

THESIS

IMPLEMENTING DIGITAL VISUALIZATION TECHNOLOGY WITHIN AEC
EDUCATION:
A PEDAGOGICAL INTERVENTION

Submitted by

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ABSTRACT

As the years progressed, the discipline of architecture, engineering, and construction (AEC) continues to evolve in education and the practice due to advances in digital visualization technology—specifically in the virtual presentations. Research has shown that digital visualization influences end-users by facilitating productive and efficient communication between stakeholders in the built environment. Digital visualizations tools give the AEC professionals and the building end-users the ability to access information quickly and easily while promoting visualization of information in a three-dimensional configuration rather than multiple two-dimensional drawings.

Not only has research shown that digital visualization has influenced the professional community, but it has also changed the context in how the higher education is taught in the AEC fields of study. In today's professional society, a common fundamental skill expected in the workforce is the knowledge of the latest software technology used in the industry: such as Autodesk Revit, AutoCAD, and SketchUp. In addition, students are expected to communicate and receive information from the latest technology and understand the graphic communications in the workforce by using their spatial cognition.

Studies have shown that when individuals use three-dimensional software programs, a person's spatial cognition scientifically improves and they can mentally visualize two-dimensional, three-dimensional, and four-dimensional drawings.

By using previous studies that focus on the importance of educating students by engaging them to virtual presentations and digital formatting software, this research was tested first-year AEC students during the fall 2017 on how developed their spatial cognition is with an eight-question quiz that challenges their spatial cognition abilities. Before the pedagogical intervention

of their first-year drafting course, which incorporates with the latest industry technology, a quiz was sent to all participants of this research during the beginning of the fall 2017 semester. After the pedagogical intervention, the same eight-question quiz sent out to the same participants at the end of the fall 2017 semester to see if their spatial cognition improved from their first-year drafting course. By comparing the pre-quiz scores to the post-quiz score, this research was able to determine if the curriculum being taught is making an impact on the student and are helping them prepare for a successful career in the AEC field.

The framework for this research focused on the academia digital visualization technology influenced by the pedagogical approaches in higher education and the student's learning in the AEC higher education. This study focused on how digital visualization tools influence a student's spatial cognition within an entry-level drafting course. This was achieved with an eight-question quiz that was given to the students twice; once in the beginning of the fall 2017 semester and again at the end of the fall 2017 semester.

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DEDICATION

To my family and Brandon

Thank you for all the love, patience, and support you have given me

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CHAPTER 1 INTRODUCTION

This chapter provides a definition of spatial cognition and a brief background use of digital visualization within higher education.

1.1 BACKGROUND

As the years progress, the discipline of architecture, engineering, and construction (AEC) are changing due to advances in computer-based technology. The emerging technology of smartphones, 3D printing, mobile applications, virtual reality (VR), augmented reality (AR), drones, are just a few game-changing technologies that have impacted the industry. Specifically, one advancement that has made an enormous influence in today's AEC industry is the growing technology of Building Information Modeling (BIM). Because of the advances in computer-based technology, there have been particularly high rates of software advancements that have been observed in the area of digital visualization (Horne & Thompson, 2008, p. 6). Digital visualization is defined as using graphic aids to provide a link between images, thoughts, and text to communicate messages through visual imagery (Jessop, 2008, p. 281). Digital visualization technologies simplify communication between project stakeholders during the design, construction, and operation phases. In these phases of infrastructure creation, digital visualization promotes efficient access to information and understanding of building components through three-dimensional virtual representations.

Studies, like by Horne and Thompson in 2008, show that digital visualization is linking the connection necessary for communication between the architect, designer, engineer, and the client. The impact of the digital age has contributed to shaping the way that people communicate with one another in the architectural work environment. This has

allowed co-workers to collaborate within the design phases more efficiently (Ibrahim & Pour Rahimian, 2010, p. 978). Not only has digital visualization has made it easier to communicate with other people, but it also has made it easier to solve problems with the help of three-dimensional viewing. It has given professionals the ability to access information with greater ease as well as visualize the information in an enhanced 3D view. The use of technology and BIM has resulted in “faster delivery and advanced levels of building performance and quality than was previously possible” (Sharag-Eldin & Nawari, 2010, p. 1677). BIM has become one of the most “promising recent developments” in the industry and can produce accurate virtual models of a building that is digitally constructed (Azhar, 2011, p. 241; Sharag-Eldin & Nawari, 2010, p. 1676). It has become a primary design tool, and because digital visualization has become such an influence in the AEC industries, it has influenced the context in how the education is taught at universities in AEC related fields.

In today’s professional society, a common fundamental skill expected in the workforce is the knowledge of spatial visualization through utilization of software technology to communicate visually. To be familiar with the software that firms expect from talented graduates, a curriculum that teaches how to use visual presentations successfully is now a major aspect of education. Because of the advancements in technology and the need for new graduates with skilled spatial visualization, it is not surprising that the issue of digital visualization interventions has “divided educators and professionals” (Duarte, 2001, p. 423). Learning software programs such as Autodesk Revit to digitally render and represent a model in a three-dimensional space environment are giving the incoming students a chance to develop their spatial cognition. Now students

and seasoned professionals are more prepared to produce virtual presentations of physical space in a more successful and efficient manner.

To gain an understanding of the preparation needed for students in architectural related professions; this research utilizes an eight-question quiz and classroom pedagogical interventions on how digital visualization technology can improve an undergraduate's spatial cognition.

To give an idea how much digital visualization has influenced AEC, chapter two will discuss the observations on how today's architectural professions use technology and how digital visualization is influencing the lectures used in the universities of architecture. In chapter three, research and data are collected and analyzed to support the question on how the learning experiences of digital visualization are improving (or not improving) a student's spatial visualization. Chapter four will show the findings and interpreted results. Finally, in chapter five, there will be analyzed results and conclusion of the research.

1.2 PURPOSE OF THIS RESEARCH

The purpose of this research is to demonstrate the idea of using a pedagogical intervention within the current AEC curriculum at universities in conjunction with the latest technology utilized in the support of the theory that digital visualization will help students understand spatial visualization more effectively. The main objective of having a pedagogical intervention in the curriculum is to allow the student to have a more immersive experience with digital visualization technology, and implement the concept of spatial cognition. The ideal result of the interventions will allow the student to have a better understating of two-dimensional and three-dimensional drawings that will prepare them for their future in a construction related field.

As advances in digital visualization continue to change in the professional AEC community and practice, it has also made pedagogical approaches in AEC curriculum at the university level as well. “The ability to visualize in three-dimensional is a cognitive skill that has been shown to be important for success in engineering and other architectural related fields” (Sorby, 2009, p. 459). Because of the high demand in post-secondary graduates in the industry, it is crucial that they develop both their spatial cognition as well as their knowledge with digital visualization technology used in the AEC industry. This has brought up some important issues for AEC curriculum at universities such as; “how, when, and what type of computing to introduce into the curriculum for [AEC] education” (Horne & Thompson, 2008, p. 6). Also questions of “what are the potential benefits of [digital visualization] to [AEC] education that makes the effort of introducing into design courses worthwhile and how will one be able to measure the impact of technology on design education” (Kalay, 2009, p. 348). With these curiosities in mind, this research follows the subsequent question: How will the pedagogical intervention with advanced digital visualization technology in the current AEC curriculum improve a student’s spatial cognition?

This study would not necessarily prove, but provides strong evidence that the impact of digital visualization in AEC education, a pedagogical intervention in the current curriculum is suggested. The intervention would specifically measure the impact on a student’s spatial cognition to determine if the curriculum helps strengthen stronger spatial cognition.

CHAPTER 2 REVIEW OF LITERATURE

This chapter presents a comprehensive literature review on spatial cognition and digital visualization within higher AEC education.

2.1 HISTORY OF TECHNOLOGY IN AEC INDUSTRY

The disciplines of architecture, engineering, and construction (AEC) are changing due to advances in computer-based technology, especially in Building Information Modeling (BIM). Since the introduction of BIM, the “conjunction with other emerging digital technologies have been adopted by the building industry. It is transforming the way building and building systems are designed, manufactured, assembled, commissioned, operated, and maintained” (Sharag-Eldin & Nawari, 2010). Due to the promising advancements in technology, high rates of software advancement have been observed in the areas of digital visualization (Horne & Thompson, 2008, p. 6).

Before computers were introduced in the 1980s, professionals and AEC undergraduates hand drafted multiple two-dimensional communicate their designs. Now it has become easier in the design industry with the help of computer-aided design software. The first computers were first used for recordings and calculation tools (Yi-Feng & Shen-Guan, 2013, p. 99), but now the text interface has evolved into modern graphic user interfaces (Yi-Feng & Shen-Guan, 2013, p. 100). In the early 1970’s, computers started to slowly replace the repetitive hand drafting with paper and pencil. In return, drafting accuracy and speed improved. By the late 1980s and early 1990s, computers were “employed as a drafting tool and auxiliary tool” (Yi-Feng & Shen-Guan, 2013, p. 100). Yi-Feng and Shen-Guan continue to state that during the “PC age” of 1980-1990s, the PC ensured a widespread adoption of graphic interface and introduced with the development

of AutoCAD. This caused a shift in the industry for designers to start producing three-dimensional drawings in addition to the standard two-dimensional drawings. By the early 2000s, computers were becoming more developed to “handle more complex calculations and forms that cannot be easily rendered using compass and ruler. AutoCAD has had a significant influence on architectural design” (Yi-Feng & Shen-Guan, 2013, p. 98). This allowed more “diversity of architectural forms and shortening the construction time within the industry” (Yi-Feng & Shen-Guan, 2013, p. 98). “After the successful introduction of AutoCAD in the early 1980s, the next important change came with the implementation of network technologies” (Andia, 2002, p.7). Due to the advancement of computers and CAD, studies show that there been an increasing tendency of using these tools in architectural professional fields (Ibrahim & Pour Rahimian, 2010, p. 978; Robertson & Radcliffe, 2009, p. 136). Today, advancements with cloud computing and the internet has allowed designers and engineers to “link collaborators in different fields to databases of architectural design and virtual design with the use of BIM to construct and enhance the design planning and management process” (Yi-Feng & Shen-Guan, 2013, p. 98). All of which continues to improve to this day.

