active teaching techniques, collaboration, visual content and consideration for assessment techniques will better engage the postsecondary CM student in order to improve their spatial skills a new pedagogical tool in AR could be the answer. The literature review examined the history and compared problematic implementation issues to recommend a (1) practical, (2) non-interfering, and (3) a familiar technology for improving the spatial skills in postsecondary CM students.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Becoming a successful participant of a construction project requires good spatial skills. These skills enable one to interpret verbal instruction within a 3D environment, translate between 2D and 3D visual information, solve complex abstract spatial problems, and visualize an unfinished project in an empty 3D space. These spatial skills are also the language the AECFM industry uses to communicate a problem, recommend a solution, generate new ideas, and to foresee future problems in an ever increasingly complex design environment.

The research questions established in this study were developed to validate the use of a MAR tool that could be used in a conventional classroom setting. Moreover, this research is set to determine if the use of a MAR tool would improve the spatial skills of postsecondary CM students. The research questions are as follows:

Question 1

Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?

Question 2

Can a mobile augmented reality pedagogical tool be used to improve the speed of executing spatial tasks in CM students at the postsecondary level?

Question 3

Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skills in CM students at the postsecondary level over time?

This study followed a quantitative between-group double-blind experiment model using pre-assessment and post-assessment data gathering instruments. Upon explanation of the study and voluntary completion of the Institutional Review Board approved consent documents, the students completed a background survey followed by a pre-assessment. Then the researcher conducted an educational lecture for both groups simultaneously. Immediately following, the group was divided into separate rooms. Both groups were administered a lab assignment that they were allowed to complete in smaller groups of 2 to 3 students per group. The Test Group intervention included a mobile hand-held device equipped with augmented reality software that the students could use to aid in the completion of their lab assignment. Following the lab assignment, and with the students still segregated, the post-assessment was administered along with a NASA TLX survey. All pre- and post-assessment data, along with the background survey and NASA TLX survey were collected and analyzed using descriptive and inferential statistics. This procedure, start to finish, was completed twice to obtain a total population of twenty-five

students ($n=25$). The first instance of the experiment included 16 students and the second instance, completed 15 days later, included 9 students.

3.2 Setting

This study took place at a postsecondary institution in Gwinnett County Georgia; an adjacent surrounding county to Atlanta, Georgia. This postsecondary institution operates as a technical college and has an overall student population of 10,068 students as of 2015. The technical college operates a two-year construction management program that has an enrollment population of 60 students as of 2015. The construction management program is currently seeking ACCE accreditation and is listed as an “Accreditation Candidate” within the ACCE 2014 Annual Report (American Council for Construction Education, 2014).

The study was conducted at Gwinnett Technical College’s main administration building during the student’s normally scheduled evening class. The lecture room, where the study initiated, was normally used as a technical drafting lab. This room consisted of an elevated front platform along with a whiteboard and projection screen. The students were situated in the lab space that consisted of four rows of L-shaped desks, each with a desktop computer (the computer was powered off and not used during the study). The intervention room was located approximately 40 feet from the technical drafting lab and consisted of a whiteboard and projection screen along with three rows of rectangular tables arranged to face the whiteboard side of the room.

The full study was conducted two times. The first instance occurred on Monday, October 15, 2015, in the evening during the students' normally scheduled Estimating II class; beginning at 6:00 pm and completing at 7:50 pm. The second instance occurred 15 calendar days later, on Tuesday, October 20, 2015, in the afternoon during the student's normally scheduled Plan Reading class; beginning at 10:00 am and completing at 11:20 am. During each instance, the students' instructor was present but did not participate or interact with the students.

3.3 Participants

3.3.1 Sampling

The sampling procedure used by the researcher was a nonrandom convenience sampling. The participants for this study were restricted to willing students that were available at a predetermined time as coordinated with the students' instructor, hence, the sampling took place during the students' normally scheduled class time. Furthermore, the participants were also selected because of their enrollment in a postsecondary construction management curriculum, the impetus for this research. Twenty-five ($n=25$) students participated in this study.

3.3.2 Description of Participants

Upon completion of consent, the participants completed a background survey to gauge the demography of the sampling. Of the 25 students, 76% were male and 24% were female. Within the control group, 85% reported male and 15% reported female, while within the test group, 67% reported male and 33% reported female. Age was nearly evenly distributed with 36% reported 18-25 years, 28% reported 26-35 years and the remaining 36% reported 36 years or older. Within the control group, 31% reported 18-25 years, 38% reported 26-35 years and the remaining 31% reported 36 years or older, while within the test group, 42% reported 18-25 years, 17% reported 26-35 years and the remaining 42% reported 36 years or older. In terms of previous work experience within the AECFM industry, a combined 68% reported more than one year of experience (Figure 3.1). Participants in the control group reported having less than one year of experience (20%) to not having any experience (12%). This is important to note in that it may have an effect on the outcome of the assessment scores because there is correlation between more work experience and improvement in spatial skills (Martin-Gutierrez et al., 2009; McCuen, 2014).

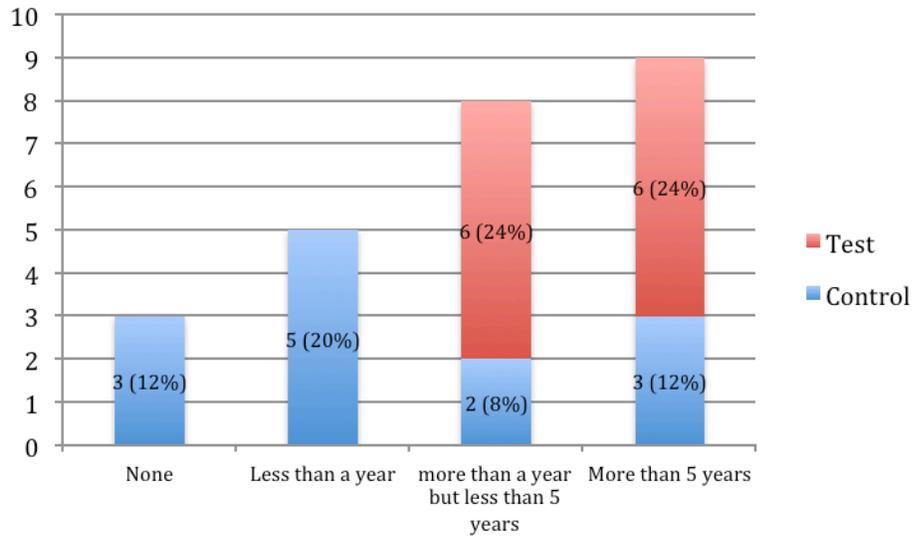


Figure 3.1: Participant Previous Work Experience. Participant responses to, “Please indicate your level of experience working in some aspect of the construction industry.”

While all of the students reported a high school or equivalent education level, there were 19% that already had another Associates Degree and 5.4% that had Bachelors Degree (Figure 3.2).

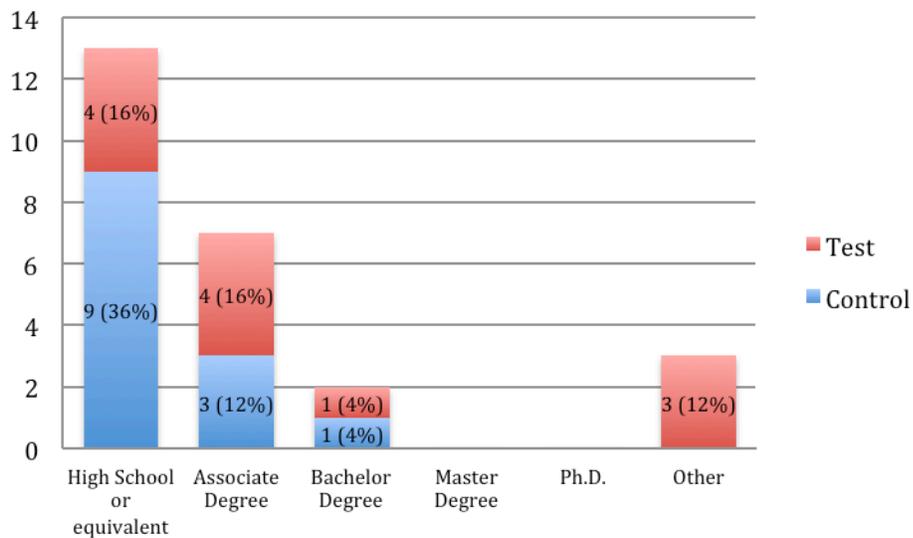


Figure 3.2: Participant Current Education Level. Participant responses to, “What is your level of education thus far?”

All of the students were pursuing a Construction Management Associate’s Degree and reported some level of past experience with courses that used visual skills or visual technology (Figure 3.3). The participant’s experience base with these course types was evenly distributed between the control group and the test group.

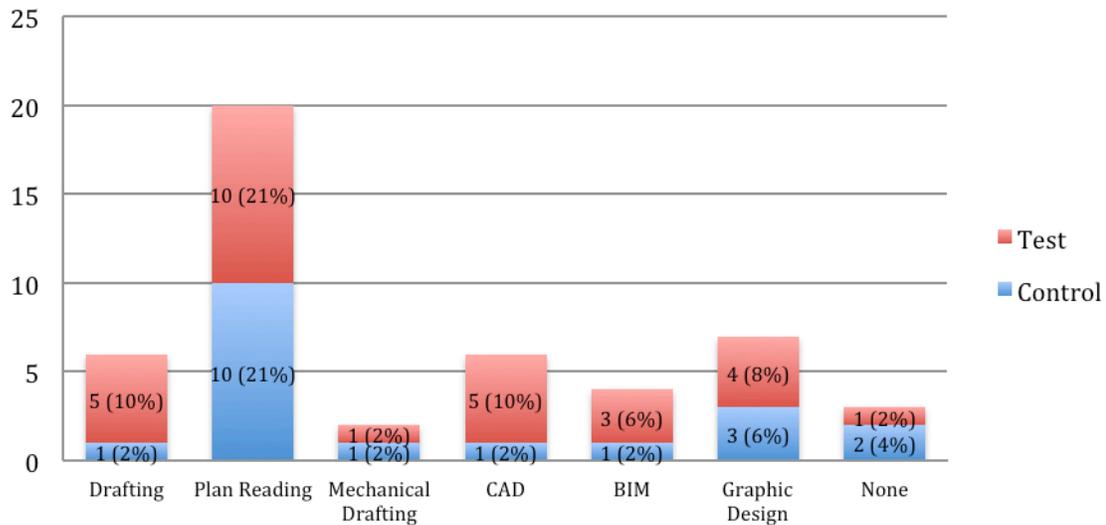


Figure 3.3: Participant Past Experience with Visual Skills or Visual Technology. Participant responses to, “Are you or have you taken one of the following courses? Circle as many as apply.” Percentages have been rounded to the nearest whole number.

In an effort to gauge comfort level with the use of technology in the classroom, the participants were asked if they were agreeably comfortable using mobile technology to obtain more information about things they had questions about. 80% of the participants responded as “Strongly Agree” and the remaining 20% responded with “Agree”. Conversely, when the participants were asked if technology was an interference with their ability to learn in the classroom, the responses were a little more varied with 8% perceiving an agreement that technology was an interference, 24% were neutral and a combined 60% disagreed that it (technology) was an interference. For the most part,

these participants' experiences in the classroom already include technology, as a combined 72% reported that technology is being used at least regularly in the classroom. Only 4% reported that it was rarely used (Figure 3.4).

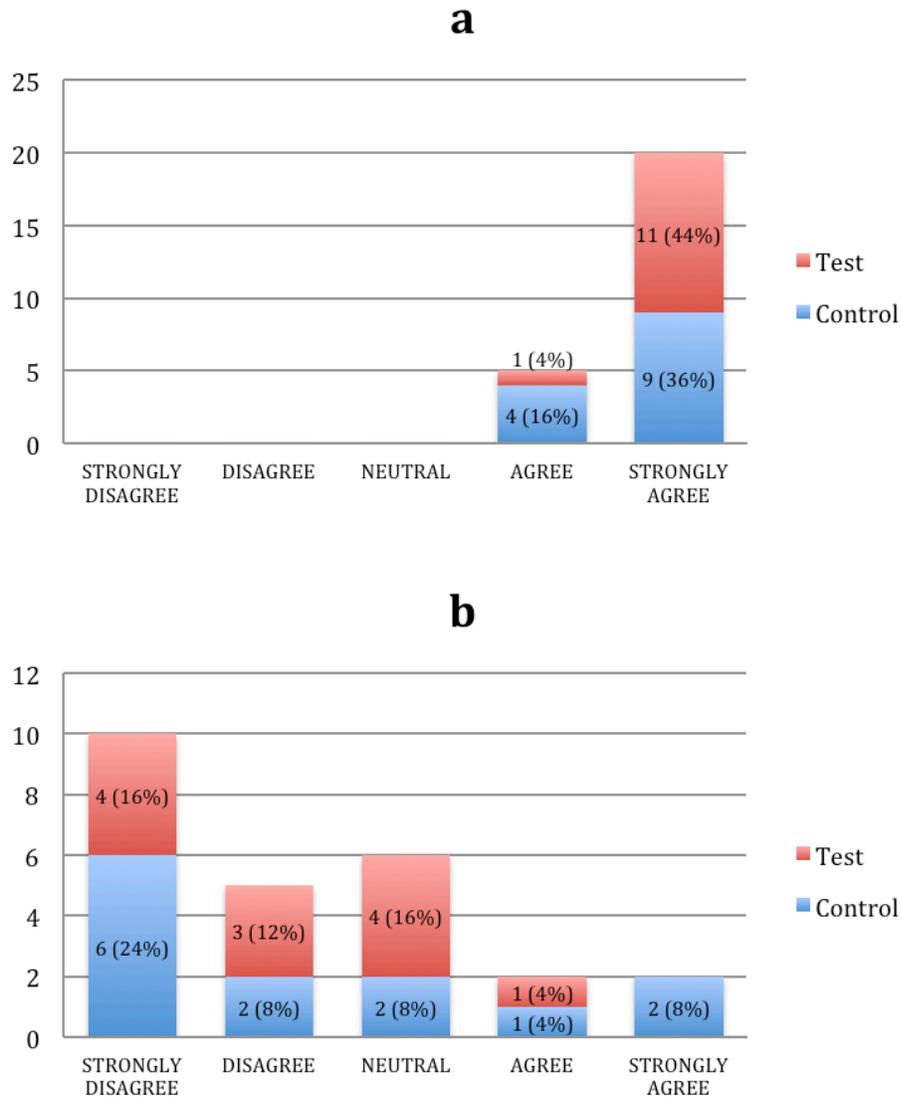


Figure 3.4: Participant Comfort Level with Technology and Technology in the Classroom. Participant responses to, (a) “I feel comfortable using mobile technology to obtain more information about things I have questions about.”, (b) “I feel that technology has interfered or may interfere with my ability to learn in the classroom.” and (c) “Considering your time in class, how much technology is used to aid you in your learning?”

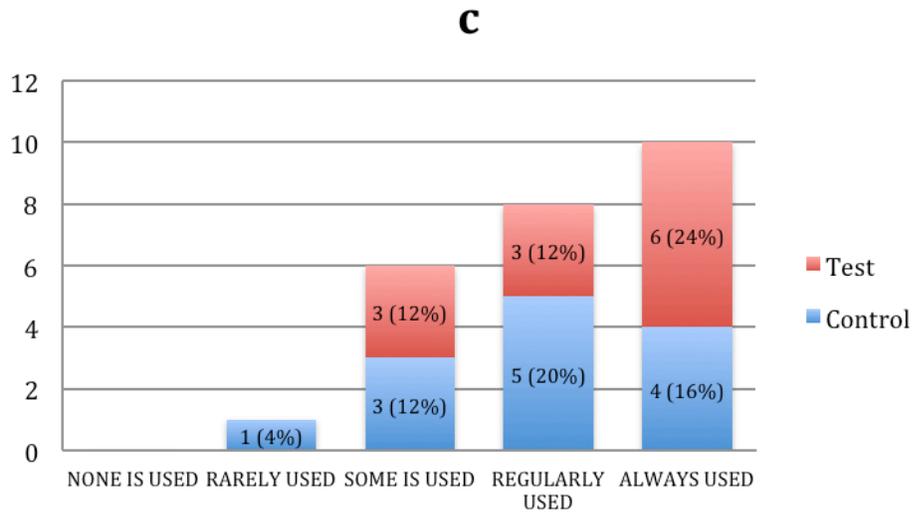


Figure 3.4: Participant Comfort Level with Technology and Technology in the Classroom. Continued.

The participants were asked to gauge their skill level in plan reading, as this skill, if practiced often, could have an effect on the participants' spatial skills proficiency. The proficiency was spread between 12% claiming "Highly Proficient", 28% "Advanced Experience", 24% "Intermediate Experience" and 36% "Basic Experience". No one reported, "No Experience". Furthermore, considering current innate spatial skills, the participants were asked if they routinely used written instructions to assemble something. Only 8% always assembled things in this manner (Figure 3.5).

