RESEARCH INTO VIRTUAL REALITY AND THE BENEFITS IT MAY HAVE ON CONSTRUCTION SAFETY EDUCATION

by

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This Master's Thesis is dedicated to all of my friends and faculty from my undergrad who pushed me to pursue my education further.

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ABSTRACT

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The purpose of this study is to determine if Virtual Reality safety training is more effective at teaching fall protection safety than traditional methods of instruction. A literature review of previous research was conducted and a theoretical framework and methodology was developed to test the two groups for this study. The research design is a difference-in-differences method comparing the pre-test and post-test scores of the participants of each group. There will be other small pieces of analysis that will be done to further understand the results of the data collection. The data will be analyzed and interpreted to better understand how the research question was answered in comparison to previous work and the theoretical framework. Finally, other questions that arose during the process will be addressed and future areas for more research will be defined.

CHAPTER 1. INTRODUCTION

Chapter One provides a basis to complete a research study in the field of Construction Safety Education. The study will be accomplished by defining and answering a focused research question. The research question is flushed out through the understanding of the scope and significance, along with previous literature on the subject.

1.1 Background

In a study conducted by William Winn he states, "Virtual Reality has caught the imagination of many people." (Winn, 1993, p.1). This sentiment has only increased in society since this paper was written. The direct interest in the topic of Virtual Reality for the author came from undergraduate coursework. A project was assigned, as part of a second year architecture design studio, with a requirement to produce a walkthrough of a structure using Virtual Reality. The project left an "empty feeling", as the use of Virtual Reality was implemented well in the course, but was extremely ineffective at teaching anything through the use of the technology. This project is the area that sparked the interest in this thesis topic, to understand better how effective Virtual Reality can be at teaching students. Construction Safety is a perfect field to do research on Virtual Reality as an educational tool for a variety of reasons. These reasons include real-life applications, limited research in this area, and the fact that falls are the main cause for injury on construction sites (OSHA, 2018). By the conclusion of this study, a methodology will be developed to understand if Virtual Reality can be used as an effective teaching tool in construction safety. Along with using Virtual Reality as a teaching tool, the hope is that the methodology that will be developed can also be applied to other areas of construction management education, as well as, being able to translate to be used and studied in a professional training environment.

1.2 Significance

The significance of Virtual Reality Research in Construction Safety is two-fold, affecting separate areas. The first is that technology is always being developed and enhanced. Being able to find applications for the technology is of the utmost importance. The other area that is effected greatly is education. In recent years there has been a large push in academics to expand on older teaching methods in light of new technology that can be implemented in the classroom. Examples of this increased use of new technology can be seen at all levels of education from K-12 into Higher Education. Virtual Reality is an emerging technology that has started to receive more traction in academics. This process began in the 1990s when different Virtual Reality programs such as Science Space, Safety World, and Cell Biology, were introduced in K-12 and higher education (Merchant, 2013). This research will take the next step in helping Virtual Reality technology become a more accepted standard teaching method.

1.3 Statement of Purpose

The implementation of Virtual Reality has the possibility of shortening the gap between academia and field work considerably in Construction Education. Reduction of this gap can be accomplished by placing students in “real life” environments during their education. Educating students using this teaching tool allows them to experience situations that they will eventually face in the field. Virtual Reality will allow the students to experience these environments as if they were really there. One study classified the methods and strategies used in construction safety education as “passive, boring and not sufficiently motivating” (Pedro, 2016, p.1). Using Virtual Reality as an educational method can help combat these issues, which could also lead to it being a more effective method to teach construction safety education.

There have been many examples of Virtual Reality being used in other fields, but few examples can be found in the construction industry. The most closely related study to the current research was conducted by Sacks, Perlman, and Barak. The study by Sacks (2013), compared traditional and Virtual Reality educational methods. However, they used participants that could have had extensive knowledge on construction safety. Sack's research did conclude that the Virtual Reality training was more effective in some situations, but some of their results were inconclusive or showed that there was no significant difference shown in the data. The Virtual Reality Training for this study will look to provide evidence that Virtual Reality is more effective in fall protection safety training. The study will also develop a methodology that could be used to test other areas of construction safety, once more modules are developed.

This research study will look to understand the effectiveness, not just methods of implementation, for Virtual Reality in Construction Safety. This research will determine to what extent Virtual Reality may be more effective at teaching students compared to more traditional methods, such as lecturing or testing. By testing both educational methods, it allows for a future study to look at the possibility of mixing these two educational methods to find an even more effective teaching tool. This would be an intensive study that could only begin to be covered in the short time for a master's thesis. It would, however, provide a solid base to continue with in the future, for others to build off of.

1.4 Research Question

1. Which method of educational instruction: Traditional or Virtual Reality, is more effective at teaching college students, at a Tier One Research University, about fall protection in construction safety?

1.5 Assumptions

Assumptions are important to define when conducting research. They are generally noted as thing that are out of the researchers control but that are immensely important to the research at hand.

- Participants will answer truthfully and to the best of their ability through all different aspects of the research.
- Virtual Reality technology will continue to be relevant in the future, with continued use and development within education.
- All technology utilized in the research will perform to the manufacturers specifications.

1.6 Limitations

Limitations are also variables that effect the research, that are also out of the researcher's control. However, limitations are easily definable compared to assumptions.