Further advancement in computers has led to the introduction of AEC focused fields such as Autodesk 3DMAX, Autodesk Revit, Autodesk Navisworks, and Sketchup, for an example. With the latest object-oriented interface software introduced to the industry, it has resulted in “faster delivery and advanced levels of building performance and quality than was previously made” with paper and pencils (Sharag-Eldin & Nawari, 2010, p. 1677). Due to the evolving computers and software, Alfred Andia, 2006, adds that the manual skills of documentation, drawings, and written reports are not imported in computers. It is important to note that the practice in AEC industries that largely use

computers; the concept of standards of plans, sections, elevations, and models remain virtually unaffected. The use of computers and technology in practice are “primarily [used] improve their effectiveness and better perform the design/build process” (Andia, 2002, p. 7).

Hand sketching and drafting are still used in the industry to develop and communicate early design ideas in the primary phase. However, regardless of its continual use in the respective professional fields, it has become obsolete. One major disadvantage in using the traditional hand drafting method is the “time consumption to model three-dimensional architectural scale models and hard-to-asses concept design scheme regarding of building surrounding environment” (Wang, Wang, Shou, & Xu, 2014, p. 445). When comparing the traditional hand drafting methods to the latest digital visualization technology, time consumption is the main drawback in hand drafting. It takes more time to hand draft a design than it is to illustrate the design using the latest technology. In addition, hand drafting also lacks the accuracy within the design and also lacks the ease it is to communicate designs with other stakeholders.

In recent years, there have been major advancement made to digital visualization technologies used in AEC fields. In the magazine, *Engineering News-Record*, there was an article titled “Game Changer” that discussed the introduction of video games being used in the professional field. The article noted that “the construction industry has widely adopted three-dimensional tools, like BIM... but video games are taking these [BIM] models to a new level of immersion” (Van Hampton, Rubenstone, & Sawyer, 2016, p 29). The article continues to demonstrate the benefits of using video games to do clash detection that helps to “identify potential problems before work is executed in the real world” (Van Hampton et al., 2016, p. 30). The companies developing digital visualization technology practice

smart risk taking with regards to technical development and product launch. This saves the construction industry both time and money this dual benefit between software development companies and AEC companies will continue to spur the innovation of digital visualization. Both industries have recognized the demand and importance of digital visualization technology.

Digital visualization technologies facilitate communication between project stakeholders during the design, construction, and operation phases. In these phases of infrastructure creation, digital visualization promotes efficient access to information and understanding of building components through three-dimensional virtual representations. To communicate and produce a successful design concept, one needs to have spatial cognition skills.

2.2 DIGITAL VISUALIZATION IN AEC EDUCATION

Advancements of digital visualization used in the AEC professional community have led to advancements in AEC higher education with the pedagogical approaches implemented specifically in the AEC curriculum. To be successful within the AEC related fields, it has been encourage by the industry that their incoming employees to be able to visualize in three-dimensional using cognitive skills. (Sorby, 2009, p. 459). Because of the high demand in post-secondary graduates in the industry, it is crucial that they know both spatial visualizations as well as digital visualization while using the latest technology and software. This has brought up some important issues for AEC curriculum at universities such as; “how, when, and what type of computing to introduce into the curriculum for [AEC] education” (Horne & Thompson, 2008, p. 6). An additional question arose of “What are the potential benefits of [digital visualization] to design education that make the effort of introducing into design courses worthwhile?” (Kalay, 2009, p. 348). Azhar,

2011, stated in his research that the use of computers and the use of BIM are widely used in the industry. 43% of architects are users of BIM; in addition, 60% of their projects are generated using with BIM software. It is also shown that contractors were the lightest users of BIM with about 45% (Azhar, 2011, p. 243). Kalay states that “the role of computers in design will continue to strengthen in the coming years, it appears an appropriate time to study fundamental issues in design education”. And just like the AEC industry, the trend of using manual pencil and paper are decreasing because of the increasing use of Computer-Aided Drafting and Design systems (Barr & Jurici, 1997, p. 9). The exposure of digital visualization in AEC education has become a necessity.

Students must now prepare for the technological advancements the professional industry has adopted over the previous four decades. Failure to do so in the educational system puts students at risk of losing their competitive advantage in job seeking as well as professional skills (Kalay, 2000, p. 349). Kalay provides a list of reasons why introducing digital visualization are necessary for AEC students and gives the students a positive impact when using digital visualization in their major courses.

1. [Digital visualization] may alleviate certain technical difficulties students may have in expressing their ideas and exploring complex architectural forms that they may not be able to express through manual methods.
2. [Digital visualization] may allow students to explore more alternatives in a shorter time period, and thereby perhaps arrive at a better solution to the design problem and better understanding of the problem itself.
3. [Digital visualization] may help students to visually and numerically understand the implications of the design decisions they make, and to better

integrate technical aspects that are typically taught in other courses into their studio design projects.

4. [Digital visualization] may let students “discover” new ideas, by removing the risk in having to reproduce the design if an approach does not pay off
5. [Digital visualization] may provide “instant feedback” at any time of the day or night

Additionally, Livingston adds that integrating BIM in education allows the students to form a to communicate graphically between two-dimensional and three-dimensional (Livingston, 2008). It helps to develop their spatial cognition. Spatial cognition is the ability to mentally visualize two-dimensional objects with three-dimensional. Spatial cognition is a critical skill used in the modern AEC professional fields. Not only does spatial cognition play an important role in design, but also creativity when working with three-dimensional forms. (Abdelhameed, 2004). “Graphic aids to spatial thinking are not new, but the emergence of digital technology has created a new medium for these tools that provides extended functionality and many new opportunities for development” (Jessop, 2008, p. 281). Due to the reasons for digital visualization in higher education, those design tools should be “gradually introduced to [AEC] students in the early course as an undergraduate in order to gain the qualitative components of visual design thinking performed in these digital environments” (Abdelhameed, 2004, p. 93). When it comes to AEC student’s spatial cognition, it has become an important skill to have in the industry.

2.3 DEVELOPING A STUDENT’S SPATIAL VISUALIZATION

Many students may be tech savvy but have a deficiency for understanding spatial visualization. The recent shift of technological advancements in AEC fields has influenced

education. Students today are becoming more and more computer software literate. Students are expected to learn more and be introduced to appropriate technologies that relate to their career discipline (Honre & Thomspson, 2008). In addition, understanding various spatial information software and formats have proven to provide a quicker way to deliver information (Dadi, Goodrum, Taylory, & Carswell, 2014). However, in order to understand the digital visualization that technology produces, students need to develop spatial visualization skills. Spatial visualization is the ability that allows the brain to manipulate an object and understand the relationship between an object in two-dimensional and three-dimensional space (Bishop, 1978). According to Bishop, the Piagetian Theory suggests that an individual is able to grasp the context of spatial visualization by going through the three stages of development for spatial visualization (Bishop, 1978). The first stage starts at an early age when children learn topological spatial visualization to understand and distinguish an object's relationship between other objects (Bishop, 1978). They can see how close they are to each other or how isolated one object might be to one another. In the second stage, an individual can take an object and understand projective representations of an object (Bishop, 1978). Ultimately, in the third stage of the spatial visualization development, an individual learns projective abilities by combining with the concept of measurement with an object. They can measure and manipulate "notions of distance, length, area, volume, and angles" (Bishop, 1978) for a certain object. To make the connection between two-dimensional and three-dimensional objects, students need to possess appropriate digital visualization tools to improve a student's spatial cognition.

The main objective of having a pedagogical intervention in the curriculum is to allow students access to immersive experience with digital visualization technology that

implement the concept of spatial visualization. The ideal result of this intervention will allow the students to have a better understanding of two-dimensional and three-dimensional drawings that will prepare them for their future careers. The ability to visualize a three-dimensional object based on a review of two-dimensional representations can be easy for some individuals; however, others have a difficult time understanding objects given their limited spatial visualization skills. “Student entering the introductory course with deficient skills in the [spatial visualization] area often get left behind others who have strong skills” (Branoff, Brown, & Devine, 2016, p. 65). It is especially a struggle for non-AEC students who are inexperienced in reading orthographic drawings that influence in spatial visualization (Yue, 2008). Because of this limitation, standardized tests were developed during the 1970’s to measure an individual’s spatial visualization ability (Branoff, 2000; Sorby & Baartmans, 2000; Yue, 2008). One of the most common tests is the Purdue Spatial Visualization Test: Rotations (PSVT:R). “The PSVT:R was devised to test a person’s ability at the second stage of spatial development” (Sorby & Baartmans, 2000, p. 301). The test consists of 30 unfamiliar objects that the end-user has to effectively understand the orientation of that object mentally and figure out the result of an object after it is a rotated number of times. PSVT:R allows for a more precise assessment of three-dimensional spatial visualization than other tests available (Branoff et al., 2016). Statistically, the scores of freshman students are typically low. The first year students on average score about 60% or less (Gerson, Sorby, Wysocki, & Baartmans, 2001, p. 106). Figure 2.3.1 demonstrates one of the problems a student might come across in the PSVT:R test. Professionals in the construction and architecture field generally often communicate with each other using graphical context (Gerson et al., 2001; Leopold, Gorska, & Sorby, 2001). In result of this, it is extremely “important for spatial

visualization abilities of students be well-developed” (Leopold et al., 2001, p. 81). Not only does the AEC curriculum need to teach spatial visualization, but also teach software