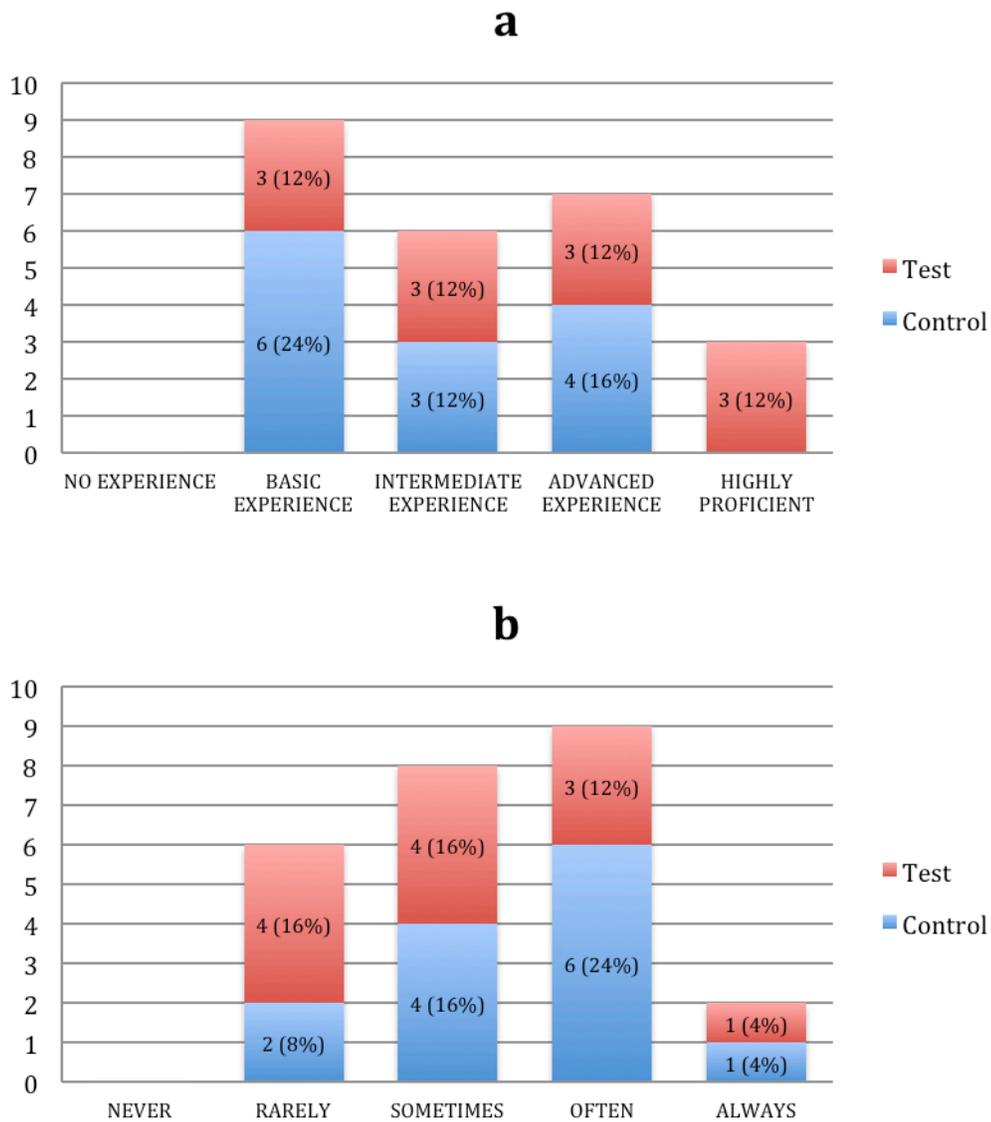


Figure 3.5: Participant Plan Reading and Assembly Experience, Participant responses to, (a) “How proficient are you in reading construction plans?” and (b) “In your past experience, how often have you successfully assembled something without the need for written instructions or a written manual?”

Lastly, the participants were asked about their preference and ability to think spatially. When asked about how they liked to understand topics of interest to them, a combined 88% of participants agreed that lots of diagrams, photos, and illustrations were their preferred method of aid. Additionally, when asked if they were capable of visualizing,

in their mind, objects that were not in front of them, a combined 72% reported that they could with only 4% perceiving that they could not (Figure 3.6).

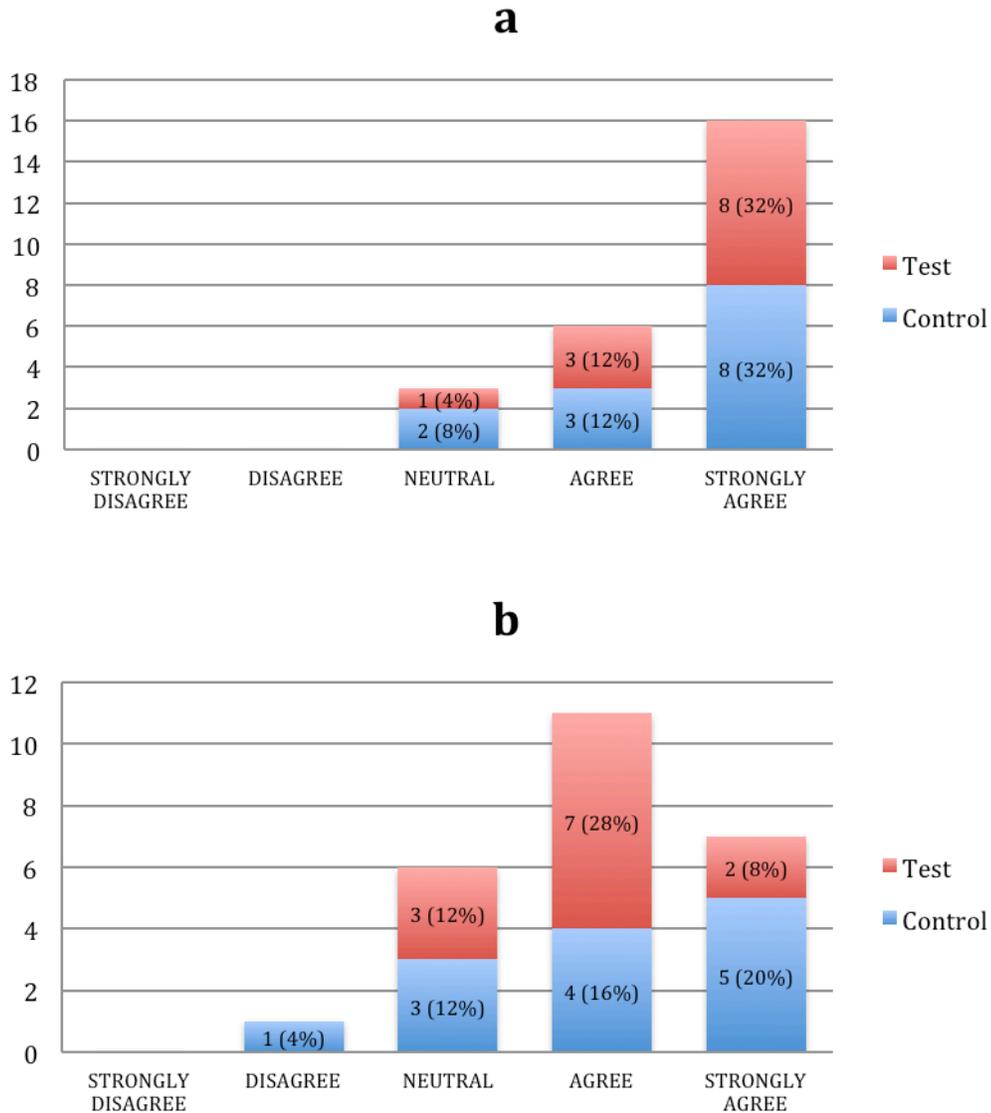


Figure 3.6: Participant Preference and Ability to Think Spatially. Participant responses to, (a) “I like to see lots of diagrams, photos, and illustrations to aid in my understanding of a topic.” and (b) “I am capable of clearly visualizing, in my mind, objects that are NOT in front of me.”

3.4 Intervention

The independent variable measured in this study consisted of a mobile device with pre-installed augmented reality software that could be used by the participants to aid them in the completion of a visual task assignment. As reasoned in Chapter 2, the need to engage postsecondary CM students in a visual and engaging manner and the analysis of the current state of mobile technology and AR software directed the decision to use this configuration as the independent variable in this study. However, an important consideration when using technology in the classroom is that if the students are capable of learning the same concepts without the use of technology does the technology then become an interference to the learning experience (Shirazi & Behzadan, 2014)? It is being supposed by this question that technology may become a burden and an interference with the learning experience. To this end, the researcher will also evaluate the students' perception of the learning intervention.

The dependent variable in this study consisted of student assessments given before and after the intervention and between both Control Group and Test Group. As will be detailed in the Measurement Instruments section, the assessments were piloted for difficulty and included a variety of questions that had a basis in prior research.

3.5 Materials

3.5.1 Hand-Held Mobile Device

The platform for the intervention was a hand-held mobile device (HHMD) with installed AR software. As has been discussed, postsecondary students are more media aware (Moskal et al., 2004) and have access to, and experience with, mobile technologies (Riedel, 2014; Yu & Conway, 2012). Therefore, it was determined that this form factor would be most comfortable, and least intrusive, to the students' learning experience.

There was some variability in the make and model of the HHMDs, however, despite the diversity, each device along with the pre-installed AR software operated in the same manner. Participant interaction with the HHMD occurred through a touch-sensitive feedback on the display of each HHMD that allowed the participant to operate the AR software. The HHMDs all included a back-facing camera that was used for scanning a paper-formed marker. Table 3.1 details the inventory of mobile hand-held devices used for this study.

Table 3.1:
Inventory of Mobile Devices Used in Study

Device Manufacturer	Device Model	Quantity Used in Study
Apple, Inc.	iPad Air 2	1
Apple, Inc.	iPad Air	1
Apple, Inc.	iPad 4th Generation	1
Apple, Inc.	iPad Mini 2	1
Samsung Corporation	Galaxy Tab 7.0	2

3.5.2 Marker (fiducial)

Markers were used by both the control and test groups in the form of a lab assignment. The marker was created using a standard off-the-shelf word processor editing package. The content on the marker was that of a standard spatial skills assignment (Figure 3.7 and Appendix - D). A paper printed version of the marker was used for this study.

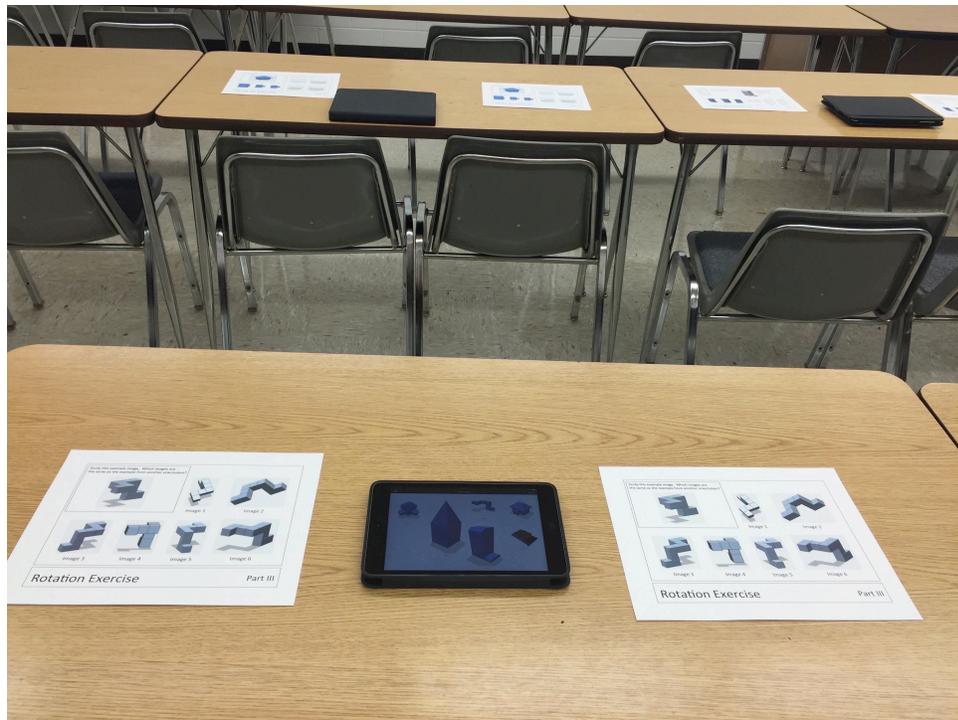


Figure 3.7: Marker Lab Assignment. Illustration contains the paper version of the lab assignment (marker) and a HHMD used by the Test Group to aid in completion of the lab assignment.

3.5.3 3D Modeling Software

The 3D models used in this study were created by Autodesk's 123D Design (<http://www.123dapp.com/design>); a commercially available desktop software package capable of creating and editing 3D models. Once a 3D model was created in 123D Design, it was exported for use in the AR software.

3.5.4 Augmented Reality Software

The AR software used in this study was Augment (<http://www.augment.com>); a commercially available mobile software package used to scan a marker (fiducial) and render a 3D model on the screen of a HHMD. Augment consists of a HHMD application and an administrative website interface. The website interface is used to manage and upload user created images of the markers and 3D models. An association between the marker and 3D model is specified by: (1) assigning a 3D model to a marker image, (2) defining the size of the model to be displayed and (3) locating where on the marker image a 3D model will display.

Associating a marker image to a 3D model as outlined above completes the administrative setup for the lab assignment. A participant, along with a HHMD and the AR software, would scan the paper-form of the marker using the AR software. Once the image was recognized and matched with the inventory of stored marker images from the server, the HHMD's AR software would call the corresponding 3D model from the

server and would combine it along with the image of the marker being captured by the HHMD's back-facing camera. The combined image on the HHMD would show the marker with a 3D AR model displayed on it (Figure 3.8).

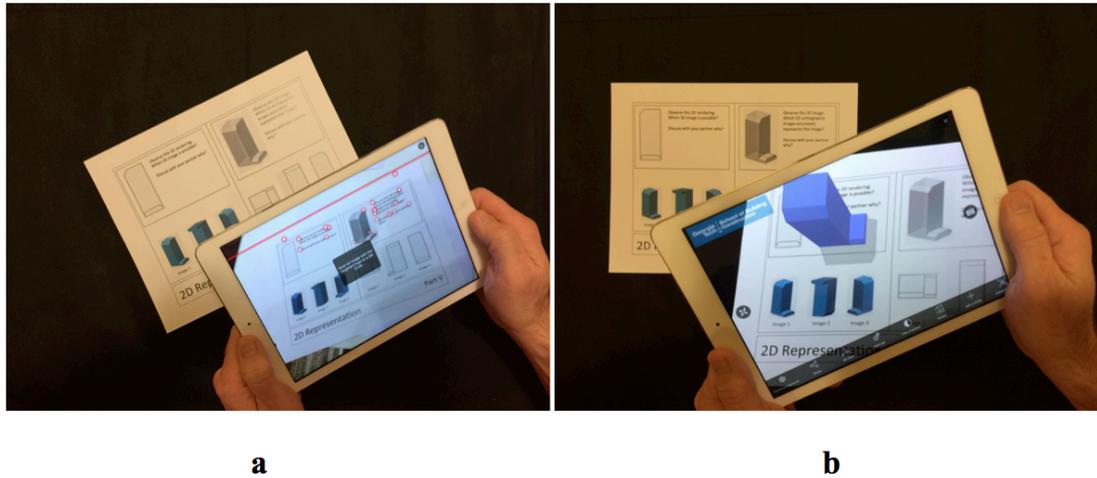


Figure 3.8: Marker Scanning. (a) A paper form marker is scanned using the back facing camera on a HHMD, once the marker is recognized (b) the 3D model associated with the marker is displayed on the HHMD and the participant can view the 3D model from various angles by moving the HHMD or by moving the paper-form marker.

Lastly, the 3D model that would display on the HHMD's screen would be superimposed over, and attached to, a live image of the marker that is being displayed by using the HHMD's back facing camera (Figure 3.9). The participant could then interact by moving the HHMD or the paper-form marker.

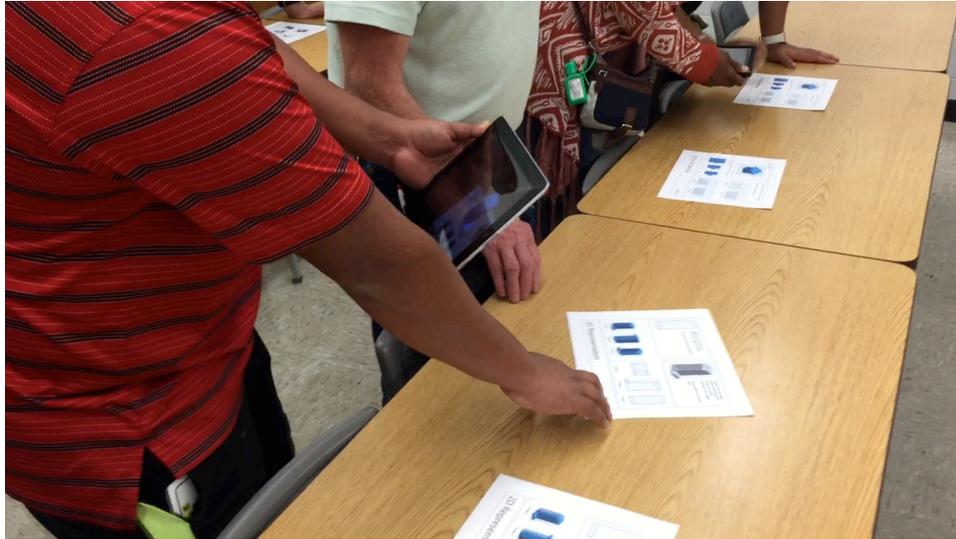


Figure 3.9: A Student Interacting with HHMD and Marker for the Lab Assignment.

3.6 Measurement Instruments

The measurement instruments were designed to obtain data pertinent to the research problem for this study. The participants of this study were kept anonymous by way of identification numbers that they used to record on each of the instruments. The measurement instruments described here are listed in chronological order as they were employed in this study.

3.6.1 Background Survey

The background survey instrument was used to obtain student perceptions about their prior experiences with (1) mobile technology, (2) visual learning, (3) using technology in the classroom, (4) past experience with visualization tasks, (5) past experience with AR, (6) previous level of work experience, and (7) demographic information (Appendix - A).