- Time limitations; through the May 2019 semester.
- The amount of students that register for the safety course in the BCM program in the 2019 spring semester.

1.7 Delimitations

Delimitations very often fall closely in line with limitations, however they are choices that are made by the researcher that limit the scope of the research and define the boundaries of the study. All of these factors are within the researcher's control.

- No professionals will be used as part of the sample for this research. This is an attempt to limit prior knowledge on the subject being tested. While this research may eventually be translated for professional use and training, at this point in time it is believed that having too much prior knowledge in the area of fall protection could vastly skew the data. This delimitation was chosen to help limit this as much as possible.

- For the duration of this study, only one type of Virtual Reality Head Mounted Display (HMD) will be used. The headset used will be an HTC VIVE. There will be a backup HMD in case of malfunction with the first HMD.
- Students for the study will be part of the required safety education class in the Building Construction Management program.
- Degree of Guidance through Virtual Reality training modules will be limited to the functionality of the program and headsets.

1.8 Definition of Key Terms

Virtual Reality (VR): is a technology that uses computers, software and peripheral hardware to generate a simulated environment for its user. (Sacks, 2013)

Stratified Random Sampling (SRS): population is partitioned into non-overlapping groups, called strata and a sample is selected by some design within each stratum. (Penn State Eberly College of Science, STAT 506, Sampling Theory and Methods)

Quasi-Experimental Research: Research where “different treatment conditions are not assigned to units at random.” (Reichardt, 2009, p.46).

Head Mounted Display (HMD): Image display units that are mounted on the dead. A unit consists of a helmet and small CRT’s or liquid-crystal displays (LCDs) in a pair of goggles… Some types are mounted on the face in the form of glasses (Shibata, 2002).

1.9 Summary

The first chapter covers the basics of the research being conducted. It includes the background and significance of the topic as well as the research question. The Assumptions, Limitations, and Delimitations were all covered in this section as well. Lastly, several key terms were defined to help the readers understand more complex or topic specific terms. This provides the base for the research that will be detailed in the following chapters.

CHAPTER 2. LITERATURE REVIEW

This chapter will cover how the literature review was approached, along with the literature review itself. It will cover different topics pertinent to the research. It will also mesh these three variables together to help understand how they will have an impact on the research.

2.1 Literature Review Approach

When approaching this literature review several considerations are needed. The literature review will be broken up into the three main variables that effect this research: Virtual Reality, Education, and Construction Safety. Literature that is relevant to these three variables will be critically reviewed. Following this a review of how the variables will come together and have an effect on the research. The final two pieces of the literature review will cover gaps in previous research and areas for potential research in the future.

2.2 Introduction

Over the last several decades, Virtual Reality has become used for a wide variety of applications including but not limited to: medical fields, telepresence, and educational purposes (Satava, 1995; Mazuryk, 1996; & Winn, 1993). The goal of this master's thesis is to determine how effective Virtual Reality will be as an educational tool for construction education, specifically in the field of construction safety and training. The focus of this literature review will be understanding relevant literature to the three variables listed above, Virtual Reality, Education, and Construction Safety.

2.3 Virtual Reality Technology

Virtual Reality (VR) is a field that is evolving at a rapid rate. According to Sacks (2013, p.1007), “Virtual Reality is a technology that uses computers, software, and peripheral hardware to generate a simulated environment for its user.” Understanding this definition is extremely important to comprehending the extent to which Virtual Reality can reach. Many times the general population will only think of Virtual Reality technology as a VR headset that is commonly used. Beyond this Virtual Reality has the capabilities to extend to whole environments. The two major conditions that must be met are that the world is generated by a computer and that the user can interact with the virtual environment to have some effect on the situation. “The world of three-dimensional graphics has neither borders nor constraints and can be created and manipulated by ourselves as we wish.” (Mazuryk, 1996, p.1). This statement is one of the reasons that so many people are interested in the possibilities of Virtual Reality.

According to Jayaram, (1997, p.575) “Virtual Reality is a technology which is often regarded as a natural extension to three dimensional (3D) computer graphics.” Virtual Reality allows users to take an environment or situation that is generated on a computer and then interact with that simulation. The study by Jayaram, (1997) attempted to use virtual reality for several reasons to help improve the assembly in manufacturing. One of the great powers of Virtual Reality is the ability to produce an environment that is anywhere in the world at any time. This allows for people to learn anywhere despite geographical boundaries that are natural or imposed by humans (Hussain, 2007). This moves closer to the area of education that makes use of Virtual Reality as a tool to teach students. Now the history of Virtual Reality will be covered along with how it has changed and developed over the years.

2.4 History of Virtual Reality and Current Virtual Reality Systems

Virtual Reality has changed drastically over several decades since the first systems were invented in the early 1960s. The first Virtual Reality system, the Sensorama, was developed in 1962 by Morton Heilig. This system had multiple sensory stimulations, but lacked interactivity (Mazuryk, 1996). After this over the next several decades there were numerous different Virtual Reality systems that were developed. One of the most notable Virtual Reality systems was the Cave Automatic Virtual Environment (CAVE). This Virtual Reality system does not use a HMD but rather projects images onto the walls of a room and the user wears a pair of LCD glasses (Mazuryk, 1996). However, for this research Head-Mounted Displays (HMDs) will be the Virtual Reality system used.