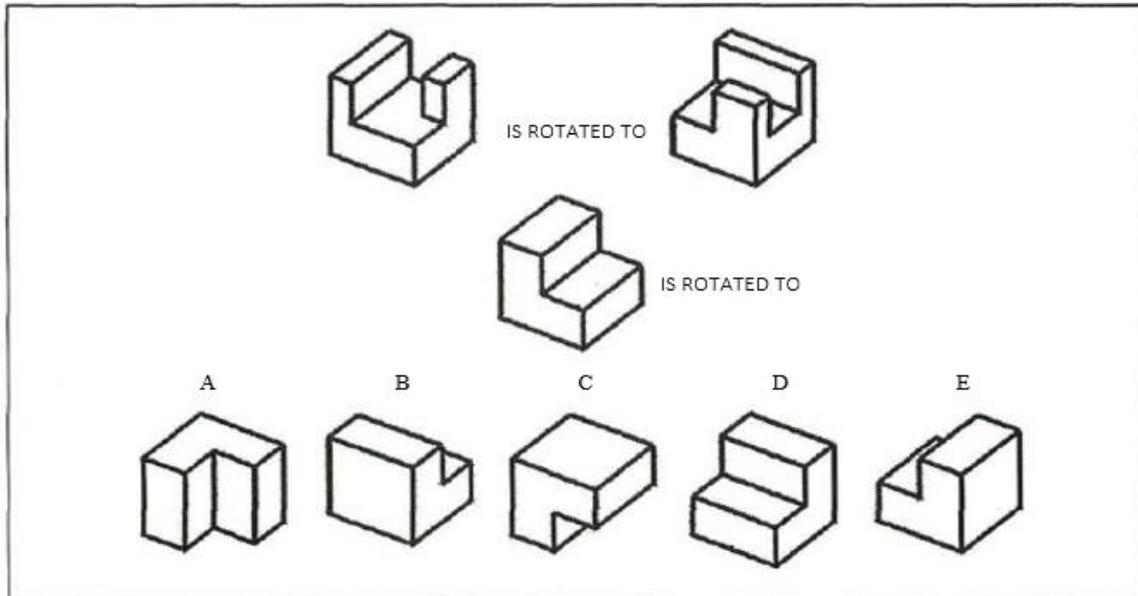


Figure 2.3.1 Example problem from the PSVT:R test and technology that is used in the professional industry to communicate.

More and more, the AEC industry requires post-secondary graduates that can use current software and the latest technology. The construction industry has started to adapt to the changes in technology by using three-dimensional tools to communicate to both professionals and clients. These technologically advanced tools use digital visualization platforms to represent the built environment. As such, this digital visualization platform necessitates the use of spatial visualization skills. It is, therefore, crucial that students can visualize three-dimensional objects when they are given two-dimensional representations. “Many professions demand a considerable amount of spatial aptitude...all find that good spatial conceptualization is not an asset but a necessity” (Bishop, 1978, p. 20). Without spatial visualization skills, it would be difficult for someone to generate and translate two-dimensional designs into three-dimensional designs successfully using digital visualization tools.

2.4 PEDAGOGICAL INTERVENTION IN AEC EDUCATION CASE STUDIES

The growing demand for graduates that are knowledgeable in BIM technology and spatial visualization are causing universities to introduce BIM in their current curriculum to help prepare the students for their future career. Sharag-Eldin and Nawari stated, “Academic institutions, however, are customarily slow to adopt changes especially if it pressured by a continuous flux of new technologies” (Sharag-Eldin & Nawari, 2010, p. 1677). Sharag-Eldin and Nawari continue to add, “The speed at which curricular changes take place in universities and the efforts needed to maintain professional accreditation limits the ability of architecture and engineering programs to match the speed at which the AEC industry is advancing in this arena [of technology]” (Sharag-Eldin & Nawari, 2010, p. 1677). Many AEC programs balance the demand to implement technology with the foundational need to teach principles of AEC. The question is often, should instructors seek to match technological advancements and to what extent?

Before universities know how to include technology, there needs to be an understanding of spatial visualization. To know where a student’s spatial cognition stands, there have been many variations of testing a student’s level of spatial visualization. There have also been many attempts to strengthen a student’s level of spatial visualization. In 1993, Dr. Sheryl A. Sorby developed several curriculum materials, with the assistances of Beverly J. Baartmans, for the first-year engineering students to help improve undergrad students’ spatial visualization skills by inserting a pedagogical intervention in the current AEC curriculum. The intervention focused on using current software and technology that could help a student’s development of spatial visualization. To successfully execute a pedagogical intervention in a classroom, graphic aids, like digital visualization, help communicate what a student is imagining. Typically, the structure of a classroom usually

follows the format of two-hour lecture followed by a two-hour lab. It is often difficult for instructors to lecture the material and demonstrate the technology. So, with the time they are given, typically they provide a lab portion where the students learn hand drafting then to proceed to learn the use computer-aided-design (CAD) software that incorporates spatial visualization. Taking a typical ten-week semester course, Dr. Sorby introduces spatial visualization by discussing the basics in logical order for a student to develop spatial visualization (Sorby & Baartmans, 2000). In the beginning of the semester, Dr. Sorby gave the students the PSVT:R test to the students. As Dr. Sorby predicted, the scores were low. She would later give them a similar PSVT:R test at the end of the ten-week semester after she gave an introduction to spatial visualization with various construction activities that included both pencil and paper, as well as computer software exercises. After the semester was over, the post-course PSVT:R scores have improved significantly compared to the pre-course score of 50% (Sorby & Baartmans, 2000) and it continued to improve as the engineering course continued six years later as shown in Figure 2.4.1 (Sorby and Baartmans, 2000, p. 304).

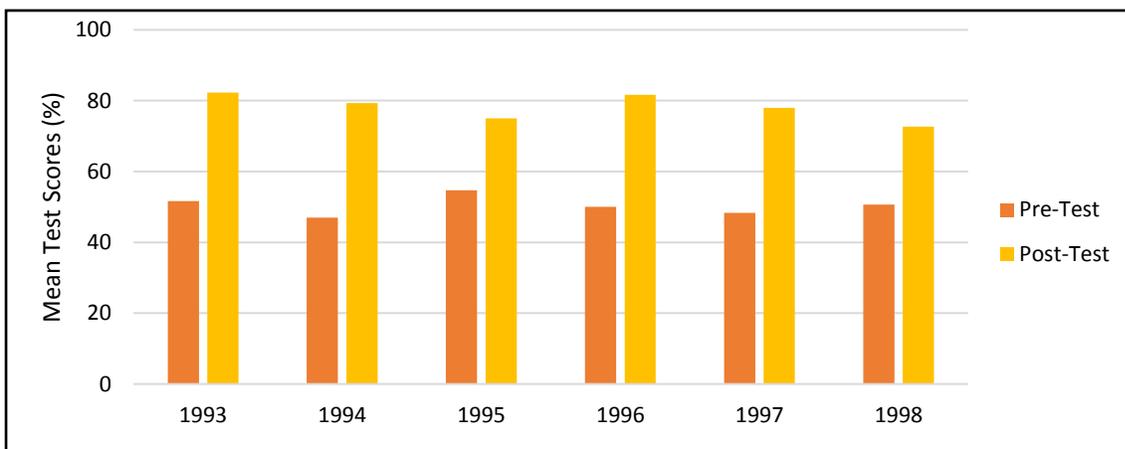


Figure 2.4.1: Test scores from Sorby and Baartmans' study in 2000.

Similar to the intervention of technology in the classroom from 1998, current technologies are revolutionizing the transitions of understanding how two-dimensional space graphically be communicated to three-dimensional objects. This understanding is not only occurring in the United States. The United States has been making efforts in trying pedagogical interventions in higher education to strengthen a student's spatial cognition, but the United Kingdom is also realizing the effects of technology in both the professional fields and in the education systems. The UK has noticed that there was a shortage of case studies about pedagogical teachings regarding BIM in the UK at a higher level (Adamu & Thorpe, 2016,). In 2010, studies done by Barison and Santos, studied about twenty-five AEC programs, all at different locations throughout the United States, and found that some universities have taught some form of the BIM technology with their introductory courses, as well as their intermediate and advanced course (Barison & Santos, 2010). Even though the studies took place in the United States, the UK arguably thought that to make the most impact on the student's ability to use digital visualization tools that incorporated BIM, needed early influence in the undergraduate level, preferably beginner's level. As a student proceeds through the program, more information and techniques would add to strengthen their ability. However, Adamu and Thorpe believe that universities need to plan, phase, and prioritize when developing digital visualization with BIM into the curriculum. "New BIM-focused modules may be necessary to teach concepts and skills like coordination of multi-disciplinary three-dimensional BIM models..." (Adamu & Thorpe, 2016, p. 119). Adamu and Thorpe also suggest that higher education curriculum should be developed through student-centered learning methods. They also mention that there are so many resources that are "free and professionally

made that help provide additional learning” to help, not only the students but professors on learning the latest software (Adamu & Thorpe, 2016, p. 119).

Even if the instructor does not feel comfortable teaching a program that they are not familiar with, there are multiple ways to educate the students. Adamu and Thorpe feel that there is no excuse for higher education suppress the latest technology in the educational system because of the abundance of resources that is accessible to instructors. To test their theory that teaching BIM can be accomplished with the resources provided for both the instructors and the students, Adamu and Thorpe did a case study at Loughborough University, located in the United Kingdom. The exercise began with showing the instructors the literature reviews that showed the benefits of pedagogical approaches with technology in higher education. Afterward, a discussion of the instructor's concerns and needs regarding BIM. For the most part, the biggest concern was the lack of knowledge with the latest digital visualization technology.

To resolve the lack of BIM knowledge held by instructors, two phases were formed to prepare them for BIM education. Phase one was embedding BIM in priority modules. To accomplish this, it was mapped out with existing framework of previous years of studies with various programs to prove the positive outlooks with using digital visualization, like BIM, in the curriculum. Moving onto Phase two, the goal was to raise awareness and implement various teaching resources for BIM technologies that could be taught. Phase two was completed in a five-day span workshop with students in their final year participating in the workshop. The goal of phase two was to show how actual students could learn the latest technology with existing resources. Within the workshop, there were in-house video tutorials that demonstrated how to use BIM digital visualization programs and mini exercises that corresponded what they just learned. After the

completion of two phases, an evaluation of the tutorials with a survey was sent out to the students that partook in the workshop. In Figure 2.4.2 shows a line graph on the student's evaluation of the video tutorials that they were given in the workshop (Adamu and Thorpe, 2016). The student's comments about the tutorials stated, "They would have to watch a specific video clip twice before properly understanding the task involved" (Adamu and Thorpe, 2016, p. 120). This case study shows that having an intervention early on in a student's coursework would benefit them in the end.