The survey was administered in written form and students self-reported responses to each question using a typical five-level Likert-type scale. Each response was analyzed using descriptive statistics.

3.6.2 Pre- and Post-Assessment

The purpose of the pre-assessment (Appendix - B) was to obtain a baseline from which to gauge the participant's change in proficiency of spatial skills following a lecture and lab assignment. The post-assessment (Appendix - E) would be administered following the lecture and lab assignment. Both assessments contained 10 questions with a mixture of (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976). The composition of question types was determined because of their pertinence to spatial skills required in common first-year engineering design graphics courses (Sorby & Baartmans, 2000).

Several of the questions used in the pre- and post-assessment were derived from prior research studies (Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976)). The validity and reliability of the questions used in the pre- and post-assessment may not be consistent

with prior research because they are not administered in the same manner as the prior research. Therefore, this researcher designed a pilot survey (PS) to gauge and balance the questions to be used in this research study (Appendix - H). The PS was administered with a battery of 20 questions and scored by way of an online survey to a pilot group of postsecondary CM students. Figure 3.10 shows the composition of students' ages and academic background.

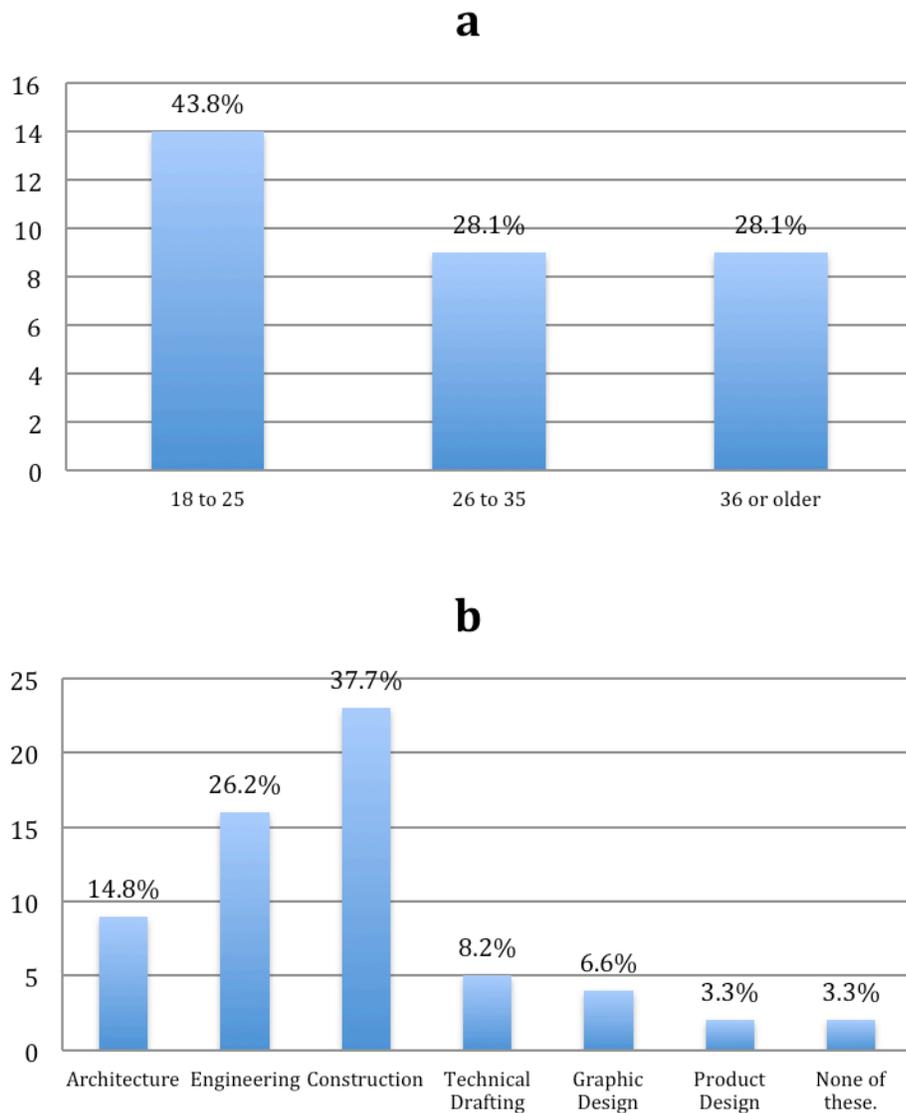


Figure 3.10: Pre- and Post-Assessment Pilot Survey - Student Composition. Participant responses to (a) “Please indicate your age group.” and (b) “Select any of the following fields of study that you have majored in or have experience in.”

The PS required the respondents to answer each question and to provide a rating of difficulty from 1 to 5 (5 = Very Difficult) on a five-level Likert-type scale. There were a total of 32 responses received (Table 3.2).

Table 3.2
Pilot Survey - Pre- and Post-Assessment Average Difficulty Score Data.

Question Identifier	Average Difficulty Score	Respondent Count
Pre-Assessment Q1	1.44	32
Pre-Assessment Q2	2.00	30
Pre-Assessment Q3	2.08	26
Pre-Assessment Q4	2.97	29
Pre-Assessment Q5	2.88	26
Pre-Assessment Q6	2.93	29
Pre-Assessment Q7	2.31	29
Pre-Assessment Q8	3.29	28
Pre-Assessment Q9	2.58	26
Pre-Assessment Q10	2.96	26
Post-Assessment Q1	2.35	26
Post-Assessment Q2	2.69	26
Post-Assessment Q3	1.97	31
Post-Assessment Q4	2.19	26
Post-Assessment Q5	2.38	29
Post-Assessment Q6	2.85	26
Post-Assessment Q7	2.92	26
Post-Assessment Q8	3.00	26
Post-Assessment Q9	2.23	26
Post-Assessment Q10	2.88	26

Note. Q1 = question number 1, Q2 = question number 2, etc.

The questions were ranked based on an Average Difficulty Score derived from the PS. The makeup of the pre- and post-assessments tests was balanced using the Average Difficulty Score from the PS. Furthermore, each assessment included the same amount of each of the question types (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976) (Table 3.3). Following administering of the assessments, they were scored and analyzed using descriptive statistics tools.

Table 3.3
Pre- and Post-Assessment Question Type Composition Matrix

Pre-Assessment Question Makeup			Post-Assessment Question Makeup		
Question Identifier	Average Difficulty Score	Question Type	Question Identifier	Average Difficulty Score	Question Type
Q1	1.44	a	Q1	2.35	a
Q2	2.00	b	Q2	2.69	b
Q3	2.08	b	Q3	1.97	b
Q4	2.97	c	Q4	2.19	c
Q5	2.88	d	Q5	2.38	d
Q6	2.93	d	Q6	2.85	d
Q7	2.31	e	Q7	2.92	e
Q8	3.29	e	Q8	3.00	e
Q9	2.58	f	Q9	2.23	f
Q10	2.96	f	Q10	2.88	f
Total Difficulty Score Pre-Assessment 25.44			Total Difficulty Score Post-Assessment 25.46		

Note. Question Types include (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976).

3.6.3 Lecture

Both Control and Test Groups received an identical lecture, given by the researcher, designed to raise their understanding of basic plan reading concepts. The participants were administered this passive teaching exercise and offered to ask questions of the researcher during the lecture (Appendix - C). The purpose of the lecture was to improve spatial skills in a conventional and passive manner, consistent with the 87% of postsecondary classrooms referred to in Table 1.1 and (Livingston, 2001).

3.6.4 Lab Assignment

The lab assignment was a series of 6 questions printed on 6 pieces of paper (Appendix - D). Each question was designed to provide the participants a working problem that involved one of the question types on the pre-assessment. The students were sub-divided into groups of 2 to 3 students per group to complete the lab assignment. The sub-groups were given the answer key to each of the questions so they could compare their results with the correct response and discuss their differences.

3.6.5 Post-Survey

The post survey instrument was used to obtain student perceptions about their experiences with the HHMD and the installed AR software as a learning tool for the lab assignment. This survey instrument was only used within the Test Group. Each response was analyzed using descriptive statistics.

3.6.6 NASA TLX Survey

The NASA TLX survey is a widely used instrument designed to subjectively assess workload on six subscales (1) mental demand, (2) physical demand, (3) temporal demand, (4) performance, (5) effort, and (6) frustration. It was developed by the National Aeronautics and Space Administration (NASA) Ames Research Center (Human Performance Research Group, 1986). The purpose of its use in this research was to

respond to the concern that technology, if not employed properly, could be a detriment to the learning experience (Cristia et al., 2012). Furthermore, this survey was used to assess the potential interference to the learning experience that the intervention may have caused.

3.6.7 Long-Term Assessment

Ultimately, the learning experience is effective if the postsecondary CM student has retained concepts from their past academic experiences and utilize those concepts within industry. Therefore, there needs to be a longer-term retention measurement than the time span between the pre-assessment and the post-assessment. Therefore, a long-term assessment was designed to gauge the retention of spatial skills after a longer period of time (Appendix - G). The long-term assessment consisted of 10 questions from the PS. The questions were identical to those found in the pre- and post-assessment, however, the correct answers were adjusted to prevent a respondent from recalling the correct answer from the pre- and post-assessment.

3.7 Procedures

This study was conducted as a quantitative between-group double-blind experiment using pre-assessment and post-assessment data gathering instruments (Figure 3.11). The experiment was repeated twice to obtain the full population for the study of 25 participants ($n=25$). The first instance was conducted on Monday, October 15, 2015,

with 16 participants in the evening during the students' normally scheduled Estimating II class; beginning at 6:00 pm and completing at 7:50 pm. The second instance occurred 15 calendar days later, on Tuesday, October 20, 2015, with 9 participants in the afternoon during the student's normally scheduled Plan Reading class; beginning at 10:00 am and completing at 11:20 am. Each instance of the experiment was conducted in exactly the same manner, however, since there were fewer students in the second instance, less time was used to complete non-timed portions of the experiment. A time-table was established for the experiment and has been included in Appendix - I.

Following consent procedures and introduction to the study, the participants were assigned a random number that would be used later to divide the entire group into a Control Group and a Test Group. Participants were then administered a background survey for the purposes of obtaining relevant experience data and demographic information. Upon collecting the background surveys, the pre-assessments were distributed face down and the participants were instructed not to turn over and begin the pre-assessment until announced. At the front of the room, on the projection screen, a count up timer was displayed. The participants were instructed that they were to self-record their completion time once they were finished with the pre-assessment. The researcher announced the start of the assessment and once the participants completed the assessment they were to turn over the assessment and keep it on their desks. Once all participants were observed to be complete with the assessment, the researcher collected the completed assessments.

The researcher conducted a lecture on visualization techniques and basic plan reading skills. The participants were encouraged to ask questions. Following the lecture, the participants were divided according to their previously assigned random numbers. Participants with an odd number were asked to remain in the room while participants with even numbers were asked to relocate to another room that was previously configured with the HHMDs and AR software.

Participants of the Control Group (odd numbered identifier) were further sub-divided into groups of 2 to 3 students and administered the lab assignment and accompanying answer key. The researcher instructed the Control Group to complete the lab assignment and to discuss correct answers with the other member(s) of their sub-group. Once the instructions were relayed, the researcher left the room under the guidance of an assistant who monitored the lab assignment. The assistant had no other significant assignment in the study and did not participate in the study.

Participants of the Test Group (even numbered identifier) were further sub-divided into groups of 2 to 3 students and administered the lab assignment and accompanying answer key. The researcher instructed the Test Group to complete the lab assignment and to discuss correct answers with the other member(s) of their sub-group. Instruction and use of the intervention were discussed with the participants, usage questions were taken and responded to and then the participants were released to complete the lab assignment.

Once the lab assignments were complete in both the Control and Test Groups, the researcher administered the post-assessment to each group separately. At the front of each room, a count up timer was displayed and the post-assessments were distributed face down and the participants were instructed not to turn over and begin the post-assessment until announced. The participants were instructed that they were to self-record their completion time once they were finished with the post-assessment. The researcher announced the start of the assessment and once the participants completed the assessment they were to turn over the assessment and keep it on their desks. Once all participants were observed to be complete with the assessment, the researcher collected the completed assessments. The Control Group (odd numbered identifier) then received the NASA TLX Survey and was instructed to complete it and turn it in before they were dismissed from the study. The Test Group (even numbered identifier) received a post-survey and the NASA TLX Survey and was instructed to complete it and turn it in. Following the survey instruments, the researcher conducted an informal interview, asking the participants for their candid feedback about the intervention. The content from this informal interview is explained further in Chapter 5.

Lastly, on Thursday, December 3, 2015, the participants received in their regularly scheduled course final examination a link to an online long-term assessment. The participants were not previously notified of this long-term assessment to prevent additional preparation for the content contained within. The participants were voluntarily requested to complete the online long-term assessment.

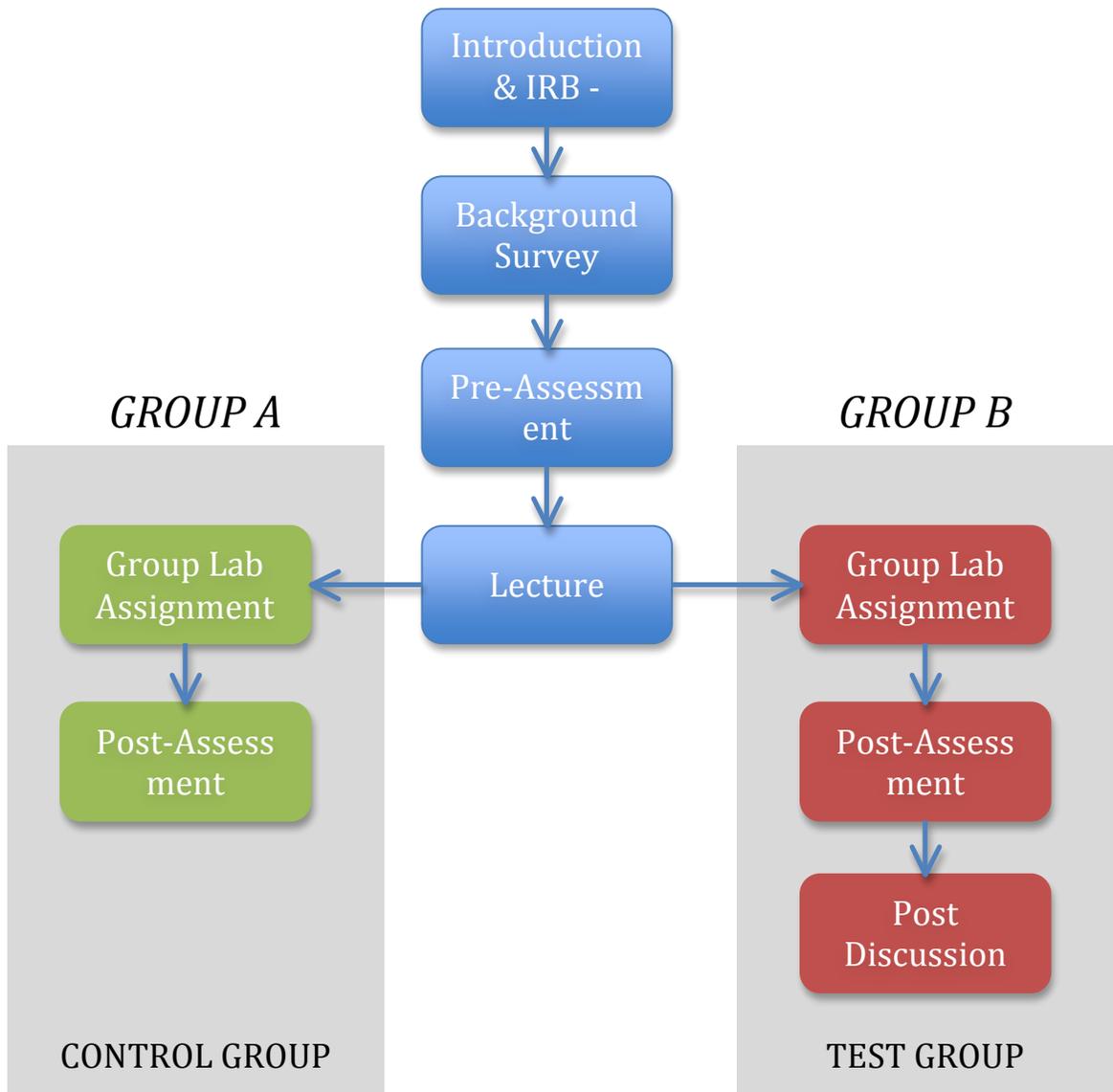


Figure 3.11: Experiment Procedure Workflow.

3.8 Data Analysis

The data were collected and analyzed using descriptive statistics. The focus of this study was constructed around three central questions and the data gathering instruments

and procedures were tailored to support a response to these questions, the results of which, will be discussed in the Chapters 4 and 5. Those questions are:

Question 1

Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?

Question 2

Can a mobile augmented reality pedagogical tool be used to improve the speed of executing spatial tasks in CM students at the postsecondary level?

Question 3

Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skills in CM students at the postsecondary level over time?

The participants were divided into two groups for data analysis purposes and to keep the independent variable findings segregated. Group A was the Control Group (odd numbered identifier) whose mean test scores on the three assessments was representative of the conventional passive teaching environment common in postsecondary institutions today (Tatum, 2010). Group B was the Test Group (even numbered identifier) whose mean test scores on the three assessments was representative of the conventional passive teaching environment common in postsecondary institutions today along with the intervention of a MAR tool to aid in the learning experience. The entire study began

with a pre-assessment to baseline the participant's current spatial skills. Following the intervention, each group was separately administered a post-assessment. Mean assessment scores would be compared in terms of accuracy and in terms of completion time. Additionally, a long-term assessment was conducted approximately one and a half months later to assess long-term retention of the newly learned spatial skills. Statistical analysis using Statistical Package for the Social Sciences (SPSS) software (<http://www-01.ibm.com/software/analytics/spss/>) was conducted on these two groups to identify mean and standard deviation for each group. Furthermore, an independent samples t-test was then conducted to identify if there was a significant difference between the two groups' mean scores.