Head Mounted Displays (HMDs) are another of the main types of Virtual Reality systems that are used today. In research by Santos et al. they give a description of HMDs:

> "HMDs consist of two LCD [Liquid Crystal Displays] screens mounted in a glasses-like device and fixed relative to the wearer's eye position, and portray the virtual world by obtaining the user's head orientation (and position in some cases) from a tracking system. Several HMD features may have an effect on user performance: HMDs may present the same image to both eyes or be stereoscopic, and offer a wide range of resolutions, usually trading off with field of view (FOV)." (Santos, 2008, p.164).

Two of the more popular Virtual Reality HMD's today are the Oculus Rift and the HTC VIVE. These HMDs are what are known as immersive systems, allowing for the user to become immersed in the Virtual Reality environment. "These systems may be enhanced by audio, haptic, and sensory interfaces." (Mazuryk, 1996, p.5). There are several key pieces that make up the components of a Virtual Reality system according to Mazuryk and Gervautz (1996). These three parts are Input Devices, Output Devices, and Software. Input Devices are the way that "a user communicates with the computer." (Mazuryk, 1996, p.14). These devices could include a mouse or controller. Next are the output devices, these "are responsible for the presentation of the virtual environment," (Mazuryk, 1996, p.15) this is where the device worn on the head (the display) communicates back to the user. The last piece of the Virtual Reality system is the software. This piece is the connector between the inputs received from the user and the feedback that the user receives from the output device.

One last piece that needs to be covered is simulator sickness cause by Virtual Reality systems. In a study done by Kennedy et al., they suggest that there are three major symptoms of simulator sickness: Physiological dysfunctions, mental dysfunctions, and oculomotor dysfunctions (Kennedy, 1992). These symptoms were reported by up to 80% of participants in a later study, with 5% of participants having to end the study prematurely due to symptoms (Sharples, 2007). Simulator sickness is a major concern when dealing with Virtual Reality systems in respect to the users and their health.

2.5 Implementation and Barriers to Entry

As seen in the history of Virtual Reality above, Virtual Reality has gained popularity over several decades. A report showed that Virtual Reality technology was among the hottest consumer trends in 2016 (Ericsson Consumerlab, 2015). While this is a new trend among consumers traditionally, Virtual Reality technology has been much cheaper and more available at the commercial level (Brown, 2016). There are still some costs associated with using Virtual Reality technology. There are however, several options that are outlined as being cheap or no cost options in the study by Brown and Green (Brown, 2016). There are some media outlets that are beginning to provide free or low cost Virtual Reality hardware. According to Brown (2016, p.517), "Low-cost VR hardware is becoming almost commonplace: The *New York Times* provides VR media content accessible with an iOS or Android device recently, viewers using Samsung Gear VR were able to view CNN;s Democratic Debate". Google has also dropped its hat into the conversation introducing their program *Expeditions,* which "[facilitates] instructor-led VR 'field trips'" (Brown, 2016, p.517). Pantelidis also mentions cost as a factor when determining if Virtual Reality implementation is applicable in an educational setting, along with the time restraints that can occur (Pantelidis, 2010). With the relative high cost of most educational Virtual Reality systems, educators must determine the relevancy of the technology that they are looking to implement. Due to the fact that Virtual Reality technology is advancing at a rapid rate, it could become outdated before the consumers are able to get a good return on their investment. This is an issue that needs to be addressed when purchasing new technology.

2.6 Education

Education is another factor that is a part of this research. There are many different aspects of education, the parts that will have the most effect on this research are the different teaching tools and methods that are used in education.

2.6.1 Teaching Tools and Methods

There are many different teaching tools that area available to educators at all levels of education. In a case study by Bourner (1997), there are six different "learning aims" (see Table 1) provided and ten different teaching methods are given for each aim. In this table, one can see many recognizable traditional teaching methods. However very few of these proposed teaching methods make use of new technology that has been developed over the last several decades. One of the most common teaching methods is the lecture teaching method. Educators use this method in many circumstances. In the lecture teaching method an educator "discusses, shows, models, demonstrates, and teaches the skills that are to be learned" (Mohammadjani, 2015, p.107). This method forces students to learn by listening and memorizing the content presented by the instructor.

These methods are known as inactive teaching methods. As a result of some of the downsides to inactive teaching

Table 2.1 Learning Aims (Boujner, 1997)

	Disseminate up-to-date knowledge	**Develop the capability to use ideas and information**	**Develop the student's ability to test ideas and evidence**	**Develop the student's ability to generate ideas and evidence**	**Facilitate the personal development of students**	**Develop the capacity of students to plan and manage own learning**
Ten common teaching methods	1. Lectures	1. Case Studies	1. Seminar and tutorials	1. Research Projects	1. Feedback	1. Learning contracts
	2. Up-to-date textbooks	2. Practicals	2. Supervision	2. Workshops on techniques of creative problem solving	2. Action learning	2. Projects
	3. Reading Lists	3. Work experience	3. Presentations	3. Group working	3. Learning contracts	3. Action learning
	4. Hand-outs	4. Projects	4. Essays	4. Action learning	4. Role Play	4. Workshops
	5. "Guest" lectures	5. Demon-strations	5. Feedback on written work	5. Lateral thinking	5. Experimental learning	5. Mentors
	6. Use of exercises that require students to find up-to-date knowledge	6. Group working	6. Literature reviewing	6. Brainstorming	6. Learning logs	6. Reflective logs and diaries
	7. Develop skills in using library and other learning resources	7. Simulations (e.g. computer based)	7. Exam papers	7. Mind-mapping	7. Structured experiences in groups	7. Independent study
	8. Directed private study	8. Problem solving	8. Critical assessment	8. Creative visualization	8. Reflective documents	8. Dissertations
	9. Open learning materials	9. Discussion and debate	9. Peer assessment	9. Use of relaxation techniques	9. Self-assessment	9. Work placement
	10. Use of the internet	10. Essay-writing	10. Self-assessment	10. Problem solving	10. Profiling	10. Portfolio development

methods, “the topic of active teaching methods and active learners has found a special place in educational discussions today” (Mogammadjani, 2015, p.107).