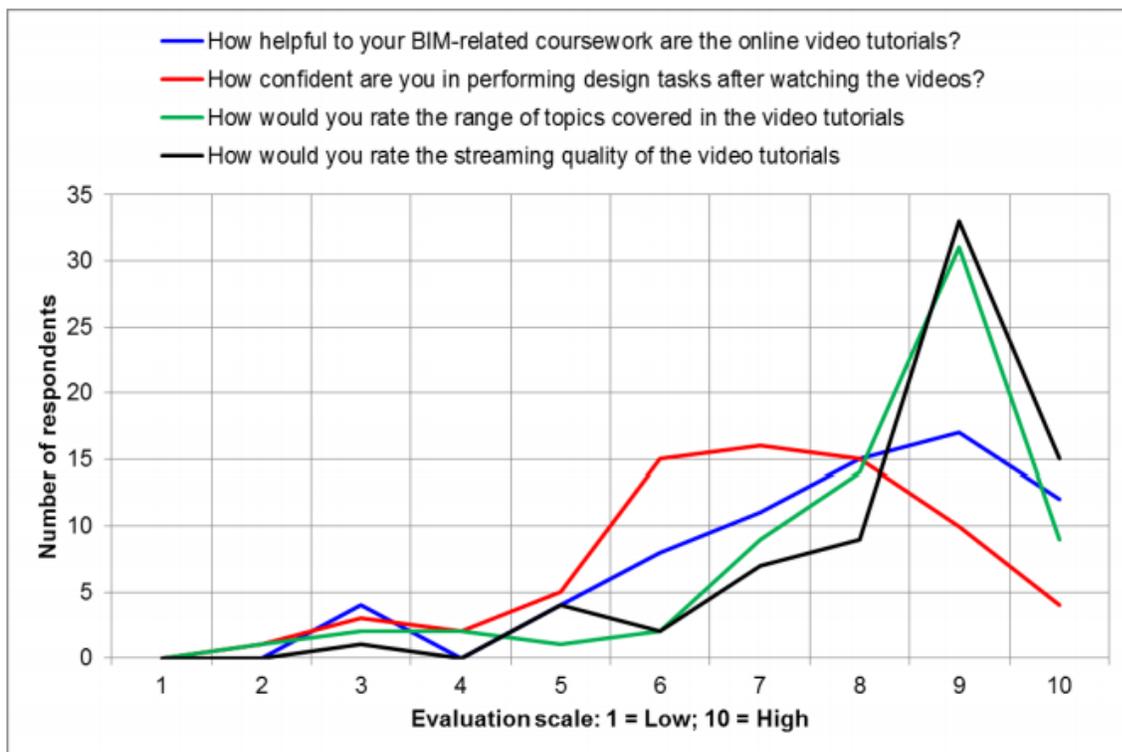


Figure 2.4.2 Student's evaluation of how video tutorials helped them with BIM

The next phase of this case study was to create modules and exercises dedicated to digital visualization with BIM software that correspond to the lessons taught in the classrooms. This case study's purpose was to stress the importance of digital visualization in the current curriculum. Also, the study's main drive was to show that the lack of

experience as an instructor is an unacceptable justification to not incorporate technology due to all the resources that are easily accessible. “The teaching of BIM could be approached in many ways and there are several options that can be pursued as suggested...this study is aimed at providing an overview of the implicit and explicit consequences of introducing BIM in multi-disciplinary schools” (Adamu and Thorpe, 2016, p. 119). To prepare for embedding digital visualization, Adamu and Thorpe suggest that there needs to be planning to prioritize the industry needs that support the student’s future in the industry that will get a positive outcome for the students.

In addition to the case studies mentioned above, it is obvious that technology continues to influence how AEC education is taught. In the school’s newspaper at Colorado State University, the impact of technology has been noted and suggested that universities should start embracing it and use it in the current curriculum. One of the current advancements in technology is the use of virtual reality (VR). VR is able to use a computer generator to simulate a three-dimensional image that can be interacted by the user (Horne & Thompson, 2008, p. 7). Connor Deblieck, who wrote the article in Colorado State University newspaper, *The Rocky Mountain Collagen*, strongly believes that “By allowing more hands on and immersive experience with three-dimensional objects, the virtual reality initiatives hopes to implement this concept into the education curriculum” (Deblieck, 2016, p. 3). VR is not the only piece of technology that is impacting the AEC fields. Along with VR there is augmented reality, smartphones, and drones. The main point that is a common theme in all the case studies is that technology has a way to help students understand three-dimensional spatial visualization.

The world of technology is changing in the AEC industry which, in return, is also changing how architecture, engineering, and construction is being taught. Chen and others

state that from an engineering perspective, the “education required to build up the spatial ability of students will assist them in transferring” (Chen, Chi, Hung, & Kang, 2011, p. 267) objects that will help them be successful in future courses and in their careers. In theory, gaining the skill of spatial visualization and knowing the latest technology and software is needed to be qualified for most entry-level AEC jobs. The curriculum in AEC courses should consider being reassessed to introduce both spatial visualizations with the use of the latest technology.

CHAPTER 3 METHODOLOGY

This chapter addresses the context of the research as well as the study population, sample size, research instruments, data gathering procedures, and statistical treatment of the data.

3.1 THE RESEARCH PROBLEM

Within the AEC industry, many companies are searching for graduates that have the spatial cognition skills needed to translate two-dimensional drawings, along with, three-dimensional drawings. In addition to the spatial cognition skills, it is also crucial for the graduates to have some understanding of the latest digital visualization technology that is commonly used in the industry. In consideration of this demand for students to have a strong spatial cognition set of skills, the current AEC curriculum provided has sufficient training to teach the AEC students to strengthen their spatial cognition.

3.2 THE RESEARCH QUESTION

In consideration of the research problem, the research question asks, are the AEC programs that are being taught in universities improving a student's spatial cognition skills that are required in the modern AEC industry?

Within the AEC programs, there are numerous courses for students to choose from. However, for this research, the main focus will be on the undergraduate students, who are majoring some aspect of AEC, and looking deeply into how their first-year drafting course is helping them develop their spatial cognition skills.

By quizzing the students before their drafting course begins with a simple spatial quiz, and again after they have completed their semester's drafting course. By comparing

pre-quiz and post-quiz scores, this research will get a perspective if the latest technology that is being used in the AEC curriculum helps improve a student's spatial cognition.

3.3 HYPOTHESIS

The hypothesis for this study is that AEC students who enroll pedagogical intervention will show improved spatial cognition scores over students who do not enter pedagogical intervention. Inversely, the null hypothesis is that there is no significant difference in spatial cognition improvement for students who enter the pedagogical intervention compared to those students who do not.

3.4 CONTEXT FOR RESEARCH

This study was quantitative, in nature. The finished intention of this research was to leverage it as a resource towards understanding the development of an AEC student's spatial cognition within their first-year drafting course. While the AEC disciplines consist of multiple communities and sub-communities, they all are expected to communicate with an understanding of drawings with their advanced spatial visualization abilities. In order to prepare a student in any AEC program, there needs to be an educational discipline that enforces the use of digital visualization tools to help explore a student's spatial cognition. The intent is that those graduates will be able to visualize two-dimensional to three-dimensional drawings with ease.

To determine if the curriculum, specifically in an entry-level drafting course, has any impact on how a student strengthens their spatial cognition, an eight-question quiz was created. The quiz's main objective was to measure and score a student's spatial cognition. The quiz was given to selected AEC majors during the first week of their first semester of their drafting course.

The pedagogical intervention was the student's entry-level drafting course during that semester. After the student's semester drafting course has ended, the same eight question quiz was given to the same AEC majors and students to compare a student's spatial cognition results from the beginning of the semester.

To test the hypothesis that a student's spatial cognition improves with the assistance of their entry-level drafting course that engages them with the latest visual technology, a quiz that challenges their spatial cognition was used. The quiz was created using the online website application, Qualtrics. Qualtrics is most known for creating online surveys. The Qualtrics template was used to formulate an assessment, which was administered to students by sending the URL via email. This facilitated easy participation by allowing participants from various locations throughout the country.

3.5 SETTING AND PARTICIPANTS

The setting and participants of this study consisted of students that are majoring in the disciplines of construction ($n=100$), interior design ($n=94$), and architecture ($n=50$), as well non-AEC majors ($n=31$). By studying the non-AEC students ($n=31$), this allowed a comparison between a major that tends to have a high cognitive visualization career requirement, like an architect, between a major that may not have that high cognitive visualization career. The entry-level drafting courses that were the focus of this study were from three different universities throughout the United States; Colorado, Oklahoma, and Wisconsin. The courses at these universities were all AEC focused, with the exception of an English entry-level course as a non-AEC major, and all are listed in the 100-level range. The AEC courses mainly focuses on using graphic communications, using pictorial images, to communicate between the professor and student. This is usually done by hand drafting or using digital software to draft a design. In addition, all courses are taught at an

undergraduate level specifically for freshmen students; however, there were a few upperclassmen, such as sophomores and juniors, who did take these level-100 courses during the time of this study. Table 3.5.1 lists the enrollment of the potential participants of this study and what drafting course they were in during the time of this study.

Prior to the administration of the assessment, all the students and faculty participants provided consent to the assessment to be administered. In addition to the student's and professor's agreement for the assessment, the correct procedure followed to obtain the Institutional Review Board (IRB) approval for the study.

As IRB protocol, a statement that guaranteed that all personal identification of participants taking this quiz is anonymous and their answers are strictly confidential. The results from the quiz will only be viewed by the research team of this study. As approved by the IRB, the students that accept the terms and conditions in the consent form will be the only students included in the study.