CHAPTER 4

RESULTS

4.1 Results

This study has been structured to address the research problem of (1) students continue to struggle with enhancing their spatial skills before they graduate, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions continue to rely on passive teaching techniques that are not well suited to enhance the visual aspects of spatial learning. Measurements were taken throughout the study that responded to these problems by addressing (1) measurement of accuracy in students' spatial skills before intervention, after intervention and longitudinally, (2) measurement of time as a result of the intervention and longitudinally, and (3) measurement of perceived workload during the lab assignment between the Control Group (Group A) and the Test Group (Group B).

4.1.1 Measurement of Accuracy

The measurement tools used in this study to respond to the research questions detailed in the previous chapters of this Thesis measured spatial skills by using isometric to orthographic projections, 3D to 2D orthographic translations, building elevation translations and mental rotation of shapes. As illustrated in Table 4.1, Group A had a

mean score ($M = 5.2$, $SD = 1.6$) similar to Group B ($M = 5.3$, $SD = 1.4$) in the pre-assessment, indicating that the baseline for both groups was similar in terms of their spatial skills entering the study. Following the passive lecture and the lab assignment, Group A was able to improve their mean score to 5.8 ($SD = 2.1$). Conversely, Group B, which had the same passive lecture and lab assignment, but also used HHMD and AR software to assist in the lab assignment received a mean score of 7.2 ($SD = 1.6$).

Table 4.1
Statistical Analysis of Results of Pre-Assessment, Post-Assessment, and Long-Term Assessment.

Group	Pre-Assessment			Post-Assessment			Long-Term Assessment		
	Mean	SD	n	Mean	SD	n	Mean	SD	n
GROUP A	5.2	1.6	13	5.8	2.1	13	7.2	2.3	9
GROUP B	5.3	1.4	12	7.2	1.6	12	8.8	1.4	9

Note. Total population for the study was 25 participants ($n=25$). Maximum possible score = 10.

Using the equation shown in Figure 4.1 for analyzing the improvement of assessment scores between the different assessments (a) pre-assessment to post-assessment, (b) post-assessment to long-term assessment, and (c) pre-assessment to long-term assessment, it was determined that there was an improvement in assessment scores from the pre-assessment to the post-assessment for both groups. However, the improvement in Group B (Improvement Percentage = 35.8%) was more than double the improvement in Group A (Improvement Percentage = 11.5%). Both groups exhibited a near similar increase in Improvement Percentage (Group A = 24.1%, Group B = 22.2%) from the post-assessment to the long-term assessment. Lastly, when considering the change from

the baseline (pre-assessment) to the long-term retention (long-term assessment), Group A exhibited less improvement (38.5%) while Group B improved significantly (66.0%) (Table 4.2).

$$\frac{\text{Mean (New)} - \text{Mean (Original)}}{\text{Mean (Original)}} \times 100 = \text{Improvement Percentage (IP)}$$

Figure 4.1: Equation For Determining Improvement Percentage (in terms of Mean scores).

Table 4.2

Statistical Analysis of Improvement Percentages of Assessment Scores.

Group	a Pre- to Post-Assessment		b Post- to Long-Term Assessment		c Pre- to Long-Term Assessment	
	IP	n	IP	n	IP	n
GROUP A	11.5%	13	24.1%	13	38.5%	9
GROUP B	35.8%	12	22.2%	12	66.0%	9

Note. Total population for the study was 25 participants ($n=25$).

4.1.2 Measurement of Time

Completion time for the pre-assessment, post-assessment and long-term assessment was recorded and is illustrated in Table 4.3. The time for Group A to complete the assessment was nearly consistent between the pre-assessment, post-assessment and long-term assessment ($M = 7:01$, $SD = 2:39$, $M = 7:28$, $SD = 2:35$, and $M = 7:32$, $SD = 3:02$ respectively). The time to complete the assessments for Group B increased for the post-assessment and normalized back to pre-assessment level for the long-term assessment ($M = 8:20$, $SD = 2:44$, $M = 9:21$, $SD = 2:39$, and $M = 8:37$, $SD = 6:32$ respectively).

respectively). Group A appeared to be faster in terms of completion time for all assessments than Group B.

Table 4.3
Statistical Analysis of Completion Time for Pre-Assessment, Post-Assessment, and Long-Term Assessment

Group	Pre-Assessment Time			Post-Assessment Time			Long-Term Assessment Time		
	Mean	SD	n	Mean	SD	n	Mean	SD	n
GROUP A	7:01	2:39	13	7:28	2:35	13	7:32	3:02	9
GROUP B	8:20	2:44	12	9:21	2:39	12	8:37	6:32	9

Note. Total population for the study was 25 participants ($n=25$).

4.1.3 Measurement of Perceived Workload

The NASA TLX survey instrument was administered after the completion of the post-assessment. The results listed in Table 4.4 have been categorized based on the six subscales (1) mental demand, (2) physical demand, (3) temporal demand, (4) performance, (5) effort, and (6) frustration.

Table 4.4
NASA TLX Survey Results Data

Subscale	Group A (Control)		Group B (Test)		Mean Variance
	Mean	SD	Mean	SD	$\Delta = (\text{Group A} - \text{Group B})$
Mental	1.5	5.2	0.2	5.4	1.3
Physical	-7.7	5.3	-8.7	2.7	1
Temporal	-5.8	5	-5.3	3.5	-0.5
Performance	4.4	5.6	6.3	2.8	-1.9
Effort	0.8	4	1.6	6.1	-0.8
Frustration	-7.5	3	-7.2	3.4	-0.3

Note. In the NASA TLX scale -10 = very low demand and +10 = very high demand within the subscales measured.

CHAPTER 5

DISCUSSION

5.1 Introduction

Successfully completing today's construction project requires sensitivity to the details and complexity by which they are designed. In addition, environmental issues, sustainability, lean construction practices, raw material shortages, and labor shortages are, but a few of the complications that a construction professional must face (Clough et al., 2015; Kelleher Jr et al., 2014; Pierce Jr, 2013). Among the various challenges, this research is chiefly focused on the continual depletion of the experience base of the construction workforce. Following World War II, the construction workforce in the U.S. grew rapidly and today, as those workers begin to retire they are taking with them valuable knowledge and experience (Hildebrandt, 2014) at a rate faster than the newer and less skilled workforce can replace them. The next generation worker will not be able to train with the faster departing more experienced workforce, consequently, they will be at a disadvantage in certain skills necessary for the industry. One of these important skills is spatial skills. These skills are used to translate 2D drawing images to a 3D building project, furthermore, spatial skills have become the language by which the industry communicates ideas and solves problems. Therefore, there is a need to improve the spatial skills of the entering workforce.

The industry has recognized this shortcoming and through accrediting organizations and industry advisory boards has informed academia of their need. Unfortunately, academia has a problem of its own where instructors are not utilizing the right teaching styles to meet the learning needs of their students. Passively lecturing to students is the norm (Tatum, 2010). All the while, many agree that the best way to truly engage students on the subject matter of spatial skills is through the use of active teaching methods (Anderson & Adams, 1992; Chickering & Gamson, 1987; Johnson, 1991; W. J. McKeachie, 1987). And so the question remains; is there a way to actively engage the improvement of student spatial skills that meets the needs of industry in an academic environment that seems to default to passive teaching techniques?

As was discussed in Chapter 2, there have been a number of studies in which the use of AR has been applied within an academic setting (Y.-C. Chen, 2006; Cooperstock, 2001; Fernández-solís, 2009; Kaufmann, 2004; Liu, Cheok, Mei-Ling, & Theng, 2007; Shelton & Hedley, 2002). With attention to keeping an intervention (1) practical, (2) non-interfering, and (3) using technology that was already familiar to postsecondary CM students it was decided that a solution composed of AR and mobile technology could offer a response to meeting the needs of industry, all while improving spatial skills of postsecondary CM students.

5.2 Discussion

As discussed in Chapter 4, the measurement instruments were designed to provide validation of MAR as a pedagogical tool to be used to improve the spatial skills in postsecondary CM students. Those measurements will be discussed here in terms of their effect on accuracy and time. Additionally, since the introduction of a new pedagogical tool can be intrusive and work counter to the learning experience (Cristia et al., 2012), analyzing the difference in workload perceptions between the Control Group and Test Group would be revealing about using this technology in the classroom setting.

5.2.1 Effect on Accuracy

Analyzing the mean assessment scores between the pre-assessment and the post-assessment, it appears that there is an improvement in spatial skills for Group B ($M = 7.2$, $SD = 1.6$) above Group A ($M = 5.8$, $SD = 2.1$) as a result of the MAR intervention (Table 4.1). This represents an improvement of 35.8% for Group B and only an 11.5% improvement for Group A (Table 4.2). For the purposes of this study, and in response to the research question, “Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?” an independent sample t-test was performed to measure the statistical significance of the mean scores of each group. Assuming a Confidence Interval percentage of 95% ($CI = 95\%$) then $t(23) = -1.785$, $p = .087$. The null hypothesis (H_0) indicates that the mean

score in Group A would be statistically similar to those in Group B and according to the test results this hypothesis cannot be rejected.

Likewise, analyzing the mean assessment scores between the pre-assessment and the long-term assessment to gauge long-term retention of the learned spatial skills it appears that there is an improvement in spatial skills for Group B ($M = 8.8$, $SD = 1.4$) above Group A ($M = 7.2$, $SD = 2.3$) as a result of the MAR intervention (Table 4.1). This represents an improvement 66.0% for Group B and only a 38.5% improvement for Group A (Table 4.2). For the purposes of this study, and in response to the research question, “Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skills in CM students at the postsecondary level over time?” an independent sample t-test was performed to measure the statistical significance of the mean scores of each group. Assuming a Confidence Interval percentage of 95% ($CI = 95\%$) then $t(16) = -1.717$, $p = .060$. The null hypothesis (H_0) indicates that the mean score in Group A would be statistically similar to those in Group B and according to the test results this hypothesis cannot be rejected.

5.2.2 Effect on Time

Among the measurement instruments, time was a recorded data point and it was analyzed to respond to the research question, “Can a mobile augmented reality pedagogical tool be used to improve the speed of executing spatial tasks in CM students at the postsecondary level?” Analysis of the data shows that in terms of time, Group A completed the task

faster than Group B in all assessments. The data within each group shows that for Group A, time to complete took longer for the post-assessment ($M = 7:28$, $SD = 2:35$) than for the pre-assessment ($M = 7:01$, $SD = 2:39$) and the long-term assessment ($M = 7:32$, $SD = 3:02$) took about the same time at the post-assessment. On the other hand, Group B's time to complete took longer for the post-assessment ($M = 9:21$, $SD = 2:39$) than for the pre-assessment ($M = 8:20$, $SD = 2:44$), but time to complete the long-term assessment ($M = 8:37$, $SD = 6:32$) normalized back again to near the same time as the pre-assessment time (Table 4.3). The data is contrary to the expectation that the time to complete a task would be smaller after the intervention, in fact, the time to complete the task increased. Furthermore, conducting an independent sample t-test on the post-assessment, assuming a Confidence Interval percentage of 95% ($CI = 95\%$) then $t(23) = -1.790$, $p = .087$. The null hypothesis (H_0) indicates that the mean time for Group A would be statistically similar to the time for Group B and according to the test results this hypothesis cannot be rejected.

5.2.3 Perceived Participant Workload

Lastly, it has been suggested that a certain measure of applied technology in the classroom can have an interfering effect on the learning experience (Cristia et al., 2012). When deploying new technology in the classroom, will its use equate to a better and more active learning experience (Shirazi & Behzadan, 2014)? For this facet of pedagogy to be measured in this study a NASA TLX survey was administered for the purpose that it measures the participant's perceived workload on six independent subscales.

Specifically, the measurement asked the participants to rate their experience during the lab assignment. The resultant measurements as shown in Table 4.4 indicate that overall, the perceived workload between Group A and Group B were very similar. The slight exceptions (the variance was ≥ 1) included mental, physical, and performance workloads. In terms of workload, the data indicate that Group A expended a small amount more mental effort and physical effort than Group B during the lab assignment. And Group B perceived higher performance from the lab assignment than Group A. In order to derive a benefit from this type of intervention, it should be expected that there be either a negligible effect on these subscales (no difference between groups) or that the test group perceives lower levels of mental and physical effort than the control group. Likewise, higher levels of perceived performance for the test group over the control group would also prove this pedagogical tool as a benefit. Overall, having very similar data between the groups seems to indicate no additional perceived effort was expended because of the intervention, an outcome that has potential benefit for this intervention as a pedagogical tool.

5.3 Limitations

While the researcher sought to minimize conditions of the study that could adversely affect the results, upon completion of the research some elements became known that should be considered if the study was to be conducted again. Furthermore, in light of the inability to reject the null hypothesis in terms of accuracy and time, as previously discussed, the researcher would like to present potential areas of the study that could be

altered in an effort to more definitively respond to the research questions about spatial skills in terms of accuracy and time.

5.3.1 Mobile Device and Human Computer Interaction

As was detailed in Chapter 3, the mobile devices used to conduct the double-blind experiment were not all exactly the same. Refer to Table 3.1 for an inventory of the devices used to conduct the study.

The devices ranged in screen size from 24.6 cm to 17.8 cm (diagonal) and the operating systems of the devices varied between Apple IOS 9 and Android OS v4.1 (Jelly Bean). Although the experience using the Augment software application was similar on all devices, there are some Human Computer Interaction issues of form, speed, usability, and student satisfaction (Zolfagharian et al., 2013) that could affect the subject's experience while using the device and it could be argued that the learning experience was affected by differing device types. In future iterations of the experiment, it would be advisable to conduct the experiment with exactly the same tool for all subject participants.

5.3.2 Engaging Students in a More Recreational Exercise

While the study was structured to test the intervention of the MAR technology, there may be some benefit to the participant that was not related to the use of the technology itself. As elaborated by (Carter, 2006) "In order to improve learning, learning should be more

fun.” It could be reasoned that the attention of the students was heightened by the introduction of an activity that the students did not perceive as typical of their normal learning routine, as suggested by (Schneider, Weinmann, Roth, Knop, & Vorderer, 2016). To a point, the activity may have been more recreational in nature, thereby allowing the students to learn through enjoyment. At the conclusion of the study, the research solicited some feedback from the participants in the Test Group about their experience with the MAR tool. Specific quotes included:

“It made it easier.”

“I find it easier to conceptualize it...it just helps me do it faster.”

“It almost does it for you.”

There is an aspect of removing students from their normally scheduled classroom routine to engage them with a “fun” activity that is different and more exciting and could be a factor in why these students responded in this way and subsequently scored better on their post-assessments. There may be a normalizing effect if the intervention becomes a part of the “normal” routine of spatial skills learning.

5.3.3 The Effect of Being Timed on Assessments

All assessments conducted in this study were timed and although the participants were allowed to take as much time as needed to complete the assessments they knew they were being timed. The participants may have felt fatigued or frustrated with the consideration of time being a factor in completing the assessment and this may have affected the reliability of the assessment (Schumacker & Lomax, 2004).

5.3.4 Subject Past Experiences and Demographics

The subjects used in the study were non-traditional postsecondary students and generally had a number of years of working experience (Figure 3.1) and were generally older compared to traditional postsecondary students. As has been mentioned, past experiences affect the proficiency of one's spatial ability (McCuen, 2014). Additionally, there has been some research to suggest that younger students entering college today perform better on spatial skills assessments than their predecessors (Wai et al., 2009), mainly through stronger support of STEM-related studies at the secondary education level. Consequently, conducting this experiment with younger and more traditional students may yield a different result. Furthermore, as was presented in Chapter 3, section 3.3, the mix of experiences and demographics between the control group and the test group were very similar for nearly all background questions, indicating that the groups were balanced in terms of experience and demographics. The only exception that appeared significant was the participant's previous work experience.

And in terms of this study and based on the population available, this was an expected variation since technical college students have a more varied mix of work experience than do other postsecondary student types (https://tcsge.edu/download/TCSG_Strategic_Assets.pdf : accessed on April 6, 2016).

The gender composition of the subjects in this experiment is consistent with that of the industry (Sewalk & Nietfeld, 2013), however, there is research to suggest that there are differences between genders in terms of spatial ability and spatial skills (Hsi et al., 1997; Maeda et al., 2011; Sewalk & Nietfeld, 2013; Sorby & Baartmans, 2000). Either sampling a larger population or segregating the results based on gender may be necessary to negate this difference.

5.3.5 Balancing Assessment Difficulty and Questions of Assessment Reliability

As was detailed in Chapter 3, the pre-assessment and post-assessment were piloted to gauge difficulty level of the questions. The composition of the pre-assessment and the post-assessment were then adjusted to balance the difficulty level between the two tests. There was an anomaly in the assessment data, causing concern for the reliability of the assessment. To illustrate this point, the assessment scores were further analyzed based on the change in score between Group A and Group B between the pre-assessment and the post-assessment.

Table 5.1
Pre-Assessment and Post-Assessment Variance Score Analysis by Question Type

Pre-Assessment Percent Correct				Post-Assessment Percent Correct				Variance
Question Types	Group A	Group B	$\Delta 1$ B - A	Question Types	Group A	Group B	$\Delta 2$ B - A	$\Delta 2 - \Delta 1$
a	92.3%	100.0%	7.7%	a	76.9%	100.0%	23.1%	15.4%
b	53.8%	83.3%	29.5%	b	30.8%	66.7%	35.9%	6.4%
c	53.8%	83.3%	29.5%	c	15.4%	66.7%	51.3%	21.8%
d	61.5%	54.2%	-7.4%	d	76.9%	83.3%	6.4%	13.8%
e	57.7%	37.5%	-20.2%	e	53.8%	62.5%	8.7%	28.8%
f	23.1%	37.5%	14.4%	f	69.2%	54.2%	-15.1%	-29.5%
Overall	52%	53%	0.2%	Overall	58%	72%	14.0%	13.8%

Note. Question Types include (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976).