Innovative learning is a newer method that attempts to "stimulate[s] innovative changes in a corresponding culture and social environment and acts as an active reaction to the problem situations" (Stukalenko, 2016, p.6613). This teaching method attempts to develop both the student as well as the teacher. While there is not one specific method or tool associated with innovative learning, this process experiments with using new technologies and approaches to education and training.

2.7 Construction Safety

"Out of 4,674 worker fatalities in the private industry in calendar year 2017, 971 or 27% were in construction—that is, one in five worker deaths last year were in construction." (OSHA, 2018, p.6). Construction safety is a major concern within the construction industry. The Occupational Safety and Health Administration (OSHA) is the agency that overlooks safety in the workplace. In the Handbook of OSHA Construction Safety and Health the authors show a table (see Table 2 below) detailing all of the different types of construction (Reese, 2006). Table 2 below shows the wide variety of construction types that are included within the construction industry. Each of these provide unique safety challenges. When an incident occurs on a jobsite "OSHA tends to hold all

Table 2.2 Construction Contractors' SICs [Standard Industrial Classification] (Reese, 2006)

SIC	**Type of Construction**
15	Building Construction -- General contractors and operative builders
152	General building contractors -- Residential buildings
1521	General contractors -- Single family houses
1522	General contractors -- Residential buildings, other than single family
153	Operative builders

Table 2.2 continued

1531	Operative builders
154	General building contractors -- Nonresidential buildings
1541	General contractors -- Industrial building and warehouses
1542	General contractors -- Nonresidential buildings, other than industrial buildings and warehouses
16	Construction other than building construction -- General contractors
161	Highway and street construction, except elevated highways
1611	Highway and street construction, except elevated highways
162	Heavy construction, except highway and street construction
1622	Bridge, tunnel, and elevated highway construction
1623	Water, sewer, Pipeline, communication and power line construction
1629	Heavy construction, not elsewhere classified
17	Construction -- Special trade contractors
171	Plumbing, heating (except electrical), and air conditioning
1711	Plumbing, heating (except Electrical), and air conditioning
172	Painting, paper hanging, and decorating
1721	Painting, Paper hanging, and decorating
173	Electrical work
1731	Electrical work
174	Masonry, stonework, tile setting, and plastering
1741	Masonry, stones setting, and plastering
1742	Plastering, drywall, acoustical, and insulation work
1743	Terrazzo, tile, marble, and mosaic work
175	Carpentry and flooring
1751	Carpentering
1752	Floor laying and other floor work, not elsewhere classified
176	Roofing and sheet metal work
1761	Roofing and sheet metal work
177	Concrete work
1771	Concrete work
178	Water well drilling

Table 2.2 continued

1781	Water well drilling
179	Miscellaneous special trade contractors
1792	Structural steel erection
1793	Glass and glazing work
1794	Excavating and foundation work
1795	Wrecking and demolition work
1796	Installation or erection of building equipment, not elsewhere classified
1799	Special trade contractors, not elsewhere classified

parties responsible for citations and penalties, even though they may not have created the violation(s).” (Reese, 2006, p.5). Since this is the way that OSHA handles incidents in the construction industry, there is a great emphasis put on safety in many companies. Reese lays out six main reasons that accidents occur in construction. These six reasons for accidents are: Actual physical hazards, environmental hazards, human factors, lack of or poorly designed safety standards, failure to communicate within a single trade, and failure to communicate between two or more trades (Reese, 2006). According to the official OSHA (2018) website falls accounted for 39.2% of all construction fatalities during the 2017 calendar year. Due to this fact, fall protection safety will be the area that is used in this research.

2.8 Practices in Construction Safety

There are numerous different measures that can be taken to help mitigate safety hazards in construction. In research by Hinze (2013), there are 104 suggested strategies listed that can be implemented to help improve safety in construction. These options are broken down into three categories: Practices that are implemented in 100% of projects, practices that are implemented 85-97% of the time, and practices that are implemented less than 85% of the time on construction projects (Hinze, 2013). Due to some of these measures, construction injuries and fatalities have decreased a large amount over several decades (Hallowell, 2013). Hallowell goes on to state that that “Construction companies must invest resources in hazard recognition training programs and orientations to communicate protocol for appropriate response.” (Hallowell, 2013, p.2). This begins to move in the direction of training and education for construction safety.

2.9 Fall Protection Safety

The construction industry is the second leading industry in work related injuries and illnesses (Reese, 2006). Within the construction industry falls (39.2%) account for the most worker fatalities, followed by struck by object (8.2%), electrocutions (7.3%), and caught-in/between (5.1%). (OSHA, 2018). There are numerous measures that are taken to help mitigate and prevent falls in construction. These measures include guard rails, securely covering any openings or holes, safety nets, and harnesses. Continued education and training on fall protection safety could further reduce the amount of related incidents in the construction industry. This claim will be addressed in the following section.