To get a more diverse set of students, the study compared five different visual-based majors; construction, architecture, engineering, landscape design, and interior design, that were enrolled in one of the four entry-level drafting course during the 2017 fall semester. The courses for this study were taught at the University of Wisconsin-Stout's interior design department (DES 114, Interior Design Communication Tools), University of Oklahoma's construction department (CNS 112, Cultures of Collaborating, Creating, and Construction), and Colorado State University's construction management department (CON 131, Graphic Communications for Construction) and the interior design department (INTD 166, Visual Communications-Sketching). In addition to the majors listed above, an additional course from University of Wisconsin-Stout was studied; English 121, Introduction to Professional Communication. The inclusion of the English

121 course allowed a comparison between a non-visual major versus a visual major, like construction management.

Table 3.5.1: Potential Participants for the study

University	Course	Description of the Course	Total # of Students Taking the Course	Type of AEC Majors taken the Course	Digital Visualization Software Used?
Colorado State University	CON 131- Graphic Communications for Construction	Reading Technical Drawings, 2D/3D visualization, manual drafting techniques, introduction to design software applications.	100	-Construction -Landscape Design -Interior Design	Revit AutoCAD
Colorado State University	INTD 166- Visual Communication- Sketching	Hand drafting, free hand sketching, and conceptualization to communication for interior design concepts and visualizing 2D/3D representations.	50	-Interior Design	Revit AutoCAD SketchUP
University of Oklahoma	CNS 112- Cultures of Collaborating, Creating, and Construction	Providing an introduction to foundations of the various planning, design, and construction disciplines.	50	-Architecture -Construction -Engineering	AutoCAD
University of Wisconsin-Stout	DES 114- Interior Design Communication Tools	Introductory study of the design process, software and communication tools used within interior design industry.	44	-Interior Design	AutoCAD Revit
University of Wisconsin-Stout	ENGL 121- Introduction to Professional Communication	Trends, opportunities, and technologies shaping the field of professional communication. Career path and specializations as well as ethical responsibilities.	31	-Non-AEC	None
TOTAL # OF POTENTIAL PARTICIPANTS			275		

3.6 SAMPLING PROCEDURE AND SAMPLING SIZE

The URL to the online assessment was delivered via email to the professors of the entry-level drafting course. From there, the professors sent the URL to their students for their students to take the quiz. In the best-case scenario, pertaining to all the sections and courses participating. The total student participants were $n=275$ students. To comply with IRB standards, the professors distributing the quiz assured the students that the quiz was voluntarily and can respectfully decline the quiz. In addition, the students must take the quiz during their own time outside of class without the assistance of their professor. Because of this, it caused a certain number of students ($n=71$) to choose to not participate in the quiz.

The initial questions on the assessment were demographic questions such as; birthday, gender, ethnic, level of education, and major. To help us associate each student's pre and post responses to the quiz, they were also asked to give their last four digits of their phone number. The phone number and the demographic answers allowed the researcher of this study to give each student a pseudocode and this also allowed a comparison of their scores from the pre-assessment administered at the beginning of the semester and the post assessment, administered at the end of the semester. This method facilitated an evaluation of the effectiveness of the entry-level drafting course.

The quiz took approximately ten to fifteen minutes to complete. The question's difficulty ranges from easy to more challenging towards the end of the quiz. The purpose of this quiz was to gain insights of the level of a student's spatial cognition before their pedagogical intervention of their drafting course, and again after they have completed their semester drafting course.

Examples of each question will be given one simple geometric shape with the question asking the student to mentally rotate that shape in increments of 90 degrees either in the positive (counterclockwise) or negative (clockwise) direction around a certain axis (X, Y, Z axis). See Figure 3.6.1 for an example.

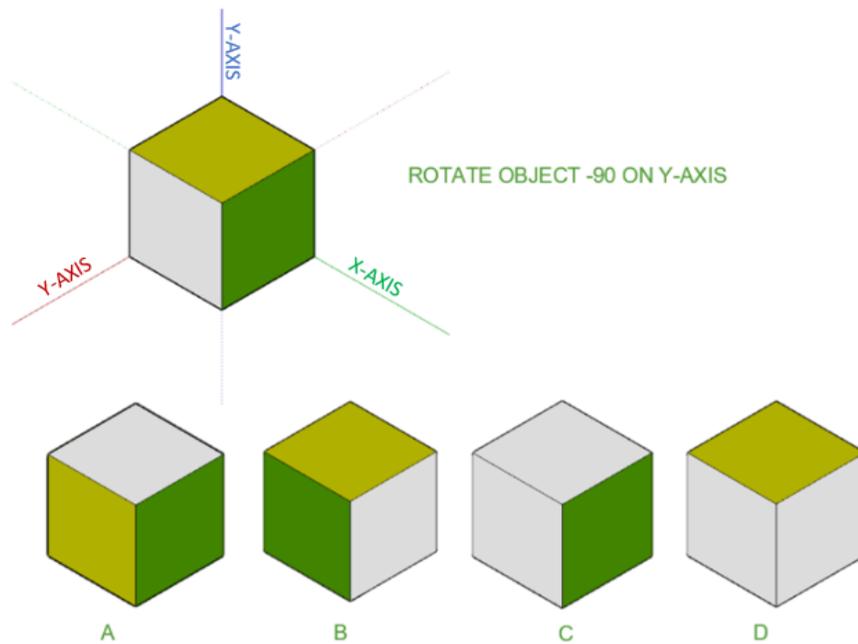


Figure 3.6.1: Example question from the quiz

Below each question will be four possible choices with one being the correct answer. The end-user taking this quiz must mentally rotate said shape and figure out which one of the four possible answers it could be. Included with each answer, the student will be asked to state their confidence level in their answer. Figure 3.6.2 shows the Likert scale of confidence level. In addition to the question with the correct answer and the confidence level, each question is timed. The end-user will not know that they will be timed on the quiz. The timer is not visible nor mentioned in the mini-quiz, only the research team of this study can see how long each question takes the participant. Not only did the research team see how long it took for the students to answer the questions, but it

also showed how many times they changed their answer. All this data was crucial when we started our data collecting.

.. On the scale below, please indicate your level of confidence in your answer to this shape rotation question:

(1 = "Not Confident At All" and 10 = "Very Confident")

Not Confident At All										Very Confident
1	2	3	4	5	6	6	7	8	9	10

How confident are you in this answer?



Figure 3.6.2: Likert scale of a student's confidence level

To introduce the students to the types of questions that they will be solving mentally throughout the quiz, the quiz started out with an easy question that is demonstrated in Figure 3.6.1. The question takes a simple box shape that has three colors to distinguish each side. The question then asks to rotate the shape 90 degrees on the Y-Axis. Four possible choices with one being the correct answer will be listed directly below the question. The student had to mentally solve the question on their own.

After they were introduced to what they will be expecting, the colors of each side of the shape will disappear and only be one solid-colored geometric shapes were the primary focus of the quiz. The questions began the same in regard to mentally rotating the shape in increments of 90 degrees around a specified axis. As the student progressed in the quiz, the questions got more challenging by inserting more complex shapes. Figure 3.6.3 shows an example of a more complex shape without the color sides that was given in question one.

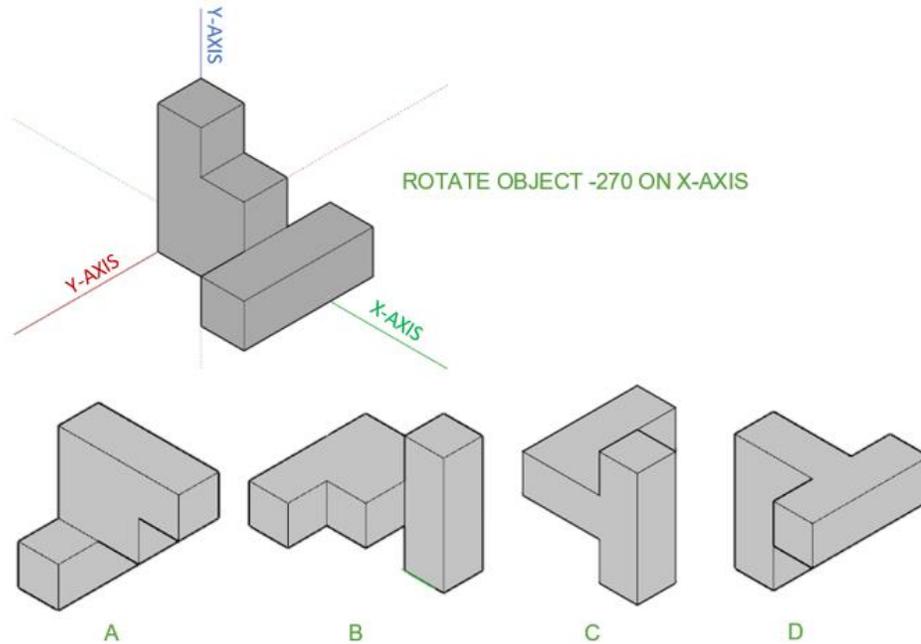


Figure 3.6.3: Example question from the quiz

It is worth noting that solving geometric shapes is not something that a student relates to in a major that primarily focused on residential and commercial building floor plans, elevations, building sections and perspective views. Being as it may, the last two questions focused on an extension of what they will be experiencing while they pursue their degree and enter the professional field. The question showed a simple residential floor plan and ask what would be the North elevation. There were four choices, like the geometric shapes, with one choice being the correct answer. The end-user taking the quiz had to cross-reference the floor plan with the four elevations to identify the correct answer. Again, the students had to state their confidence level in each question with the ten-point Likert scale.

The last question in the quiz was a bit more challenging. The question provided a residential floor plan with the kitchen shaded. The question asked which of the four perspective drawings provided was correctly depicted based on a specified point of view,

as shown in Figure 3.6.4. Again, there were four choices with one being the correct answer. The student had to visualize the space by referencing the floor plan. Consistent with the previous questions, the students were asked to give their confidence level with the ten-point Likert scale. In addition to the student's chosen answer and confidence selection, a box was provided for the end-user to type out their reasons of choosing their answer. This allowed the research team to gain an understanding if the end-user can comprehend the floor plan and utilized deductive reasoning to eliminate the wrong answers. Similar to the previous questions, question eight was also be timed. The quiz as a whole took roughly 20 minutes to complete.