Observing the variance between $\Delta 2$ and $\Delta 1$ it became evident that for question types “a”, “b”, “c”, “d”, and “e” there was some level of expected improvement between the pre-assessment and the post-assessment because all variance values are positive. However, question type “f” has a negative variance of -29.5%. For the pre-assessment, 23.1% of Group A scored question type “f” correct while a larger majority of Group B (37.5%) scored this question type correct. Conversely, on the post-assessment 69.2% of Group A scored question type “f” correct, while only 54.2% of Group B scored this question type correct, hence the negative variance. A possible problem with this question type may be a reason for the inability to reject the null hypothesis and would warrant further investigation into the use of this question type.

The same conclusion about question type “f” can be reasoned from examining the data using a Learning Gain (LG) equation (Hake, 1998). This equation is used to generate a ratio of effectiveness, comparing actual improvement over the maximum level of improvement between the assessments. The equation shown in Figure 5.1 was used to determine the LG for each question type. Table 5.2 illustrates the relation of LG by group between the pre-assessment and the post-assessment.

$$\frac{\text{POST \%} - \text{PRE \%}}{100 - \text{PRE \%}} = \text{Learning Gain (LG)}$$

Figure 5.1: Equation for Determining the Learning Gain of a Question Type (in terms of percent of correct responses).

Table 5.2
Learning Gain Analysis of Pre-Assessment and Post-Assessment by Question Type

Group A				Group B				Variance
Question Types	PRE	POST	LGA	Question Types	PRE	POST	LGB	ΔLG LGB - LGA
a	92.3%	76.9%	-200.0%	a	100.0%	100.0%	0.0%	200.0%
b	53.8%	30.8%	-50.0%	b	83.3%	66.7%	-100.0%	-50.0%
c	53.8%	15.4%	-83.3%	c	83.3%	66.7%	-100.0%	-16.7%
d	61.5%	76.9%	40.0%	d	54.2%	83.3%	63.6%	23.6%
e	57.7%	53.8%	-9.1%	e	37.5%	62.5%	40.0%	49.1%
f	23.1%	69.2%	60.0%	f	37.5%	54.2%	26.7%	-33.3%
Overall			-242.4%	Overall			-69.7%	172.7%

Note. Question Types include (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976). The Learning Gain model is adapted from (Hake1998).

Through the analysis of LG, it became evident that for question type “a”, there was no LG for Group B ($LGB = 0.0\%$), in essence, this question type had no effect on this group.

Question types “d” ($\Delta LG = 23.6\%$), and “e” ($\Delta LG = 49.1\%$) demonstrated a positive ΔLG when compared between groups, as was anticipated and furthermore, these question types indicated a more favorable change as a result of the MAR intervention. As not expected, question types “ b” , “ c” and “f” had negative learning gains. This seems to indicate that the MAR intervention had an opposite effect on the student’s ability to complete these question types. Further consideration of these question types should be addressed as this may have had an overall effect on the significance of this study.

The makeup of the pre-assessment and the post-assessment were structured in such a way so as to provide a mixture of the following type of questions (a) isometric to orthographic projections, (b) 3D to 2D orthographic translation, (c) building elevation translation, (d) Mental Rotations Test - MRT (Vandenberg & Kuse, 1978), (e) Differential Aptitude Tests: Spatial Relations - DAT:SR (Bennett et al., 1956), and (f) Purdue Spatial Visualization Tests: Visualization of Rotation - PSVT:R (Guay, 1976) (Table 3.3). While each of the question types have verifiable previous research, the methods by which the assessments were conducted was different than the methodology suggested in the respective research and so this may have some impact on the reliability of the results. Lastly, it is suggested from this analysis that the various question types overly complicate the finding of this research, as so, future research should focus more specifically on one single question type to determine significance.

5.3.6 Longitudinal Research

Although a longitudinal assessment was performed, it differed from the pre-assessment and the post-assessment in the following ways, (1) it was conducted online in lieu of in paper form, (2) it was optional, (3) it was not proctored by the researcher, and (4) although it was timed, the timer was not visible and the students were not aware that they were being timed. Each of these factors may have a role in reducing the reliability of the results.

5.4 Conclusions

All too often, solutions to problems are too complex and fail because of this. Therefore, in this research the problem facing the construction industry was compartmentalized into three focus areas, (1) students need to improve their spatial skills, (2) the industry needs these graduating students to be better trained in their spatial skills, and (3) postsecondary institutions need to reevaluate their default tendency toward passive teaching techniques. However, as has been detailed, these three focus areas require a considerable amount of mutual attention. Each focus area is dependent upon the other for the successful resolution of the overall problem. Therefore, the implementation of a simple and elegant solution was sought out.

The author has identified AR as a technology that has the potential of becoming a useful academic tool. While the results of this study are not conclusive, it does present a

methodology for the introduction of a simple-to-configure tool that can be easily employed within the classroom. Furthermore, the simplification of the assessment instruments should allow one to accurately identify significance while measuring isometric to orthographic projection, 3D to 2D orthographic translation, building elevation translation and visual rotation when each is assessed individually.

The outlying expectation of this research is to bring awareness and applicability of AR to the construction industry. It is the opinion of the author that in order for AR to gain acceptance in the greater AECFM industry there needs to be a workforce that is already familiar with the technology, therefore, the introduction of AR at all levels of the education spectrum is a great first step in bringing this awareness.

5.4.1 A Pathway for AR Implementation in Industry

Within the working environment, AR has been demonstrated to help with displaying complex visual concepts (Thomas, Piekarski, & Gunther, 1999) and assisted others in completing complex multi-step processes (Azuma, 1997; Feiner et al., 1993; Schwald & De Laval, 2003). Demonstrated research in the fields of architecture, medicine, manufacturing and repair, robotics, entertainment, and the military all attests to AR preparedness to be used in industry (Azuma, 1997; Dunston & Shin, 2008; Georgel et al., 2007; Rankohi & Waugh, 2013; Roberts et al., 2002; Schall, Schmalstieg, & Junghanns, 2010; Webster, Feiner, MacIntyre, Massie, & Krueger, 1996). Similarly, others have validated the use of AR as a pedagogical tool (Y.-C. Chen, 2006; Cooperstock, 2001;

Fernández-solís, 2009; Kaufmann, 2004; Liu et al., 2007; Shelton & Hedley, 2002). So it is interesting why there is not a more prevalent use of this technology. Addressing this problem specific to the AECFM industry, an extensive survey of more than 1,000 respondents was done that sought to learn about the use of AR and discover what potential barriers there were to its adoption (Holt & Kearney, 2015). Of the respondents, only 3% indicated that they were using this technology within their companies with the greatest barrier to adoption being budget, followed by a lack of staff support (Figure 5.2 and Figure 5.3).

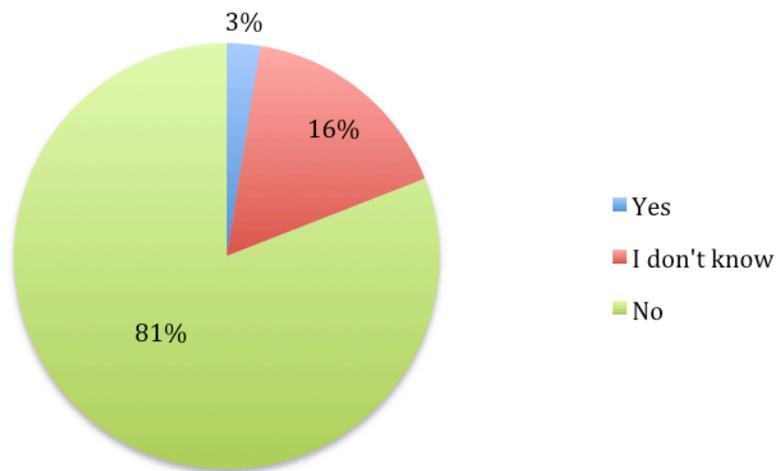


Figure 5.2: Use of AR or Virtual Reality in AECFM Industry. Adapted from Emerging Technology in the Construction Industry: Perceptions from Construction Industry Professionals, 2015 (Holt & Kearney, 2015).

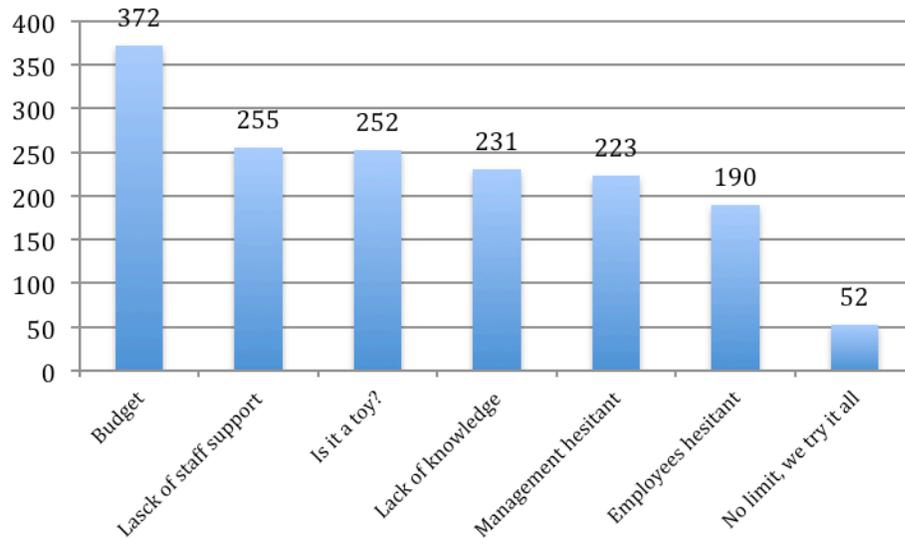


Figure 5.3: Barriers to Technology Adoption. Adapted from *Emerging Technology in the Construction Industry: Perceptions from Construction Industry Professionals, 2015* (Holt & Kearney, 2015).

As further noted by (Holt & Kearney, 2015),

“BIM continues to be the leader of advancing technology, and a lot of emerging technology falls under the BIM umbrella. Augmented reality [is] about more efficiently gathering and communicating information about the project.”

This statement implies that there is a future for AR within the AECFM industry as it continues to find a foothold in the way that BIM has. And similarly, to the way that BIM improves the quality of learning by supporting visualization (Wong et al., 2011) AR can also support visualization and therefore the learning experiences of CM students. There is optimism that AR will gain momentum in the construction industry by way of the graduating students of postsecondary institutions. As the graduating CM students

become more familiar with AR technology and its ability to benefit complex visualization and collaboration, they may become more comfortable with realizing its potential within the industry, thereby minimizing some of the barriers to its use as discovered by (Holt & Kearney, 2015)'s research.

APPENDIX A – BACKGROUND SURVEY

ID Sticker:

Background Survey

Section 1
This section has some statements pertinent to the study you are about to engage in. Please read each statement and indicate to what extent you agree or disagree. Select only one number for each question.

Q1. I feel comfortable using mobile technology to obtain more information about things I have questions about. Mobile technology for the purpose of this question refers to mobile smart phones or hand-held portable tablet computers.

STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
-1-	-2-	-3-	-4-	-5-

Q2. I like to see lots of diagrams, photos and illustrations to aide in my understanding of a topic.

STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
-1-	-2-	-3-	-4-	-5-

Q3. I feel that technology has interfered or may interfere with my ability to learn in the classroom. Technology for the purpose of this question refers to computers, laptops, mobile devices, smart displays and other similar tools.

STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
-1-	-2-	-3-	-4-	-5-

Q4. I am capable of clearly visualizing, in my mind, objects that are NOT in front of me.

STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
-1-	-2-	-3-	-4-	-5-

Q5. I am capable of clearly visualizing, in my mind, objects that are NOT in front of me AND I can manipulate those objects to gain a better understanding of them. Manipulate for the purpose of this question refers to rotating, moving and “seeing” all sides.

STRONGLY DISAGREE	DISAGREE	NEUTRAL	AGREE	STRONGLY AGREE
-1-	-2-	-3-	-4-	-5-

Section 2

This section has some statements pertinent to the study you are about to engage in. Please read each statement and indicate your closest attitude in the scale provided. Select only one number for each question.

Q6. How proficient are you in reading construction plans? For the purpose of this question, “No Experience” means you are completely unable to read constructions plans and “Highly Proficient” means you are fluent with their intent and use.

NO EXPERIENCE	BASIC EXPERIENCE	INTERMEDIATE EXPERIENCE	ADVANCED EXPERIENCE	HIGHLY PROFICIENT
-1-	-2-	-3-	-4-	-5-

Q7. In your past experience, how often have you successfully assembled something without the need for written instructions or a written manual?

NEVER	RARELY	SOMETIMES	OFTEN	ALWAYS
-1-	-2-	-3-	-4-	-5-

Q8. How would you rate your understanding of “augmented reality”? For the purpose of this question, “No Understanding” means you have never heard of it and “Highly Proficient” means you use it daily and know exactly how it works.

NO UNDERSTANDING	BASIC UNDERSTANDING	INTERMEDIATE UNDERSTANDING	ADVANCED UNDERSTANDING	HIGHLY PROFICIENT
-1-	-2-	-3-	-4-	-5-

Q9. Considering your time in class, how much technology is used to aide you in your learning? Exclude technology that you use for note taking. Technology for the purpose of this question refers to computers, laptops, mobile devices, smart displays and other similar tools.

NO TECHNOLOGY IS USED	TECHNOLGY IS RARELY USED	SOME TECHNOLOGY IS USED	TECHNOLOGY IS USED REGULARLY	TECHNOLOGY IS ALWAYS USED
-1-	-2-	-3-	-4-	-5-

Section 3

This section requests information about you, as it may relate to this study. Please read each question and circle / write in your response.

Q10. Please indicate your level of experience working in some aspect of the construction industry. Any type of work may be included as experience if you can relate it to some aspect of the built environment. Circle only one.

- a) None
- b) Less than a year
- c) More than a year but less than 5 years
- d) More than 5 years

Q11. What is your level of education thus far? Circle as many as apply.

- a) High School or equivalent
 - b) Associate Degree
 - c) Bachelor Degree
 - d) Master Degree
 - e) Ph.D.
 - f) Other _____
 - g) None
- Explain

Q12. Please indicate your age group? Circle only one.

- a) 18 – 25 years
- b) 26 – 35 years
- c) 36 or older

Q13. Gender?

- a) _____

Q14. What area of study are you currently pursuing? Circle as many as apply.

- a) General Construction
 - b) Engineering
 - c) Architectural or Design
 - d) Specific Trade Craft
 - e) Other _____
- Explain

Q15. Are you or have you taken one of the following courses? Circle as many as apply.

- a) Drafting
- b) Plan Reading
- c) Mechanical Drafting
- d) Computer Aided Drafting (CAD)
- e) Building Information Modeling (BIM)
- f) Graphic Design (Computer Graphic Design)
- g) None of the above.

APPENDIX B – PRE-ASSESSMENT

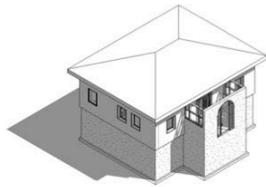
ID Sticker:

End Time: _____

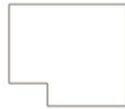
Pre-Assessment

Please circle the most correct answer for each question. Unless otherwise noted, only one answer is the most correct in each case, therefore if more than one answer is circled it will be counted as incorrect.

Q1. Study the image of this building. Based on what you are observing, and making some assumptions about what you cannot observe, which first floor plan is most likely the correct pattern?



Three-Dimensional Image



-a-



-b-



-c-

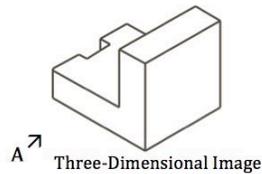


-d-

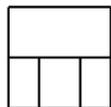


-e-

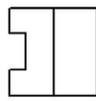
Q2. Study the three-dimensional image below. Which two-dimensional image correctly represents the view labeled as “A”?



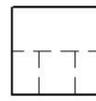
Three-Dimensional Image



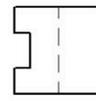
-a-



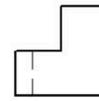
-b-



-c-



-d-

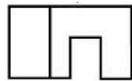
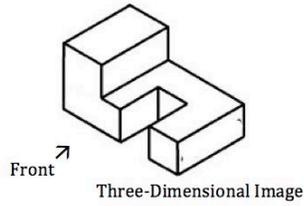


-e-

Pre-Assessment
09-03-2015
10-03-2015 rev.1

Page 1 of 5

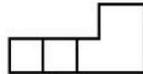
Q3. Study the three-dimensional image below. Which two-dimensional image correctly represents the “Front” view?



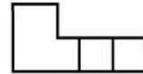
-a-



-b-



-c-



-d-

None of these

-e-

Q4. Study the “North” and “West” elevation of this house. Which elevation could accurately represent the “East” elevation of this house?