2.10 Virtual Reality in Education

One of the areas that Virtual Reality has made the greatest strides in recent year is education. Many times using Virtual Reality in education falls under the educational method of innovative learning. Virtual Reality is not the only educational tool that innovative learning can use. The implementation is not only an innovation on the technology side but also in integration and affordability of different Virtual Reality tools. The first step is to start out with the basics of understanding why the use of Virtual Reality in education is beneficial. According to Pantelidis (2010), the same reasons that people use computers in education at all are many of the same reasons that it makes sense to use Virtual Reality in Education. In her 1995 study, Pantelidis gives three major reasons to use Virtual Reality as an educational tool. First, Virtual Reality can provide a different way for students to visualize a problem. Pantelidis (2010, p.62) goes on to state that, "VR can more accurately illustrate some features, processes and so forth." The next reason, is that Virtual Reality allows students to actively interact with the material that is being presented. It moves away from passive teaching methods and will motivate students. The final reason that is given is that many times students can use Virtual Reality technology outside of scheduled class times. This then allows them to have more time to learn that material using an educational tool (Pantelidis, 2010). All three of these reasons points lead to the increased versatility of education and can at times provide a more detailed explanation of the course material than an instructor can offer.

2.11 Virtual Field Trips

Due to time, distance and disability, some students are not able to physically join field trips. Virtual Reality has virtually given them the ability to view components without physically being present. According to Klemm (2003, p.178), "the term 'virtual field trip' embraces a range of instructional approaches and technologies but generally denotes a multimedia presentation that brings the sights and sounds of a distant place to the learner." One of the benefits that this provides instructors is the ability to connect material that is taught with more traditional teaching methods with the use of a virtual field trip with a location or event. This allows the students to have an experience that they would not have been able to have otherwise with the capability of Virtual Reality. One area that is drawn some attention to is the planning of a virtual field trip by the instructors. Klemm, (2003, p.183) states, "[Planning] requires thinking about assessment of student learning before planning the details of how instruction is to take place."

2.12 Other Educational Benefits

One of the most common things students experience in education today is the phenomena of working and learning in groups. According to Bishnoi (2017, p.790), “it [collaborative learning] is a powerful tool that can allow educators to tap into new ideas and information.” While it can be challenging to accomplish group learning through Virtual Reality, research by Di Blas used a system that made group learning accessible and simple. The research by Di Blas used a system from video games called, Multi-User Virtual Environments (MUVE). The objective of the study was to explore and understand how the MUVE system can be used in education (Di Blas, 2014). The case study by Di Blas and Paolini (2014), created several different tests or “games” that were then evaluated for aspects that were both qualitative and quantitative to determine the effectiveness of the MUVE’s. The cognitive testing saw 69% of students receive scores of acceptable, good, or very good. Other areas that used qualitative data all showed benefits as well, including major increases in social skills (29.5% good improvement, 55.7% major improvement, and 13.1% excellent improvement), student motivation (36.1% strongly agree, 39.3% Agree, 23% Partially agree, and 1.6% disagree), and a better attitude (93% good or higher attitude improvements) as students were rated by their instructors (Di Blas, 2012). If this system can be successfully integrated for use in educational groups, it could become a powerful educational tool.

The next two examples of uses of Virtual Reality in education come from vastly different fields. However, both deal with aspects of understanding spaces through Virtual Reality. One of the areas that has begun to use this is rehabilitation and helping those with severe disabilities. Researchers have shown that Virtual Reality can have benefits in both the mental and physical ends of therapy (Alejandro, 2017). The study by Alejandro focused mainly on the visuospatial use of Virtual Reality systems to help with therapy of people that have severe disabilities. First, to briefly describe what visuospatial means and how it works with Virtual Reality. The concept is really simple and deals with how the user's visual perception of the spatial arrangement of objects and their relationships with one another. The combination of Virtual Reality with visuospatial therapy techniques allows for unique opportunities for patients with disabilities (Alejandro, 2017). The other study by Fogarty (2017), also uses aspects of special understanding by students using Virtual Reality. This research is based in education and also has another unique aspect to it that will be discussed later. This study used multiple participants and an instructor, using Virtual Reality systems to explore a CAVE-like environment, in an attempt to understand the space that had been created in the virtual environment (Fogarty, 2017). This was then followed up by the second part of the experiment where users were asked to identify different 3D shapes that were experienced while in the virtual environment. This study was done in the field of Civil Engineering, so the last part of the study dealt with bending moments of different structural components. This is important as the study is done in a related field to the master's thesis that will be written. To understand the viability of a study conducted in Virtual Reality in a related field can be immensely helpful when preparing for the upcoming thesis. This research used a mixed-methods approach, collecting and analyzing both qualitative and quantitative data. The most important part of the Fogarty's study to understand is the multifaceted aspect. Using different ways to test similar subject matter is imperative when doing studies with Virtual Reality. This can help to analyze the collected data to form stronger conclusions. Using examples of how Virtual Reality has been used for other educational purposes can help when looking to implement Virtual Reality into a new field. Construction education has seen early studies with Virtual Reality, but the exploration is still in the infancy stage.