After the quiz is completed, the data was automatically recorded online, and the research team of this study was able to access all responses through Qualtrics online.



A



B



C



D

Figure 3.6.4: Example question from the quiz

3.7 TOOLS OF DATA COLLECTING

Qualtrics was used to organize and assess the quiz data. The Qualtrics website allowed the research team of this study to see participant's quizzes individually or collectively as a whole group. Qualtrics provided additional analytic tools to establish average scores, the time it took to complete the quiz, and the average confidence level per question.

Data was collected two times during the fall 2017 semester: one month into the beginning of the semester, and again within the last week of the same fall 2017 semester. An identifier was created by recording the student's last four digits of their cell phone number. In this manner, the pre-quiz and the post-quiz could be associated with a single respondent. After the research team collected both sets of data, the individual's pseudocode was cross-referenced single quiz participants with single-quiz participants eliminated from the dataset, the sample size was determined at $n=275$ that consisted of AEC majors ($n=244$) and non-AEC majors ($n=31$).

3.8 OUTLIERS

This study followed a purposeful sampling of the population, which included students enrolled in AEC majors and specific courses in entry-level drafting. The sampling also included a non-AEC course (English 121), which was considered a potential baseline for future comparison. The literature review of this study presented a few of the spatial cognition tests that already exist, but this study utilized the existing Purdue Visualization Spatial Test: Rotations (PVST:R) test. For students who participated in the study, quiz scores were analyzed in how well they did in terms of percent correct. In addition to the student's quiz scores, the duration of how long it took to complete the quiz and their

confidence in their answers from a Likert Scale were also analyzed. The student's quiz time data was recorded because it was a potential for their effort.

In any study there is an expectation of outliers which have the potential to adversely impact the results. The potential outliers that could arise in this study include, 1) students who did not complete the quiz, 2) students who only participated in one of the two tests, 3) students whose total time to the quiz was too excessive. The conclusion of an excessive total time to complete the quiz suggested that the students were not focused entirely on the quiz and had other distractions. Two standard deviations from the mean of the total time to complete was established as the standard for elimination outliers.

After the outliers were determined, the responses were removed from the set of data and the remaining data was further analyzed for this study.

The assumption of this study is that students that take the pre-quiz will have lower scores and lower confidence in their answers compared to their scores and confidence after receiving the intervention. After the pedagogical intervention of their graphic communications course, the scores were expected to improve as well as their confidence level in their answers with the post-quiz results. Students that took the drafting courses were expected to perform higher in the post-quiz scores than students who do not have exposure to digital visualization tools, such as non-AEC major students. A sample t-test was used to analyze the mean score difference between AEC major students to non-AEC major students. Satisfactions for pre-quiz scores, post-quiz scores, time duration, and confidence level were analyzed. A probability level of $p < 0.05$ was used to compare the t-scores and reject the null hypothesis. P values, $p < 0.05$, suggested a significant difference between AEC and non- AEC students quiz scores, duration, and confidence level. Non-AEC students were expected to have minimal improvements in pre and post quiz results as

well as confidence level because they did not experience pedagogical intervention. AEC major students were expected to show improvements in both confidence level and quiz scores due to digital visualization exposure during their drafting courses.

CHAPTER 4 RESULTS

This chapter presents the results of both pre-pedagogical intervention and post-pedagogical intervention from the fall semester of 2017.

4.1 PARTICIPANTS USED FOR THIS STUDY

275 pre-quizzes were sent out at the beginning of the 2017 fall semester to the 275 potential participants enrolled in various AEC disciplines and non-AEC disciplines. Starting late August and a couple of weeks after into the 2017 fall semester, the quiz was locked—it could no longer be accessible to any student.

Then, in late November of 2017, a post-quiz was sent to the same 275 students from the beginning of the 2017 fall semester. The post-quiz had identical questions to the pre-quiz, the pre-quiz answers were not previously revealed to enable a 1:1 comparison of answers between pre and post quizzes. This allowed for direct observation of the growth of spatial cognition quiz scores after a semester, the pedagogical intervention of this study.

The pre-quiz and the post-quiz both occurred during the 2017 fall semester. During this time period, the students were exposed to their pedagogical intervention. 244 AEC students were enrolled in one of four entry-level drafting courses (CSU CON 131, CSU INTD 166, OU CNS 112, or UW-STOUT DES 114) and 31 non-AEC students were enrolled in an entry level English course (UW- STOUT ENGL 121) during the 2017 fall semester. Within AEC students' first-year drafting course, they were exposed to various digital visual digitalization tools such as; Autodesk Revit and AutoCAD.

This study was similar in nature to the research done previously by Dr. Sorby and Dr. Baartmanns in the 1990's. Both Dr. Sorby and Dr. Baartmanns observed that using digital visualization tools in a classroom setting did help improve a student's spatial

cognition. However, in Dr. Sorby and Dr. Baartmanns, they did not compare how a spatial cognition improves compared to a student who is not exposed to such technology that allows spatial cognition to strengthen. So, by having the AEC students enrolled in a drafting course that utilized such technology and having non-AEC students enrolled in a course that typically did not, it allowed this research to have an experimental group (AEC students) and a controlled group (non-AEC students).

Considering that this study focused on the student's spatial cognition improvement after their entry-level drafting intervention, this research collected data from students who partook in both the pre-quiz and post-quiz. To determine if a student took both sets of quizzes, the student's last four digits of their phone number was recorded in the beginning of each quiz. This gave every participant an identifier, which was used to cross-check whether that particular student both sets of quizzes.

Initially, there were 275 potential participants for this study, however, out of those 275 students, 113 students would be used for this study due to students either doing one of three things. More than half of the students were eliminated ($n=162$) from the study for one of the following two reasons: (1) not completing the quiz for the second submission at the end of the semester, (2) they respectfully declined to take the quiz. After the eliminating data from students that did not fit the criteria, 113 participants (AEC $n=98$ and non-AEC $n=15$) were utilized for the final analysis.

Even though the study did not focus on the demographics specifically, it is important to note who the population of this study consisted of.

Out of the 113 full participants, the data found that the student's ages during the time of this quiz ranged from 18-42 years of age ($m = 20$, $SD = 2.90$). The population's ethnicity was mostly White (68.7%) with Asian/Pacific Islander (9.1%), Native American

(6.1%), Hispanic/Latino (9.2%), Black/African American (0.8%), and along with other ethnicities not described (6.1%).

As for the gender of the 113 participants, 52.2% males and 46.0% females and 1.8% preferred not to respond or considered themselves another gender. Within the sample size, Table 4.1.1 breaks down the population by majors and the gender of the students that took the pre-quiz at the beginning of the semester.

Table 4.1.1: Pre and Post quiz of the participants by majors and gender

Major	<i>n</i>	Males	Females	Other
AEC	98	53	44	1
Construction	34	31	3	0
Interior Design	24	2	21	1
Architecture	33	18	15	0
Environmental Design	5	0	5	0
Engineering Related	2	2	0	0
Non-AEC Related	15	6	8	1
Total	113	59	52	2

To determine if any previous drafting exposure could alter the quiz scores, the quiz began with a question asking if the student had taken a course with drafting experience in the past—a total of 22 (19.5%) students stated that they had some sort of prior drafting experience. Broken out of the 98 students in AEC, 19 students (19.4%) had prior drafting knowledge and out of the 15 non-AEC students, 3 students (20.0%) had prior drafting

knowledge before enrolling in their 2017 fall semester intervention. This was considered in the final analysis, but was not a factor in the outcome due to the fact it did not have a significant difference in the data results.

4.2 ANALYZING RESULTS FOR PRE-SCORE

This study compared the pre and post quiz average score, and average confidence level between AEC students and non-AEC students.

In completion of the eight-question pre-quiz, the average score for AEC students was 54.3 % correct on the pre-quiz with an average confidence level of 6.83 ($SD = 1.68$). As for the non-AEC students, the average pre-quiz score was 41.3% correct with an average confidence level of 5.64 ($SD = 2.10$). Table 4.2.1 compares the overall AEC and non-AEC student pre-quiz statistics. Pre-quiz individual question results are provided in Table 4.2.2 for the AEC students and Table 4.2.3 for non-AEC students.

Table 4.2.1: Overall pre-quiz percent correct and confidence level

Major	Quiz Score (%)		Confidence Level	
	<i>m</i>	<i>SD</i>	<i>m</i>	<i>SD</i>
AEC (<i>n</i> =115)	54.3 %	0.24	6.83	1.68
Non-AEC (<i>n</i> =10)	41.3 %	0.13	5.64	2.10

Table 4.2.2: Pre-quiz results for each question on the quiz for AEC students

Question Number	Correct (%)	Confidence Level (1-10)	
		<i>m</i>	<i>SD</i>
1	66.0 %	7.10	2.03
2	35.0 %	6.51	2.19
3	46.0 %	6.15	1.99
4	55.0 %	6.49	2.49
5	38.0 %	6.05	2.37
6	48.0 %	6.51	2.18
7	83.0 %	7.77	2.34
8	65.0 %	7.99	2.10

Table 4.2.3: Pre-quiz results for each question on the quiz for Non-AEC students

Question Number	Correct (%)	Confidence Level (1-10)	
		<i>m</i>	<i>SD</i>
1	67.0 %	5.30	2.06
2	20.0 %	5.80	2.15
3	40.0 %	5.20	2.86
4	40.0 %	5.40	2.41
5	33.0 %	4.90	2.64
6	20.0 %	5.80	2.49
7	60.0 %	6.20	2.74
8	40.0 %	6.50	2.46

4.3 ANALYZING RESULTS FOR POST-QUIZ

After analyzing the post-quiz results, the average percent correct on each question for AEC students was approximately 57.3% correct, a 5.2% increase. For the post-quiz confidence level, the AEC students had an average of 7.38 ($SD = 1.64$), an 7.4% increase.