“North” elevation



“West” elevation



-a-



-b-



-c-

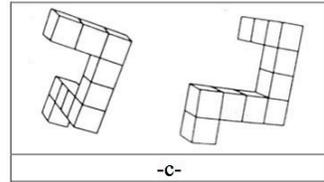
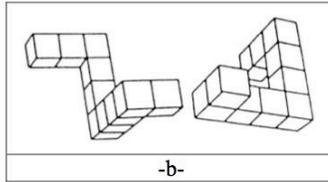
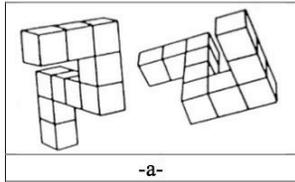


-d-

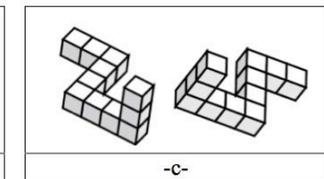
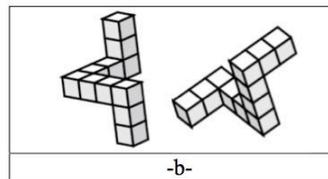
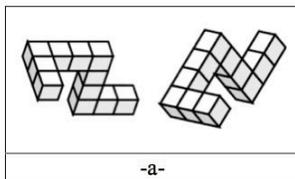


-e-

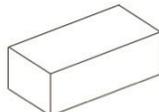
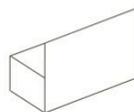
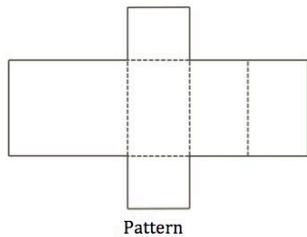
Q5. Study the three groupings of shapes, “a”, “b”, and “c”. Which grouping shows two different shapes?



Q6. Study the three groupings of shapes, “a”, “b”, and “c”. Which grouping shows two different shapes?



Q7. Study the pattern below. What is the correct outcome when the object is folded along the dashed lines?

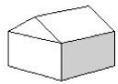
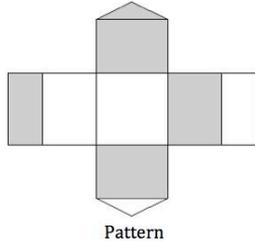


None of these

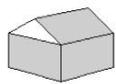
-e-

Page 3 of 5

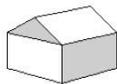
Q8. Study the pattern below. What is the correct outcome when the object is folded?



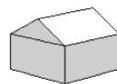
-a-



-b-



-c-



-d-

None of these

-e-

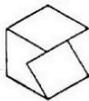
Q9. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct “rotated” image from the selection of images.



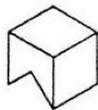
IS ROTATED TO



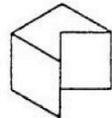
AS



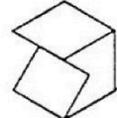
IS ROTATED TO



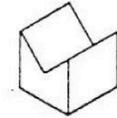
-a-



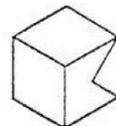
-b-



-c-

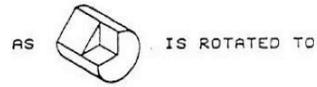


-d-



-e-

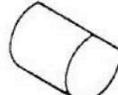
Q10. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct “rotated” image from the selection of images.



-a-



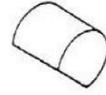
-b-



-c-



-d-



-e-

APPENDIX C - LECTURE

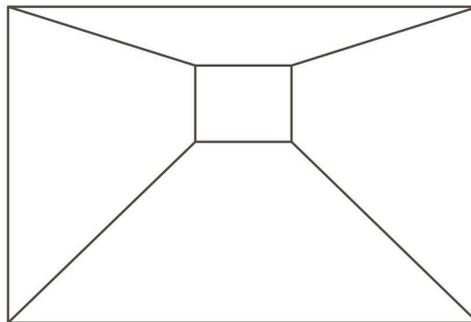
An Exercise on Visualization

Jeff Kim
2015



Which is Right?

Is the center of this drawing elevated or depressed?



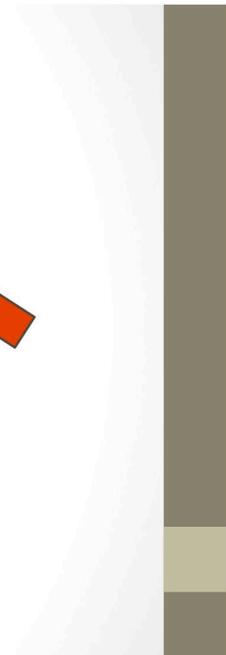
Visualization Importance

- Designing
- Construction
- Plan Reading
- Communication



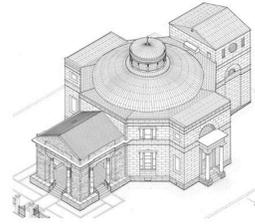
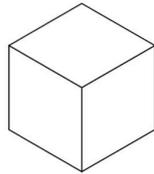
Visualization Challenges

- Not always intuitive
- Requires a specific way of thinking
- Requires some “standards of understanding”



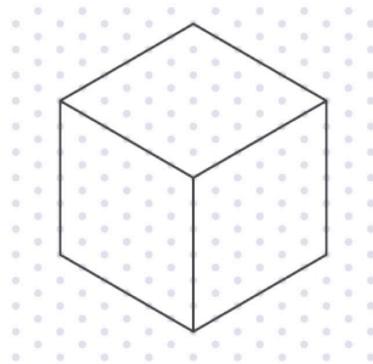
Isometric

We think of this as 3D view.

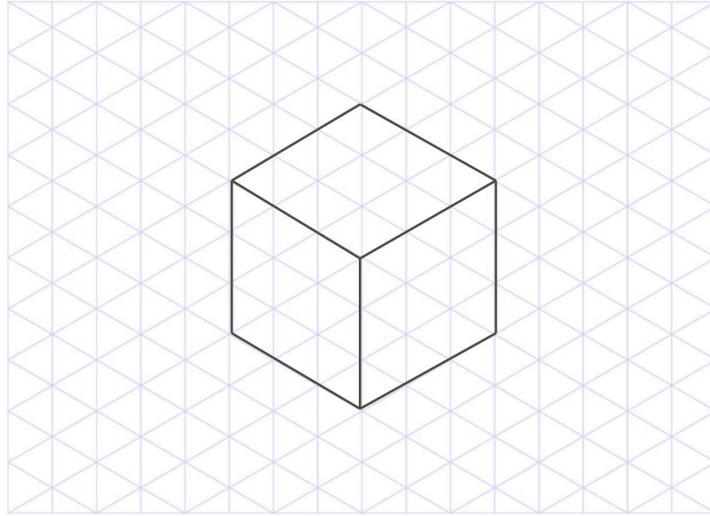


This is also isometric.

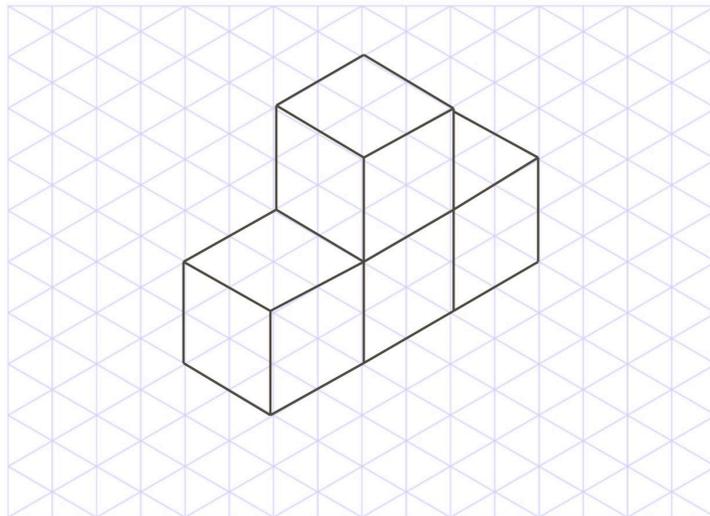
Isometric



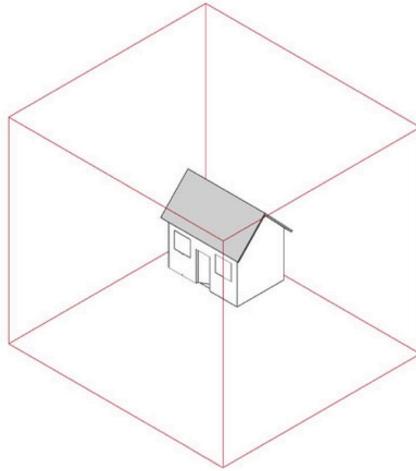
Exercise



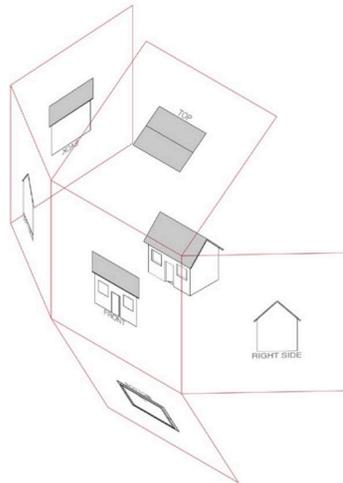
Exercise



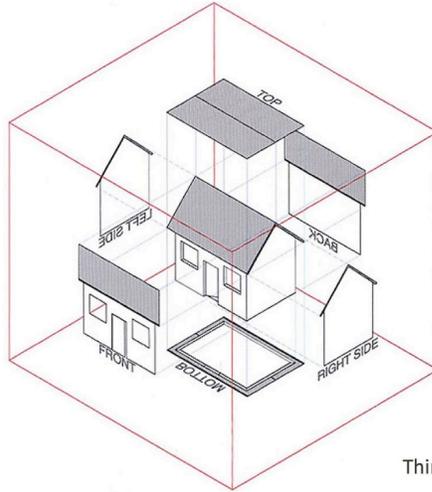
Orthographic



Orthographic

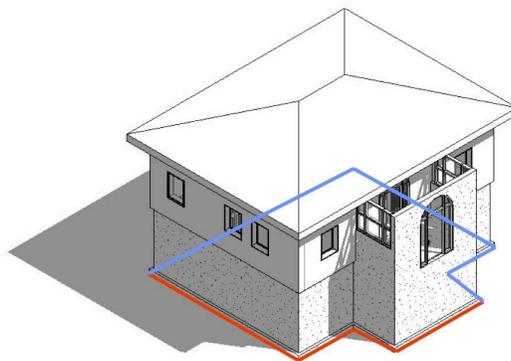


Orthographic

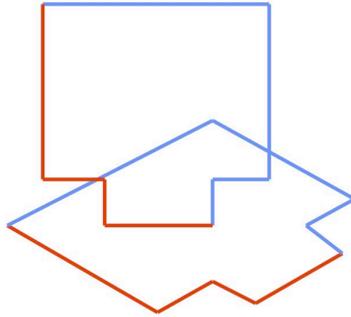


Think of stamping

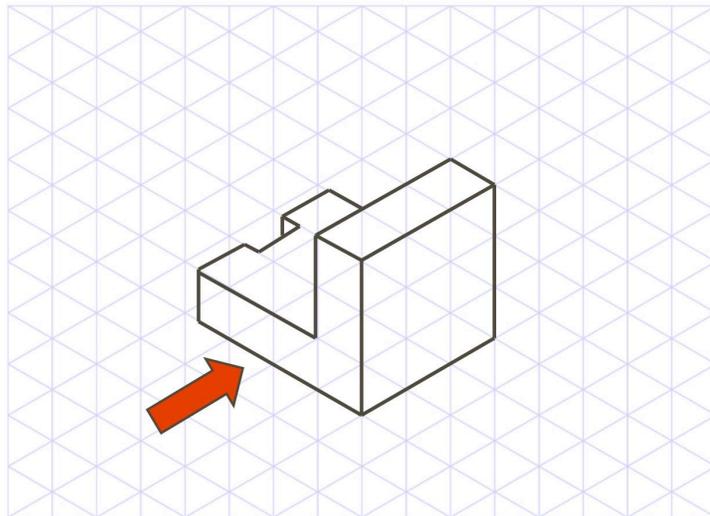
Exercise



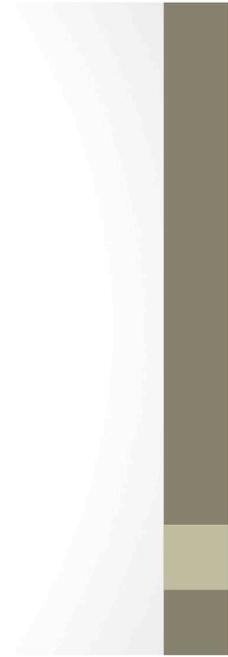
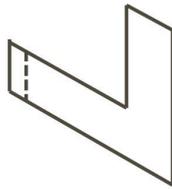
Exercise



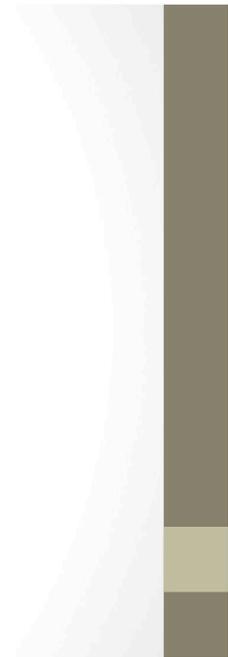
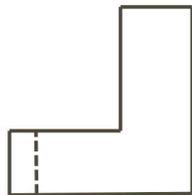
Exercise



Exercise



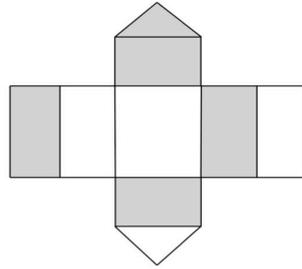
Exercise



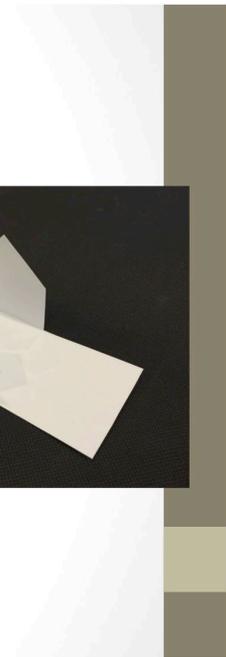
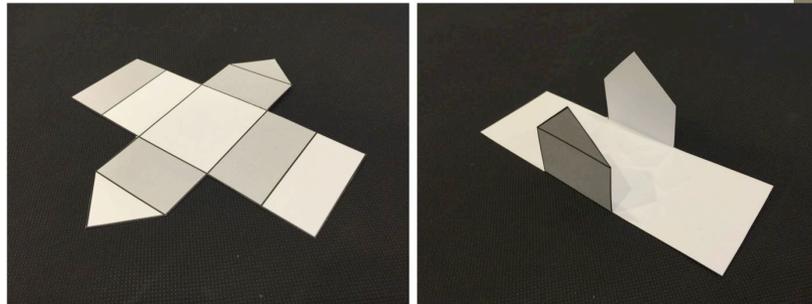
Folding

Taking 2D image and creating a 3D image from it.

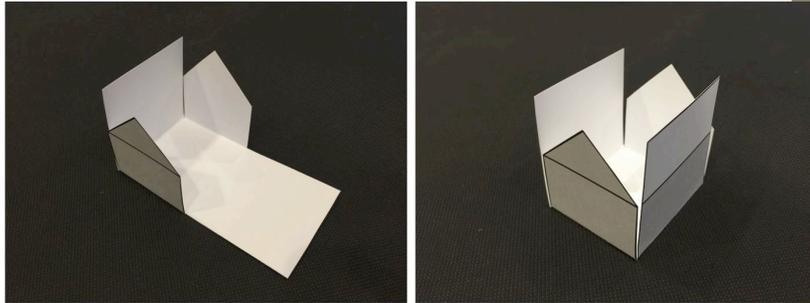
Think about box folding.



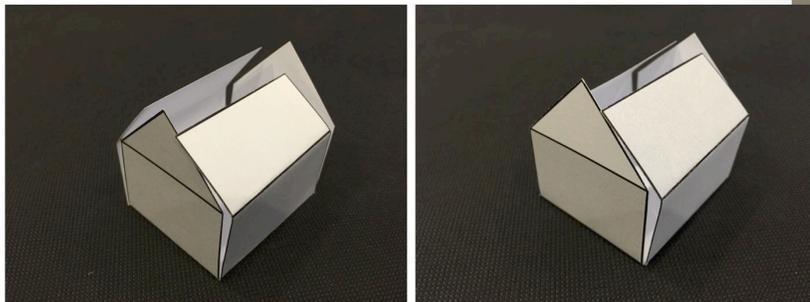
Folding



Folding



Folding

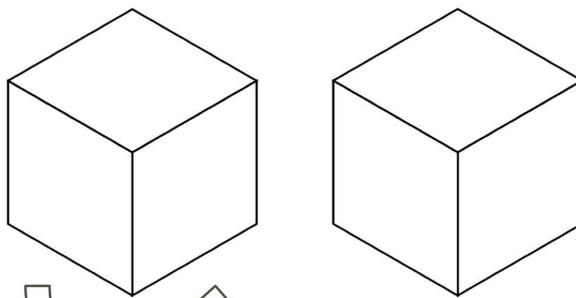


Rotation

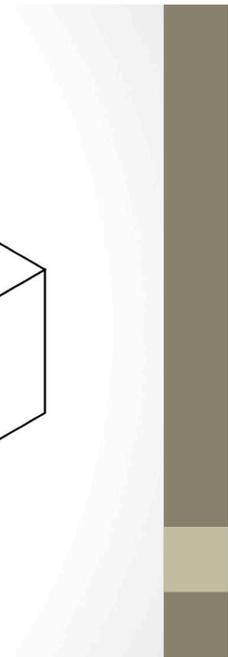
Look for changes...they are the clues.