2.13 Virtual Reality Applications in Construction Education

When looking at Construction Education, there are many different aspects of it, including design, constructability, safety, estimating, and sustainability that could be benefited by using Virtual Reality. The area that will be focused on for this master's thesis specifically will be construction safety. Construction safety has seen some limited exploration into using Virtual Reality as an educational tool, but to this point it has been somewhat limited. While this section will be dealing with Virtual Reality in construction safety education, it is also extremely applicable for ongoing training of professionals that are working in the field. In 2015 the Association for Talent Development estimates that organizations spent an average of $1,252 per employee every year on training programs (Higgins, 2017). Another area that is covered is that fact that while the construction industry is changing all the time, safety training has remained a relatively stagnant in the industry. Patel et al, (2006) conducted research that used Virtual and Augmented Reality training and compared them to traditional classroom learning. The results of this showed that users were more comfortable, in their jobs, after receiving the Virtual or Augmented Reality training (Higgins, 2017). This study used professionals as the research participants, as a result of this the data that was collected may be different than the current research that will not use professionals. Training programs can be looked at from two perspectives how they operate when the trainees have no previous experience and how trainees who have previous experience Virtual Reality training. Both sides of training need to be looked at thoroughly in research. In the current research, it will be a goal to keep the previous knowledge of participants on fall protection in construction safety to a minimum. This is an attempt to see how effective Virtual Reality training is while removing another variable that could affect the data. This is an area that will be covered in the study that will be done for this master's thesis.

The final two research studies present the closest research to the current master's thesis that is being worked on. The study by Pedro (2016), looked to create a safety educational tool for mobile devices that integrated Virtual Reality to help enhance the learning process. The research team developed several different modules to help different areas of construction safety education. These modules included: Virtual Construction Safety Education System (VSES), Safety and Hazard Lecture (SHL), Hazard Identification Game (HIG), and the Student Evaluation and Assessment (SEA). From here they provided different scenarios that could be found in construction (Pedro, 2016). There was a comparison used between a traditional "Paper based lecture" and their VSES module. The last part of the study by Pedro (2016) that makes it immensely different from the one currently being carried out is the location, Korea, and that the school carrying the study out, at the time of the study, had no construction safety course as part of their curriculum. The current research will use students that are part of the construction safety course and will be implemented as part of the course. The other study that is similar to the current research was done by Sacks. The study by Sacks (2013) "sought to build a virtual construction site using IVE (Immersive Virtual Environment) technology, to compile a set of safety training scenarios." The IVE that the researchers used, as seen in the figure below, was a power-wall that

Figure 2.1 IVE Technology Display

"consisted of three rear-projection screens each 2.4m wide and 1.8m high, arranged in a 'theatre' with a 150 degree angle between each screen." (Sacks, 2013, p.1008). The image below is of the power- wall described earlier. Sacks (2013), had three different training categories: General Site Safety, cast-in-site concrete, and safety during installation of cladding. These three scenarios were used to train both students and professionals in construction safety. The participants of Sacks study were then tested on their retention of information. Sacks research will greatly influence the current research being done because the methods and design of the research are similar. The current research will employ the use of an HMD rather than a power-wall. It will also only use participants who have little or no experience in construction safety. The last difference is that the current research will look at a specific hazard in construction safety (fall protection) rather than using specific scenarios to teach the modules. This is the basis or big picture behind the idea of implementing Virtual Reality into Construction Education, to help bring what is taught in the classroom and make it as applicable and realistic as possible to help students entering their professional careers.

2.14 Summary

The literature review covers three main points that effect the current research. These areas are Virtual Reality Technology, Education, and Construction Safety. From these three main points there were several sub-points developed. Then the literature review looked at how Virtual Reality Technology and Education fit together and how all three of the main points come together in different literature.

CHAPTER 3. FRAMEWORK AND METHODOLOGY

This chapter focuses specifically on the technical aspect of the research. It gives the basis behind how the thesis will be structured along with the methodology and theoretical framework that will be used to conduct the research. It also covers other topics including: Setting and Participants, Instrumentation, Procedures, Data and Analysis, and Ethical Considerations.

3.1 Research Design

The overall research design is made up of both the Research Methodology and the Theoretical Framework. These two pieces are critical to the research being carried out in the best way possible to complete the research. The methodology that will be used for this research will be a quantitative quasi-experimental design. Using a true experimental design in education is difficult due to a variety of reasons including time, money, and other ethical issues (Dimitrov, 2008). A quasi-experimental design was selected because true experimental research is hard to accomplish in educational research. With this in mind, it is an expectation of quasi-experimental research that as many conditions of true experimental research will be attempted to be met (Dimitrov, 2008). For this research study a nonrandomized pretest-posttest two group design will be implemented. The nonrandomized design is a good design to use since the participant groups are considered intact, since they are part of the same class. This poses some potential issues in that the groups are not randomly assigned which could slightly effect the data (Dimitrov, 2008).

3.2 Theoretical Framework

The theoretical framework in research uses constructs and theories in the field of the research along with relevant literature to help support the methodology that was selected for the study. In this section the major variables relating to the research will be covered. Relevant literature will also be reviewed. These two steps are taken to help discuss the different constructs and theories in relation to the methodology.