As for the non-AEC students, the average post-quiz percent correct was 48.8% correct, a 15.4% increase. For the confidence level, non-AEC students had an average of 6.71 ($SD = 1.88$), an 16.0% increase. Table 4.3.1 shows the overall post-quiz scores and confidence level for both AEC and non-AEC students. Descriptive statistics for each individual question on the post-quiz are provided in Table 4.3.2 for the AEC students and Table 4.3.3 for the non-AEC students.

Table 4.3.1: Overall post-quiz percent correct and confidence level

Major	Quiz score (%)		Confidence Level	
	M	SD	M	SD
AEC	57.3 %	0.23	7.38	1.64
Non-AEC	48.8 %	0.28	6.71	1.88

Table 4.3.2: Post-quiz results for each question on the quiz for AEC students

Question Number	Correct (%)	Confidence Level (1-10)	
		<i>m</i>	<i>SD</i>
1	73.0 %	7.48	2.04
2	34.0 %	7.26	2.21
3	40.0 %	6.67	2.32
4	59.0 %	7.58	2.12
5	43.0 %	6.51	2.53
6	37.0 %	6.98	2.28
7	83.0 %	8.33	1.99
8	70.0 %	8.31	1.84

Table 4.3.3: Post-quiz results for each question on the quiz for non-AEC students

Question Number	Correct (%)	Confidence Level (1-10)	
		<i>m</i>	<i>SD</i>
1	67.0 %	6.50	2.27
2	27.0 %	6.40	2.07
3	27.0 %	6.80	2.44
4	47.0 %	6.60	2.22
5	40.0 %	5.80	2.15
6	13.0 %	6.20	2.39
7	73.0 %	7.90	2.77
8	40.0 %	7.50	2.17

4.4 COMPARING AEC AND NON-AEC STUDENTS

Comparing AEC students to non-AEC students, both groups increased their post-quiz scores, however, AEC students obtained higher scores for both the pre-quiz and the post-quiz than the non-AEC students. For the pre-quiz, AEC scored 13.0% higher than non-AEC students and for the post-quiz, AEC students scored 8.5% higher than non-AEC students. Score improvements increased for both student groups, however, surprisingly, non-AEC increased their post-quiz score by 15.4% from their pre-quiz, whereas, AEC students increased their post-quiz score by 5.2%. Figure 4.4.1 graphically shows the groups increased in quiz scores. It is important to note, that the non-AEC student's population was only 15 students, where AEC had 98 students, so the non-AEC student's results weighted heavier than AEC student's results.

In addition to the increased quiz scores, both groups also increased their confidence level in the post-quiz. Non-AEC students had the greatest increase in

confidence level (16.0%), little more than double the increase of AEC students (7.4%). Similar to the results of the quiz scores, non-AEC had the greatest increase, but AEC students had a higher pre and post-quiz confidence level compared to non-AEC. For the pre-quiz, AEC students had an average of 6.83 confidence level, 21.1% higher than non-AEC student's confidence level ($m=5.64$).

As for the post-quiz, AEC students had an average confidence level of 7.38, about 10.0% higher than non-AEC student's post-quiz confidence score ($m=6.71$). See Figure 4.4.2 which compares the two groups on their confidence levels for both the pre and post quiz.

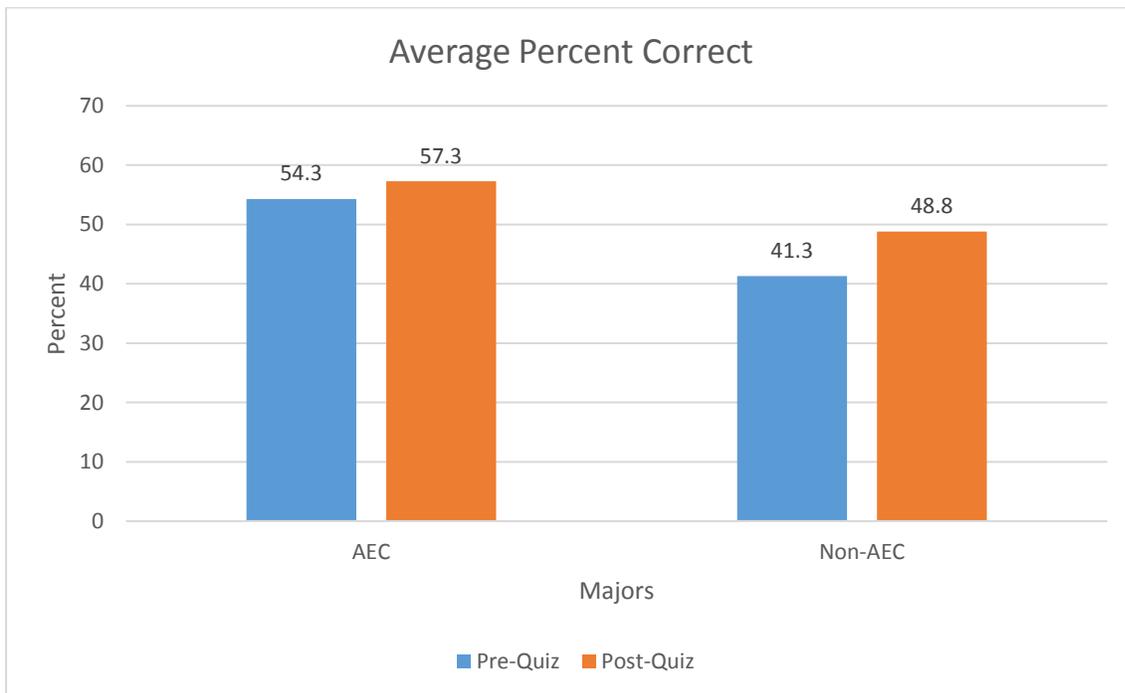


Figure 4.4.1: Average percent correct for AEC and non-AEC students from pre and post quiz

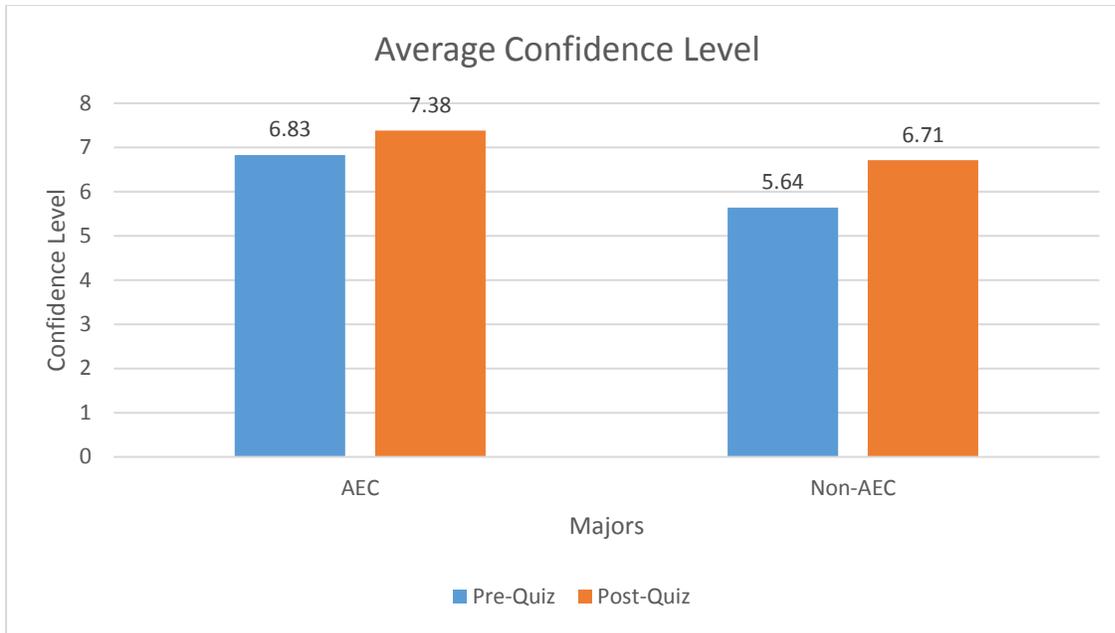


Figure 4.4.2: Average confidence level for AEC and non-AEC students from pre and post quiz

4.5 ANALYSIS OF THE PEDAGOGICAL INTERVENTION

To help support the hypothesis that AEC students who enroll in a pedagogical intervention will show improved spatial cognition scores over students who did not enter in a pedagogical intervention, and reject the null hypothesis that there is no significant difference in spatial cognition improvement for students who enter the pedagogical intervention compared to those students who do not, a sample t-test was used to compare the mean score difference between AEC students and non-AEC students. Using a p-value of $p < 0.05$ suggested that there was significant difference between the student's score and the success of the pedagogical intervention during the 2017 fall semester.

For this analysis Construction Management, Construction Science, Architecture, Interior Design, and Engineering majors were aggregated as "AEC majors" ($n=98$) and all other reported majors were aggregated as "non-AEC majors" ($n=15$). An independent samples t-test (Table 4.5.1) revealed no significant differences ($p=0.404$) on pre-quiz

score between AEC and Non-AEC students. Specifically, non-AEC students achieved significantly lower pre-quiz scores ($m=47.5\%$, $SD=0.223$) compared to AEC students ($m=53.1\%$, $SD=0.242$). The null hypothesis was not rejected this research question due to the non-significant difference in mean pre-quiz scores observed between AEC and non-AEC students.

Table 4.5.1: Independent sample t-test results: pre-quiz score by AEC and non-AEC majors

Major	<i>n</i>	<i>m</i>	<i>SD</i>	<i>t</i>	<i>df</i>	<i>p</i>
				0.838	111	0.404
AEC	98	0.5306	0.242			
Non-AEC	10	0.4750	0.223			

The data showed that there was a higher resulting score and confidence level for AEC students compared to non-AEC students in the pre-quiz. This could be attributed to AEC students having prior exposure to drafting and generally a greater understanding of graphically communicating three-dimensional spaces.