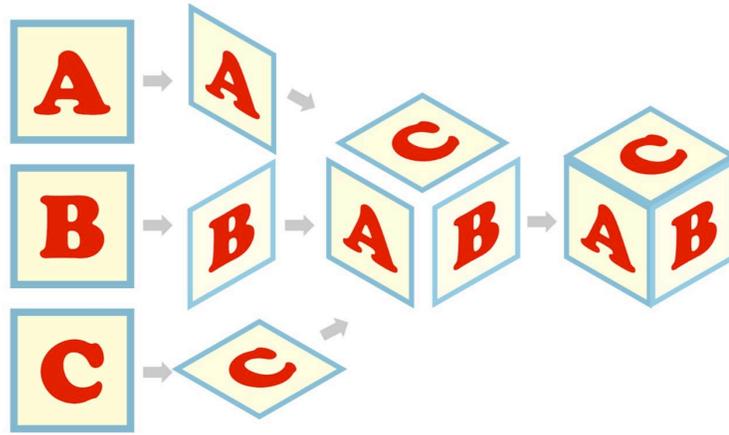
Rotation



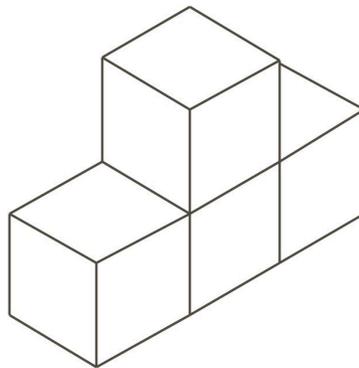
Rotate 90 degrees



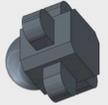
Rotation



Rotation



APPENDIX D – LAB ASSIGNMENT (MARKER)

	Is rotated to		
	AS		Image 1
	Is rotated to	?	
			Image 2
			
			Image 3
Like Rotations I			Part I

	Is rotated to		
	AS		Image 1
	Is rotated to	?	
			Image 2
			
			Image 3
Like Rotations II			Part II

Study this example image. Which images are the same as the example from another orientation?

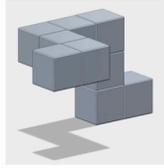


Image 1

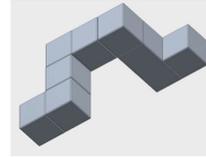


Image 2

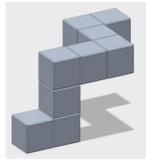


Image 3

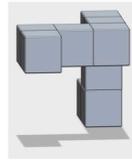


Image 4

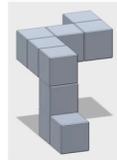


Image 5

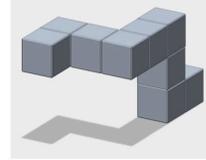
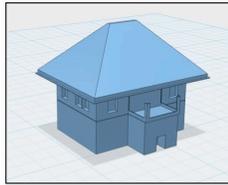


Image 6

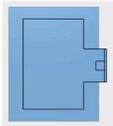
Rotation Exercise

Part III

Example image.



Which is the correct first floor plan? Discuss with your partner why?



Plan 1



Plan 2



Plan 3

Which elevation(s) are correct for this image?

Discuss with your partner why?



Elevation 1



Elevation 2



Elevation 3



Elevation 4

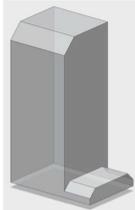
3D to 2D Exercise

Part IV



Observe this 2D rendering.
Which 3D image is possible?

Discuss with your partner why?



Observe this 3D image.
Which 2D orthographic images accurately represents this image?

Discuss with your partner why?

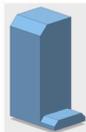


Image 1



Image 2

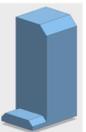


Image 3

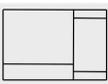


Image 1



Image 2



Image 3

2D Representation
Part V

Based on the Ground Floor Plan, which elevations could be correct?



Elevation 1



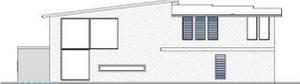
Elevation 2



Ground Floor Plan View



Elevation 3



Elevation 4

Elevations
Part VI

APPENDIX E – POST ASSESSMENT

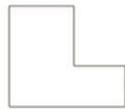
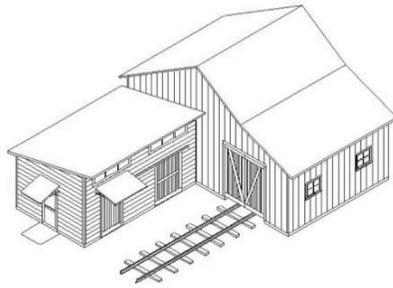
ID Sticker:

End Time: _____

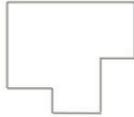
Post-Assessment

Please circle the most correct answer for each question. Unless otherwise noted, only one answer is the most correct in each case, therefore if more than one answer is circled it will be counted as wrong.

Q1. Study the image of this building. Based on what you are observing and making some assumptions about what you cannot observe, which first floor plan is most likely the correct pattern?



-a-



-b-



-c-

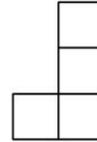
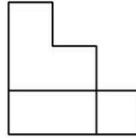
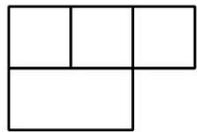
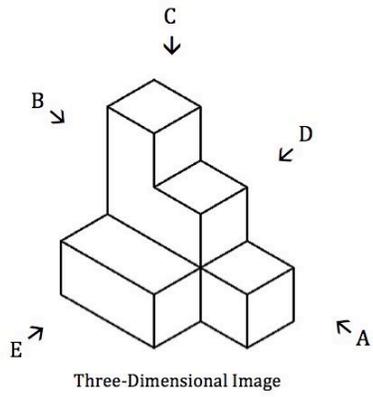


-d-

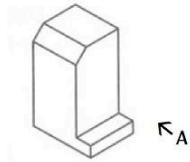


-e-

Q2. Study the three-dimensional image below. There are five views labeled “A”, “B”, “C”, “D” and “E”. In the space below each of the two-dimensional images, write in the correct view label from the three-dimensional image.



Q3. Study the three-dimensional image below. Which two-dimensional image correctly represents the view labeled as “A”?



Three-Dimensional Image



-a-



-b-



-c-



-d-

None of these

-e-

Q4. Study the “North” elevation of this house. Which elevation could accurately represent the “South” elevation of this house?



“North” elevation



-a-



-b-



-c-

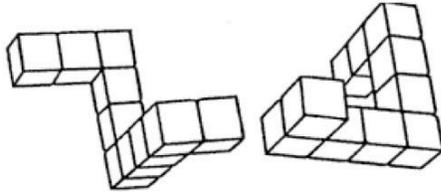


-d-

None of these

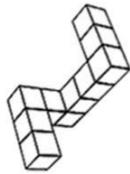
-e-

Q5. Aside from their orientation, are these two objects exactly the same?



- a) Yes
- b) No
- c) Cannot be determined

Q6. Study the example image below. Which image is the same as the example image from another orientation?



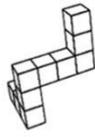
Example Image



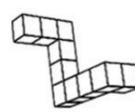
-a-



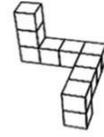
-b-



-c-

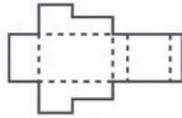


-d-

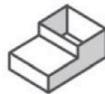


-e-

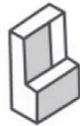
Q7. Study the pattern below. What is the correct outcome when the object is folded along the dashed lines?



Pattern



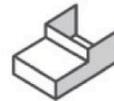
-a-



-b-



-c-

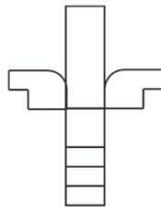


-d-

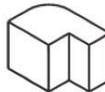


-e-

Q8. Study the pattern below. What is the correct outcome when the object is folded?



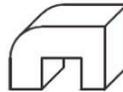
Pattern



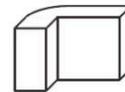
-a-



-b-



-c-

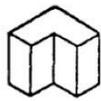


-d-

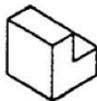
None of these

-e-

Q9. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct “rotated” image from the selection of images.



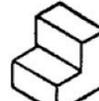
-a-



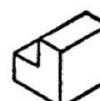
-b-



-c-

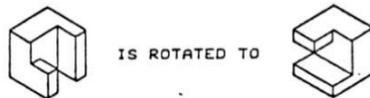


-d-



-e-

Q10. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct “rotated” image from the selection of images.



-a-



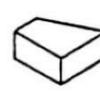
-b-



-c-



-d-



-e-

APPENDIX F – POST SURVEY / NASA TLX SURVEY

ID Sticker:

Post Survey – Group C

THIS SURVEY PERTAINS ONLY TO THE GROUP WORK EXERCISE, NOT THE LECTURE OR TEST.

Below are several statements about the EXERCISE. With each statement consider how much effort you put into the EXERCISE. On the scale provided place an “X” indicating low or high levels of effort.

Q1. Mental Effort – How mentally demanding was today’s EXERCISE?



Q2. Physical Effort – How physically demanding was today’s EXERCISE?



Q3. Temporal Effort – How hurried or rushed was today’s EXERCISE?



Q4. Performance – How confident do you think you were in learning something new from today’s EXERCISE?



Q5. Effort – How hard did you work to accomplish the EXERCISE?



Q6. Frustrations – How insecure, discouraged, irritated, stressed or annoyed were you with the EXERCISE?



ID Sticker:

Post Survey – Group E

Section 1

THIS SURVEY PERTAINS ONLY TO THE GROUP WORK EXERCISE, NOT THE LECTURE OR TEST.

Please read each statement and make your selection on the scale provided. Select only one number for each question.

Q1. The augmented reality tool used in this lecture was helpful in my learning experience today.

- | | | | | |
|----------------------|----------|---------|-------|----------------|
| STRONGLY
DISAGREE | DISAGREE | NEUTRAL | AGREE | STRONGLY AGREE |
| -1- | -2- | -3- | -4- | -5- |

Q2. The augmented reality tool was a distraction to my learning experience today.

- | | | | | |
|----------------------|----------|---------|-------|----------------|
| STRONGLY
DISAGREE | DISAGREE | NEUTRAL | AGREE | STRONGLY AGREE |
| -1- | -2- | -3- | -4- | -5- |

Q3. How would you rate the ease of use of the augmented reality software installed on the mobile devices?

- | | | | | |
|-------------------|-----------------------|---------|------------------|--------------|
| VERY
DIFFICULT | SOMEWHAT
DIFFICULT | NEUTRAL | SOMEWHAT
EASY | VERY
EASY |
| -1- | -2- | -3- | -4- | -5- |

Q4. Please rate your learning experience today.

- | | | | | |
|--------------------------|--------------|---------|-----------|-----------------------|
| STRONGLY
DISAGREEABLE | DISAGREEABLE | NEUTRAL | FAVORABLE | STRONGLY
FAVORABLE |
| -1- | -2- | -3- | -4- | -5- |

Q5. How likely are you to recommend today's type of learning experience?

- | | | | | |
|---------------|---------------|---------|--------------------|----------------|
| NOT AT
ALL | NOT
LIKELY | NEUTRAL | SOMEWHAT
LIKELY | VERY
LIKELY |
| -1- | -2- | -3- | -4- | -5- |

APPENDIX G – LONG-TERM ASSESSMENT

Long Term Assessment

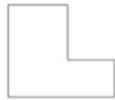
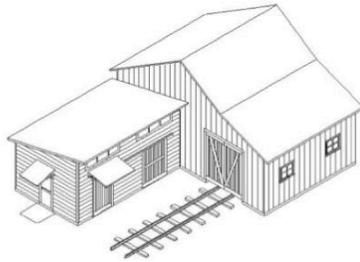
Welcome

* 1. Before you start, please enter your first and last name.

This assessment is similar to the one you completed several weeks ago. Use the concepts that we discussed in that class to complete this final assessment. You can move forward and back through the test questions. Any question left blank will be marked as incorrect. Once you are complete, on the final screen click "End Assessment" to finish the assessment.

Long Term Assessment

Question 1



-a-



-b-



-c-



-d-



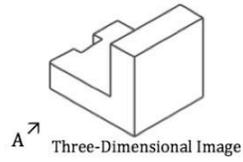
-e-

2. Study the image of this building. Based on what you are observing and making some assumptions about what you cannot observe, which first floor plan is most likely the correct pattern?

- a
- b
- c
- d
- e

Long Term Assessment

Question 2



-a-



-b-



-c-



-d-

None of these

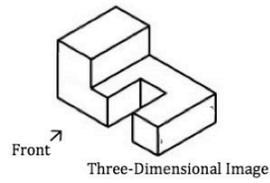
-e-

3. Study the three-dimensional image above. Which two-dimensional image correctly represents the view labeled as "A"?

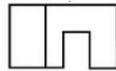
- a
- b
- c
- d
- e

Long Term Assessment

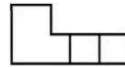
Question 3



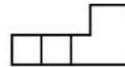
-a-



-b-



-c-



-d-

None of these

-e-

4. Study the three-dimensional image above. Which two-dimensional image correctly represents the "Front" view?

- a
- b
- c
- d
- e

Long Term Assessment

Question 4



"North" elevation



-a-



-b-



-c-



-d-



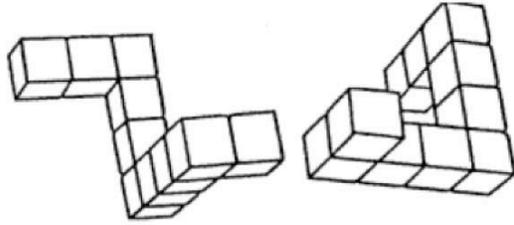
-e-

5. Study the "North" elevation of this house. Which elevation could accurately represent the "South" elevation of this house?

- a
- b
- c
- d
- e

Long Term Assessment

Question 5

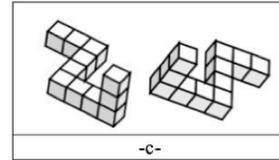
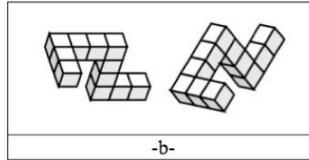
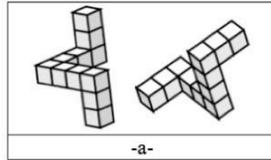


6. Aside from their orientation, are these two objects exactly the same?

- Yes
- No
- Cannot be determined

Long Term Assessment

Question 6

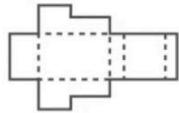


7. Study the three groupings of shapes, "a", "b", and "c". Which grouping shows two different shapes?

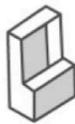
- a
- b
- c

Long Term Assessment

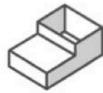
Question 7



Pattern



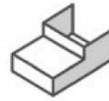
-a-



-b-



-c-



-d-



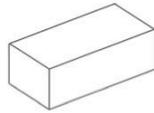
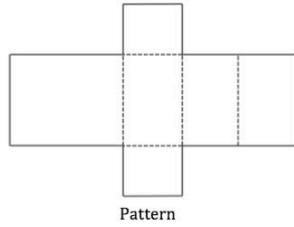
-e-

8. Study the pattern above. What is the correct outcome when the object is folded along the dashed lines?

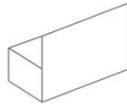
- a
- b
- c
- d
- e

Long Term Assessment

Question 8



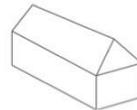
-a-



-b-



-c-



-d-

None of these

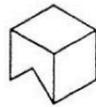
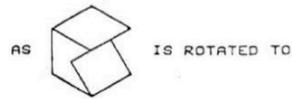
-e-

9. Study the pattern above. What is the correct outcome when the object is folded along the dashed lines?

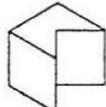
- a
- b
- c
- d
- e

Long Term Assessment

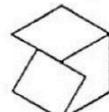
Question 9



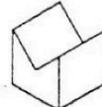
-a-



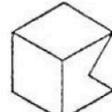
-b-



-c-



-d-



-e-

10. Study the images above. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and select the correct "rotated" image from the selection of images in the third row.

- a
- b
- c
- d
- e

Long Term Assessment

Question 10



-a-



-b-



-c-



-d-



-e-

11. Study the images above. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and select the correct "rotated" image from the selection of images in the third row.

- a
- b
- c
- d
- e

APPENDIX H – PILOT SURVEY (PRE- AND POST-SURVEY)

Opinions on Test Question Difficulty

Thanks for taking the time to help. On the pages that follow are test questions. Don't worry about getting the right answer, just look at the question and tell me how difficult you think it is - that's all. There are 20 questions so this shouldn't take much of your time.

Thanks very much for your help.
Jeff

Opinions on Test Question Difficulty

1. Please indicate your age group.

- 18 to 25
- 26 to 35
- 36 or older

* 2. Select any of the following fields of study that you have majored in or have experience in (you may select more than one).

- Architecture
- Engineering
- Construction
- Technical Drafting
- Graphic Design
- Product Design
- None of these.

Opinions on Test Question Difficulty

Q1. Study the image of this building. Based on what you are observing, and making some assumptions about what you cannot observe, which first floor plan is most likely the correct pattern?



Three-Dimensional Image



-a-



-b-



-c-



-d-



-e-

* 3. How difficult is this question?

Very Easy

Easy

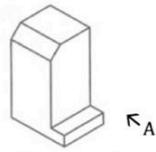
Neutral

Difficult

Very Difficult

Opinions on Test Question Difficulty

Q2. Study the three-dimensional image below. Which two-dimensional image correctly represents the view labeled as "A"?



Three-Dimensional Image



-a-



-b-



-c-



-d-

None of these

-e-

* 4. How difficult is this question?