There are several different major variables that will have an effect on this research:

1. Virtual Reality Technology
2. Students and how they learn
3. Construction Management Education
4. Safety Education
5. Similar Studies and Previous Research

These five variables listed above are the major variables that will effect this research.

The next step to developing a theoretical framework is reviewing relevant literature to the topic. This will look at several academic papers covering Virtual Reality, Education, and Construction Safety. In research by Sacks it is stated, “The use of VR in training workers of various kinds is common” (Sacks, 2013, p.1007). The paper goes on to touch on a couple of examples of this including flight-simulations and surgical procedures. This concept of using Virtual Reality for professional training can be translated to be used in an educational setting. In a study done by Park and Kim, they break a Virtual Reality study down into three distinct parts. These three parts are the Planning, Education, and Inspection Modules (Park, 2012). In Park’s research these three modules meet in the middle in their Visualization Engine. In the current research this Visualization Engine is replaced by the six fall protection safety training modules. The current research also only focuses on the Education module from the three proposed by Park. “The QAG [question answer game] has been designed for workers to pre-experience safety risks virtually prior to the work execution” (Park, 2012, p.97). By using this approach Virtual Reality in education can be even more proactive than training workers already in the field. One of the keys to providing a benefit to using Virtual Reality as an educational tool is that the instruction modules need to be engaging to the students. In these modules students should have an active role in the learning process (Pedro, 2015). Pedro proposes a framework (seen below in the chart) that takes several different steps through the safety education process to ensure that the relevant and important information is learned and retained by the student. This framework, seen below in Figure 2, proposed three separate Virtual Construction Safety Education Modules (VSES) to teach the students or trainees (Pedro, 2015).

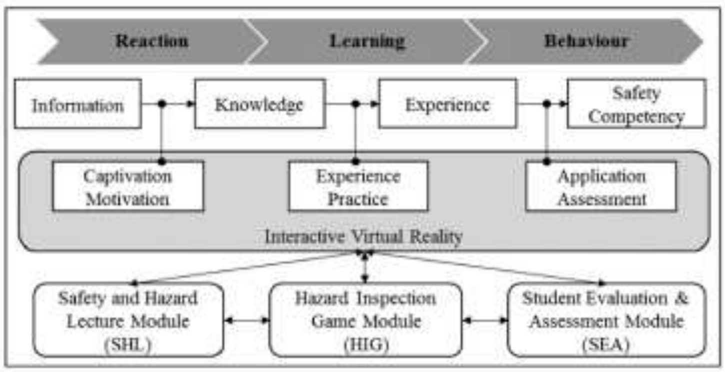

Figure 3.1 VSES Framework Flowchart

A similar set of modules teaching specifically fall protection safety will be used in this research. The data collected from tests of these modules will be compared to the data gathered from a traditional classroom setting to determine if one method or the other is more effective at teaching fall protection safety. The framework for this study into Fall Protection Safety comparing Virtual Reality Training Modules with Traditional Education Methods is informed by different variables stated above including, Construction Education, Virtual Reality, and Previous Research Frameworks.

3.3 Setting and Participants

There are two parts to this section, the setting of the study and who the participants of the study will be. There will be two settings for this research study. The first will be the classroom that the safety course will be held in. The other setting for the research will be the locations on campus where the two Head Mounted Displays are located. The first location for this will be in the 3rd floor of Knoy Hall. The other location is in the Envision Center located on Purdue's campus. These two different locations for the Virtual Reality training modules should not have any effect on the data collected.

The participants will all be students who will be registered for the Building Construction Management Departments Construction Safety Couse in the spring of 2019. The expected enrollment for the course is around 140 students. From this group 20 students will be selected to complete the Virtual Reality training modules. The remainder of the participants will take part in the traditional lecture for the fall protection safety portion of the class.. After all pre-tests and post-tests are completed all participants that have an identifiable matching pre-test and post-test, will be analyzed for an improvement in score.

3.4 Instrumentation

There will be one (1) Virtual Reality Head Mounted Display (HMD) that will be used for the fall protection safety training modules. This headset will be an HTC VIVE. There will be one (1) backup HTC VIVE HMD that is owned by the CGT department. This will be used in case of scheduling conflicts, extended malfunction of the main HMD, or other unexpected circumstances with the main HMD. The potential for using two separate HMD's for this research will not have any significant impact on the data. They will both function in a similar matter and no participant will be asked to use both HMD's.

3.5 Procedures

This section will detail the procedures that will be used to collect the data for the different teaching methods. Before students are selected for either the Virtual Reality training modules or the traditional teaching methods, there will be a few introductory steps. Students will receive credit in the class for completing the pretest and posttest. Students will receive credit even if their test scores are not randomly chosen for analysis.

Research Introduction:

1. Research Study will be introduced to all members of the construction safety class.
2. Pretest will be administered to all participants. The pretest will be the same for each group.

Now the procedures will be broken down by the specific training that each participant will receive.

Virtual Reality: (20 tests selected at random from total group.)

1. Participants will be asked to sign a waiver.
2. Participants will be given instruction on how to use and operate the Virtual Reality Head Mounted Displays for the training modules.
3. Participants will complete all six (6) fall protection safety training modules outside of standard class periods. All six (6) modules will be introduced and completed within one session with breaks, unless unforeseen circumstances occur. The sessions will last between 1.5 to 2 hours long.
    a. Module 1: Fall Protection Basics
    b. Module 2: Harnesses and Lanyards
    c. Module 3: ABCDs of Fall Protection
    d. Module 4: Ladders
    e. Module 5: Scaffolding
    f. Module 6: Flat Roof Safety
4. Posttest will be administered to participants during the next class period following the completion of the training modules.