Similar to the pre-quiz, an independent samples t-test was used again to compare the differences in post-quiz's score and confidence level between AEC and non-AEC students. Table 4.5.2 revealed significant differences ($p=0.050$) on post-quiz score between AEC and Non-AEC students. Specifically, non-AEC students achieved significantly lower post-quiz scores ($m=48.8\%$, $SD=0.279$) compared to AEC students ($m=57.3\%$, $SD=0.225$). The null hypothesis was rejected this research question due to the significant difference in mean pre-quiz scores observed between AEC and non-AEC students.

Table 4.5.2: Independent sample t-test results: post-quiz score by AEC and non-AEC majors

Major	<i>n</i>	<i>m</i>	<i>SD</i>	<i>t</i>	<i>df</i>	<i>p</i>
				1.977	111	0.050
AEC	98	0.5732	0.225			
Non-AEC	15	0.4875	0.279			

4.6 LIMITATIONS AND ASSUMPTIONS

To produce foundational research on how an AEC student’s spatial cognition skills strengthens after a pedagogical intervention, this research needed to analyze the correlation between a student’s graphic communication course and the student’s spatial abilities after a semester. It is hypothesized that the AEC students that enroll in a semester’s graphic communication course will perform better on the spatial quiz than the non-AEC students who did not enroll in a graphic communications course.

In an attempt to fill the study, there are assumptions that were considered prior to the conduction of the statistical analysis. Assumptions were considered after outliers were removed from the study. Some assumptions of this study were 1) it is assumed if the student classified themselves as any of the AEC majors, that it is assumed that the student was enrolled in one of the graphic communications course. However, it is not specified what graphic communications course that the student was in during the time of this study. 2) It is assumed that students participating in the study put forth their best effort and the scores of their quiz will reflect their actual spatial cognition capabilities. 3) It is assumed that the students took the quiz on their own time with no additional help from outside resources or from their instructor. 4) It is assumed that the students participating will not

be at an advantage over their peers that did not take the quiz when progressing through their undergraduate AEC course for the fall 2017 semester.

In addition to the assumptions that this study had, it is also important to note that limitations had an impact on the research and additional research would have to be collected to gain more data. The limitations of this study were 1) the time duration of this study was limited to one five-month semester. The data was only collected and compared after one semester. Collecting data from more semesters would help strengthen the hypothesis that the graphic communications course does have a positive impact on an AEC student's spatial cognition skills. Collecting data from more semesters would also increase the study's population and eliminate heavily weighted control group data. 2) This research only focused on four AEC graphic communications courses that had students that majored in; construction, interior design, architecture, environmental design, and engineering. However, it is not specified what course they were enrolled in during the 2017 fall semester. Further research should categorize the students from course to determine if that specific course is helping a student heighten their spatial cognition skills. 3) This study's participants were from three universities; Colorado State University, University of Oklahoma, and University of Wisconsin-Stout. Having more universities that authorize graphic communication courses to be in the research would allow more data to be constructed to compare how universities are helping to improve AEC student's spatial cognition skills. 4) Data was only accepted to analyze for this study from students whom participated in both the pre and post quiz study. This caused a decrease in participants for the post quiz which resulted in less data to analyze after the study was conducted. Future studies should survey a larger control group to mitigate the vast decrease in collective participation between pre and post quizzes.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the conclusions derived from the results presented in the previous chapter. First, a summary of the research with the results and comments from the participant responses. Next, a discussion on the conclusion of the pre-quiz and post-quiz results and how a pedagogical intervention of a first-year drafting course in AEC higher education has impacted a student's spatial cognition. This chapter will conclude with a discussion on possible future research related to this study.

5.1 STEPS TAKEN FOR THE RESEARCH

There are many spatial cognition tests that assess a student's spatial cognition abilities. By conducting a similar quiz to the PSVT:R test and a similar study that was done by Dr. Sorby and Dr. Baartmans in the early 1990's, this study was able to evaluate a student's spatial cognition to an underclassmen in their first-year drafting course focused in AEC related programs. Additionally, this study was used to determine if their drafting course that teaches digital visualization tools, such as Autodesk Revit, would help strengthen a student's spatial cognition. To fulfill the purpose of this research, the following steps were taken: 1) Acquire IRB's approval of the study, 2) Create an eight-question quiz that is similar to PSVT:R test, 3) Find first-year drafting courses to participate in the study, 4) Obtain instructor's permission to send out quiz to their students, 5) Send the quiz to participating first-year drafting students, 6) Collect data to be analyzed, 7) analyze the data.

5.2 SUMMARY OF THE RESEARCH

Before and after the fall semester of 2017 began and ended, an eight-question quiz was sent out to a group of AEC students ($n=244$) enrolled in their entry-level drafting

course from three universities; Colorado State University (CON 131 and INTD 166), University of Oklahoma (CNS 112), and University of Wisconsin-Stout (DES 114). In addition to the AEC students, the eight-question quiz was sent out to non-AEC students ($n=31$) that was enrolled in an entry-level English course (ENGL 121) from University of Wisconsin-Stout during the 2017 fall semester. By sending a pre-quiz during the beginning of the fall 2017 semester and then sending a post-quiz at the end of the 2017 fall semester, this allowed the data to be analyzed to see if this research supported the hypothesis. The hypothesis for this study was to see if AEC students who enroll pedagogical intervention would show improved spatial cognition scores over students who do not enter pedagogical intervention. Inversely, the null hypothesis is that there is no significant difference in spatial cognition improvement for students who enter the pedagogical intervention compared to those students who do not.

When the post-quiz results were in, the prior results from the pre-quiz were then compared to the post-quiz results. The main objective of this research was to determine if there was an improvement from the pre-quiz score to the post-quiz score when an AEC student was exposed to an entry-level drafting course that utilizes digital visualization tools. Not only would this research determine if a drafting course could alter a student's spatial cognition abilities, but this study would expand on student's spatial cognitive reasoning related research studies.

5.3 CONCLUSION OF RESULTS

At first glance at the descriptive statistics from this research when comparing AEC and non-AEC students, AEC students had an increase of 5.2% in their post-quiz scores after the pedagogical intervention but the non-AEC students also increased their post-quiz scores from their pre-quiz scores by 15.4% without the pedagogical intervention of the

drafting course. AEC students did score higher than the non-AEC students for both the pre and post-quiz. (AEC students scored 13.0% higher than non-AEC for the pre-quiz and 8.5% higher than the non-AEC students for the post-quiz).

Before the quiz began, there was a question asking if the student had prior exposure to drafting, and 19.4% of AEC students responded that they did have some exposure before enrolling in their 2017 fall semester drafting course, and 20.0% of non-AEC said the same thing. This was considered in the final analysis, but was not a factor in the outcome due to the fact it did not have a significant difference in the data results. It can be observed that the other 80.6% of the AEC students with higher quiz results who did not have prior drafting experience, might have had hands on three-dimensional experience related to their interest to the construction industry: high school shop classes, woodworking, or even growing up playing with building blocks to make structures. Disregarding that only 19.4% of the AEC students, and 20.0% on non-AEC, had prior drafting exposure, the higher AEC pre and post scores could be due to a general understanding of three-dimensional spaces in construction that drew the students' interest to AEC related programs in the first place.

The improvement of AEC scores supports the hypothesis that the pedagogical intervention of the entry-level drafting course could improve the AEC student's spatial cognition, however the fact that non-AEC students also improved their scores indicates that external factors other than the pedagogical intervention can play a role in improving spatial cognition. It is important to note that the population for non-AEC students was 15 students while the AEC students had a population of 98 students. Non-AEC student's results are heavily weighted in this study because of this factor.

When comparing the confidence levels between AEC and non-AEC, they both had significant improvement on the confidence in their answer during the post-quiz then the pre-quiz. Similar to the quiz scores, AEC had a higher confidence level for both the pre-quiz and the post-quiz compared to non-AEC students.

AEC students should have had a greater advantage and improvement of quiz scores in comparison to non-AEC students in this study. There are several conclusive possibilities to answer why there was not a greater change in the pre-quiz and post-quiz overall scores for AEC students. Effort can be considered a major factor in post-quiz results. The post quiz was conducted at the end of the semester when external factors like winter break and final exams could be on the minds of the participants.

A result that was not surprising, non-AEC students had the lowest quiz scores compared to the AEC students. Since non-AEC students do not commonly use their spatial cognition abilities on a daily basis, compared to AEC students, it was anticipated that the non-AEC students would score lower for both the pre-quiz and the post-quiz.

5.4 FUTURE RESEARCH

Although the study of this research was vast and included five AEC undergraduate courses and one English course from three universities, this study had a major limitation on time. The study only lasted one five-month semester. A longer duration could provide a more accurate measure of growth of spatial cognition. Future studies should consider collecting data six-eight instances throughout a two-year time duration. This would differ from past studies like Dr. Sorby and Dr. Baartmann's research that analyzed results year to year. The additional data points could determine if there was in fact a drop-in effort at the end of a semester external factors like winter/ summer breaks and final exams play a role in student focus.

While this study measured how a student grows in utilizing their spatial cognition, not all means of how spatial cognition were used was obvious in the study. Students at the three different universities might have had varying exposure to digital visualization programs. The split between hand-drafting and computer-drafting could vary significantly between courses and have a greater effect on the results. Future studies could assess the student growth of spatial visualization in hand-drafting segments of a course versus student growth during computer drafting segments. In addition, this study could be explored how a student's spatial cognition improves when enrolled in a lectured based classroom setting than a more hands-on approach method of learning.

Does the tools that are be integrated in the curriculum helping the students be more successful in their fields? That is the question every instructor wants to know. This research will benefit the instructors teaching in an undergraduate AEC discipline at any university. The results of this study are a beginning step for professors and instructors to understand how their curriculum is contributing to the success of the students by improving their spatial cognition. The goal of an advanced curriculum in the AEC program is to teach students how to visualize two-dimensional and three-dimensional designs more efficiently to prepare them for their careers.

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