Very Easy

Easy

Neutral

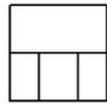
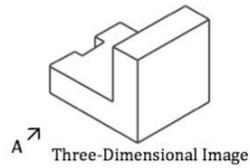
Difficult

Very Difficult



Opinions on Test Question Difficulty

Q3. Study the three-dimensional image below. Which two-dimensional image correctly represents the view labeled as "A"?



-a-



-b-



-c-



-d-



-e-

* 5. How difficult is this question?

Very Easy



Easy



Neutral



Difficult



Very Difficult



Opinions on Test Question Difficulty

Q4. Study the "North" and "West" elevation of this house. Which elevation could accurately represent the "East" elevation of this house?



"North" elevation



"West" elevation



-a-



-b-



-c-



-d-



-e-

* 6. How difficult is this question?

Very Easy

Easy

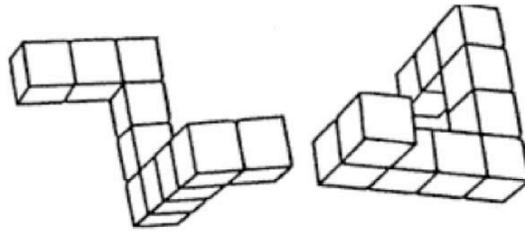
Neutral

Difficult

Very Difficult

Opinions on Test Question Difficulty

Q5. Aside from their orientation, are these two objects exactly the same?



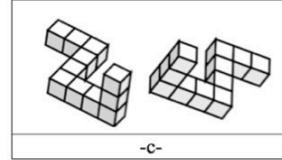
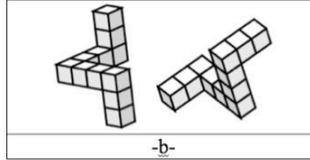
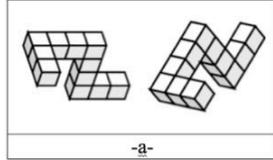
- a) Yes
- b) No
- c) Cannot be determined

* 7. How difficult is this question?

Very Easy	Easy	Neutral	Difficult	Very Difficult
<input type="radio"/>				

Opinions on Test Question Difficulty

Q6. Study the three groupings of shapes, "a", "b", and "c". Which grouping shows two different shapes?



* 8. How difficult is this question?

Very Easy

Easy

Neutral

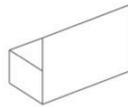
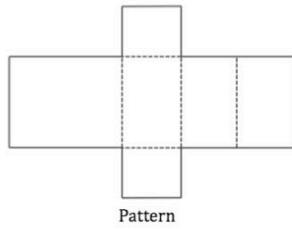
Difficult

Very Difficult



Opinions on Test Question Difficulty

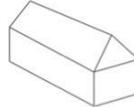
Q7. Study the pattern below. What is the correct outcome when the object is folded along the dashed lines?



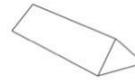
-a-



-b-



-c-



-d-

None of these

-e-

* 9. How difficult is this question?

Very Easy

Easy

Neutral

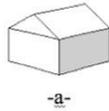
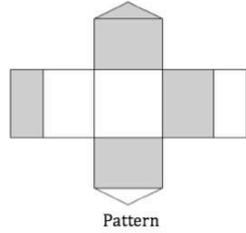
Difficult

Very Difficult

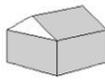


Opinions on Test Question Difficulty

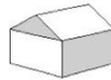
Q8. Study the pattern below. What is the correct outcome when the object is folded?



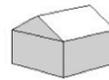
-a-



-b-



-c-



-d-

None of these

-e-

* 10. How difficult is this question?

Very Easy

Easy

Neutral

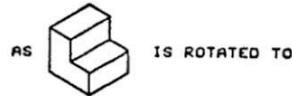
Difficult

Very Difficult



Opinions on Test Question Difficulty

Q9. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct "rotated" image from the selection of images.



-a-



-b-



-c-



-d-



-e-

* 11. How difficult is this question?

Very Easy

Easy

Neutral

Difficult

Very Difficult



Opinions on Test Question Difficulty

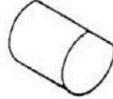
Q10. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct “rotated” image from the selection of images.



-a-



-b-



-c-



-d-



-e-

* 12. How difficult is this question?

Very Easy

Easy

Neutral

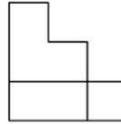
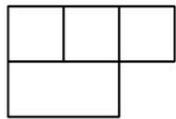
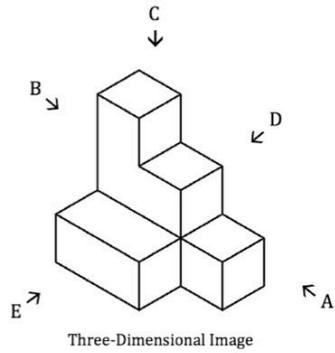
Difficult

Very Difficult



Opinions on Test Question Difficulty

Q1. Study the three-dimensional image below. There are five views labeled "A", "B", "C", "D" and "E". In the space below each of the two-dimensional images, write in the correct view label from the three-dimensional image.

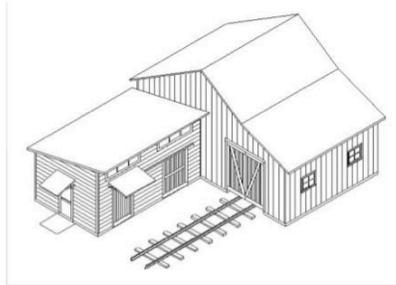


* 13. How difficult is this question?

Very Easy	Easy	Neutral	Difficult	Very Difficult
<input type="radio"/>				

Opinions on Test Question Difficulty

Q2. Study the image of this building. Based on what you are observing and making some assumptions about what you cannot observe, which first floor plan is most likely the correct pattern?



-a-



-b-



-c-



-d-



-e-

* 14. How difficult is this question?

Very Easy

Easy

Neutral

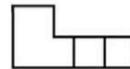
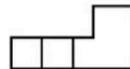
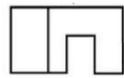
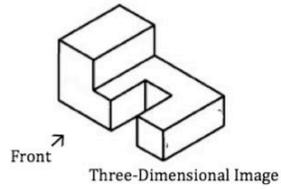
Difficult

Very Difficult



Opinions on Test Question Difficulty

Q3. Study the three-dimensional image below. Which two-dimensional image correctly represents the "Front" view?



None of these

-e-

* 15. How difficult is this question?

Very Easy

Easy

Neutral

Difficult

Very Difficult



Opinions on Test Question Difficulty

Q4. Study the "North" elevation of this house. Which elevation could accurately represent the "South" elevation of this house?



"North" elevation



-a-



-b-



-c-



-d-

None of these

-e-

* 16. How difficult is this question?

Very Easy

Easy

Neutral

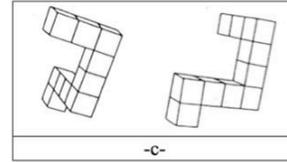
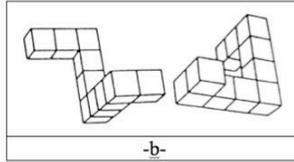
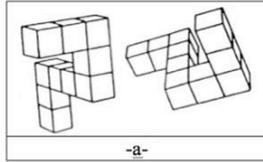
Difficult

Very Difficult



Opinions on Test Question Difficulty

Q5. Study the three groupings of shapes, "a", "b", and "c". Which grouping shows two different shapes?

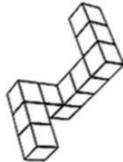


* 17. How difficult is this question?

Very Easy	Easy	Neutral	Difficult	Very Difficult
<input type="radio"/>				

Opinions on Test Question Difficulty

Q6. Study the example image below. Which image is the same as the example image from another orientation?



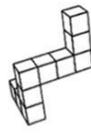
Example Image



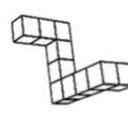
-a-



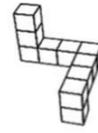
-b-



-c-



-d-



-e-

* 18. How difficult is this question?

Very Easy

Easy

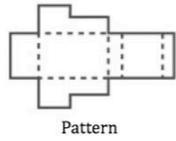
Neutral

Difficult

Very Difficult

Opinions on Test Question Difficulty

Q7. Study the pattern below. What is the correct outcome when the object is folded along the dashed lines?



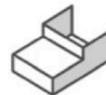
-a-



-b-



-c-



-d-



-e-

* 19. How difficult is this question?

Very Easy

Easy

Neutral

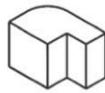
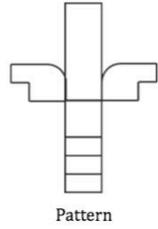
Difficult

Very Difficult

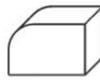


Opinions on Test Question Difficulty

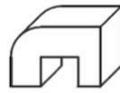
Q8. Study the pattern below. What is the correct outcome when the object is folded?



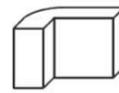
-a-



-b-



-c-



-d-

None of these

-e-

* 20. How difficult is this question?

Very Easy

Easy

Neutral

Difficult

Very Difficult



Opinions on Test Question Difficulty

Q9. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct "rotated" image from the selection of images.



-a-



-b-



-c-



-d-



-e-

* 21. How difficult is this question?

Very Easy



Easy



Neutral



Difficult

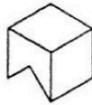
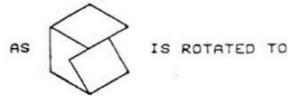


Very Difficult

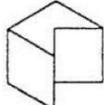


Opinions on Test Question Difficulty

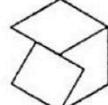
Q10. Study the images below. The top row shows what the image looks like after a rotation. Apply the same rotation to the image in the second row and circle the correct "rotated" image from the selection of images.



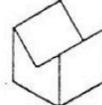
-a-



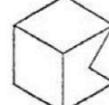
-b-



-c-



-d-



-e-

* 22. How difficult is this question?

Very Easy

Easy

Neutral

Difficult

Very Difficult



APPENDIX I – EXPERIMENT TIME TABLE

Experiment Time Table

October 5, 2015
6:00 pm – 7:50 pm

ALL Subjects		
6:00pm – 6:10pm 10 min	Introduction / Consent / Randomize <ul style="list-style-type: none"> • Discuss the experiment with the students. • Distribute Consent forms and explain. • Students are randomly selected for the “control” and “experiment” groups. • Students are assigned Group “C” or Group “E”. 	Allow student to decide if they want to participate. Distribute students a copy of the consent. Odd students are Group “C” Even students are Group “E”
6:10pm – 6:20pm 10 min	Introductions / Background Survey <ul style="list-style-type: none"> • Discuss again with the students the experiment. • Issue the background survey and allow students to complete the survey. 	Allow students time to complete the background survey.
6:20pm – 6:35pm 15 min	Pre-Assessment <ul style="list-style-type: none"> • Issue the pre-assessment test. Explain its purpose and allow the students to complete the assessment. • Answer questions as needed. 	This test is timed, have the students record the time they complete the test.
6:35pm – 6:55pm 20 min	Lecture <ul style="list-style-type: none"> • Review the course material. • Answer questions as needed. 	

- SEPARATE GROUPS -

CONTROL Group		EXPERIMENT Group	
6:55pm-7:15pm 20 min	Group Lab Work Students arrange into small groups and work on solving some example problems together. Assistant will remain to answer questions.	7:00pm-7:20pm 20 min	Group Lab Work The room will have markers set up at stations within the room and the subjects can move from station to station exploring the content on the mobile device at each station. Allow students time to explore the AR tools. Troubleshoot and answer questions as necessary.
7:15pm-7:35pm 20 min	Post - Assessment / Closing Survey Issue post-test and answer questions as needed. Once students are complete, record completion time and issue student a closing survey.	7:20pm-7:40pm 20 min	Post - Assessment / Closing Survey Issue post-test and answer questions as needed. Once students are complete, record completion time and issue student a closing survey.
		7:40pm – 7:50pm 10 min	Qualitative Interview Interview group about their impressions of working with AR during their exercise and if it “enhanced” their learning experience.

09-17-2015
10-03-2015 rev.1

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Experiment Time Table

October 20, 2015
10:00 am – 11:20am

ALL Subjects		
10:00am – 10:05am 5 min	Introduction / Consent / Randomize <ul style="list-style-type: none"> • Discuss the experiment with the students. • Distribute Consent forms and explain. • Students are randomly selected for the “control” and “experiment” groups. • Students are assigned Group “C” or Group “E”. 	Allow student to decide if they want to participate. Distribute students a copy of the consent. Odd students are Group “C” Even students are Group “E”
10:05am – 10:10am 5 min	Introductions / Background Survey <ul style="list-style-type: none"> • Discuss again with the students the experiment. • Issue the background survey and allow students to complete the survey. 	Allow students time to complete the background survey.
10:10am – 10:25am 15 min	Pre-Assessment <ul style="list-style-type: none"> • Issue the pre-assessment test. Explain its purpose and allow the students to complete the assessment. • Answer questions as needed. 	This test is timed, have the students record the time they complete the test.
10:25am – 10:45am 20 min	Lecture <ul style="list-style-type: none"> • Review the course material. • Answer questions as needed. 	

- SEPARATE GROUPS -

CONTROL Group		EXPERIMENT Group	
10:45am-11:05am 20 min	Group Work Students arrange into small groups and work on solving some example problems together. Assistant will remain to answer questions.	10:45am-11:05am 20 min	Group Work The room will have markers set up at stations within the room and the subjects can move from station to station exploring the content on their mobile devices. Allow students time to explore the AR tools. Troubleshoot and answer questions as necessary. Mobile devices will be provided.
11:05am-11:20am 15 min	Post – Assessment / Closing Survey Issue post-test and answer questions as needed. Once students are complete, record completion time and issue student a closing survey.	11:05am-11:20am 15 min	Post – Assessment / Closing Survey Issue post-test and answer questions as needed. Once students are complete, record completion time and issue student a closing survey.

09-17-2015
09-28-2015 rev.1

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APPENDIX J – IRB APPROVED CONSENT DOCUMENT



Protocol Number: H15307
Funding Agency: N/A
Review Type: Exempt , Category 1
Title: An Opportunity for Improving Spatial Learning in Construction Management Students by Leveraging Augmented Reality
Number of Subjects: 35

September 22, 2015
Jaiver Irizarry
College of Architecture
0155

Dear Dr. Irizarry:

The Institutional Review Board (IRB) has carefully considered the referenced protocol. Your approval is effective as of **September 22, 2015**. The proposed procedures are exempt from further review by the Georgia Tech Institutional Review Board.

Project qualified for exemption status under 45 CFR 46 101b. 1.

Thank you for allowing us the opportunity to review your plans. If any complaints or other evidence of risk should occur, or if there is a significant change in the plans, the IRB must be notified.

If you have any questions concerning this approval or regulations governing human subject activities, please feel free to contact Dennis Folds, IRB Chair, at 404/407-7262, or me at 404 / 894-6942.

Sincerely,

A handwritten signature in black ink that reads "Melanie Clark".

Melanie J. Clark, CIP
Associate Director of Research Integrity Assurance

cc: Dr. Dennis Folds, IRB Chair

**CONSENT DOCUMENT FOR ENROLLING ADULT PARTICIPANTS IN A
RESEARCH STUDY**

Georgia Institute of Technology

Project Title: An Opportunity for Improving Spatial Learning in Construction Management Students by Leveraging Augmented Reality

Principal Investigator: *Javier Irizarry, Ph.D.*

Co Investigator: *Jeff Kim*

You are being asked to be a volunteer in a research study.

Purpose:

This study is being done to find out if there are benefits from using mobile phones and mobile hand-held tablets along with “augmented reality” software when educating construction management students about visualizing objects in 3 dimensions

Procedures:

If you select to be a part of the study, we will begin with a survey and pre-test.

Following the survey and pre-test the group will be divided into two smaller groups. The first group will attend a training class to help them better understand how to visually convert objects that they see on paper and on slides into 3 dimensional images. Following the training the first group will take their second test.

Once the first group is done, the second group will do the same thing except that they will use mobile phones and hand-held tablets to assist them in converting objects they see on paper and on slides into 3 dimensional images. Following the training the second group will take their second test.

In December when you take your final exam for this class, you will have some voluntary test questions issued by your regular instructor, when you answer those test questions, the responses will be sent to me.

Risks or Discomforts:

There are NO foreseeable risks in participating in this study.

Benefits:

There will be NO direct benefit to you by participating in this study. However, there may be benefit to the construction industry in the form of increased understanding about how to better educate construction management students in the future.

Page 1 of 3
Adult Consent Template June 2012
Modified 09-03-2015



Consent Form Approved by Georgia Tech IRB: September 22, 2015 - Indefinite

Compensation to You:

There are NO compensations (monetary, grade points or favoritism) being offered for participation in this study.

Confidentiality:

The following procedures will be followed to keep your personal information confidential in this study. The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. To make sure that this research is being carried out in the proper way, the Georgia Tech IRB will review study records.

Costs to You:

There are NO costs (monetary, grade points or favoritism) to you for participating in this study.

In Case of Injury/Harm:

If you are injured as a result of being in this study, please contact Principal Investigator, Javier Irizarry, Ph.D., at telephone 404-385-7609 or javier.irizarry@coa.gatech.edu. Neither the Principal Investigator nor Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting from participation in this study.”

Participant Rights:

Below are your rights before/while participating in this study.

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.



Questions about the Study:

If you have any questions about this study, you may contact the Principal Investigator, Javier Irizarry, Ph.D. at telephone 404-385-7609 or javier.irizarry@coa.gatech.edu.

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact

Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Integrity Assurance, at 404-894-6942.

[or]

Ms. Kelly Winn, Georgia Institute of Technology
Office of Research Integrity Assurance, at 404-385- 2175.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

Participant Name (printed)

Participant Signature

Date

Signature of Person Obtaining Consent

Date



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