Traditional Teaching: (Remaining participants not partaking in Virtual Reality Training)

1. Participants will be asked to sign a waiver.
2. Participants will be given instruction on fall protection safety, including a lecture and PowerPoint. Students will receive 90 minutes of lecture on fall protection safety in accordance with the OSHA guidelines for OSHA 30 certification.
3. Posttest will be administered to participants during the next class period following the 8completion of the lecture and PowerPoint.

Following the completion of Posttests by all participants, all of the pre-tests and post-tests that can be matched together will be analyzed as per the process detailed in the next section.

3.6 Data Processing and Analysis

Data processing and analysis will be completed through the use of the difference-in-differences method and with the help of the statistics lab located on Purdue University's campus. Difference-in-differences is a good analysis method to use in educational settings because it helps to detect and account for differences in two test groups. In the current research the students receiving traditional instruction on fall protection safety will be considered the control group. Students participating in the Virtual Reality modules will be considered to have received the treatment. Difference-in-differences takes measures in both pre-treatment and post-treatment time periods (Lechner, 2010), in this case the pretest and posttests. "Assuming that the treatment happens between the two periods means that every member of the population is untreated in the pre-treatment period." (Lechner, 2010, p.9). Having the treatment occur between measurement periods is key to the research and is the reason that students who have not had safety training before will be the population for the study. Difference-in-differences will be the method used to analyze the data on a whole group basis, the Statistics Lab at Purdue University will be used to help produce the analysis by this method.

Data will also by analyzed on a question by question basis. This analysis will be done to see if either treatment method would be more effective in teaching certain more detailed subjects under the wider net of fall protection. The analysis for this section of the data will be done on a case by case basis. For the data there are three available cases a description of the cases can be found in the table below. Case 2 will be the main case looked at when analyzing each question. Case 2 shows when a participant improved on a question whereas Case 1 only shows that the participant did not improve whether they answered they answered the question correctly or incorrectly. This data will not be tested for significance as this is not the primary area of analysis for this research but rather supplements the data analyzed for the entire group.

Table 3.1 Question by Question Analysis Cases

Question by Question Analysis Cases		
	Condition 1	Condition 2
Case 1	0-0	1-1
Case 2	0-1	N/A
Case 3	1-0	N/A

3.7 Ethical Considerations

When doing research using Virtual Reality systems there are some ethical considerations that need to be covered. These ethical considerations that effect Quasi-experimental research are respect for persons, beneficence, justice, and respect for communities. The first three considerations are detailed in the Belmont Report. The first consideration is respect for persons. This covers autonomy, in other words it “allows people to make their own choices and decisions.” (Miracle, 2016, p.225). To make sure that this principle is followed participants will be informed that they are allowed to withdraw from the training modules at any point in time, if they so choose.

The second principle is beneficence, having two parts. According to Miracle (2016, p.225) beneficence, "there are two rules to guide research…do no harm and increase potential benefits and decrease possible adverse events or harm." The major concern deals with participants using the Virtual Reality Head Mounted Display's for the Virtual Reality training modules. There are several different side effects that can occur from the use of a Head Mounted Display. In a study by Sharples, she states that "From data obtained from over 200 participants, 80% of participants across all experiments reported some experience of VR induced symptoms. For most people these were mild and short-lived but 5% of participants experienced symptoms so severe that they had to end their period of VR exposure" (Sharples, 2007, p.59). This is a major concern for research using Virtual Reality. To handle this all participants will be required to sign a waiver that details all of the potential side effects of using a Head Mounted Display. The third consideration is justice. Miracle (2016, p.226) states that "Risks and benefits, if known, must be made known to potential subjects or participants in research." The risks and benefits of the research will be made know to the potential participants when the research is introduced and then again in the waiver that participants will be asked to sign. The final consideration falls outside of the Belmont Report. "Respect for communities confers on the researcher an obligation to respect the values and interests of the community in research and wherever possible, to protect the community from harm" (Weijer, 1999, p.275). This consideration looks to protect the participants and the community or group they are a part of as a whole during the research. The ethical considerations for the current research will be carried out in accordance with these four areas of ethical principles that are commonly used for research involving human participants.

3.8 Bias

There are five major areas that bias can develop as outlined in research by Smith and Noble. These areas of bias are: Design bias, Selection bias, data collection/measurement bias, analysis bias, and publication bias (Smith, 2014). Design bias occurs when the beliefs of the researcher(s) influence parts of the research. Selection bias according to Smith (2014, p.101), “relates to both the process of recruiting participants and study inclusion criteria.” The current research is intended to benefit students in construction safety courses, which is where participants will be recruited from. The next area of bias is data collection and measurement bias. This will be avoided by collecting objective quantitative data from the scores of the pretest and posttest that the participants will complete. All equipment will be calibrated to manufacture’s standards to avoid measurement bias. To avoid analysis bias where, “the researcher may naturally look for data that confirm their hypotheses” (Smith, 2014, p.101), the statistics lab on Purdue University’s campus will be used to analyze the data collected. The final type of bias outlined by Smith and Noble is publication bias. This occurs in quantitative research often because publishers are more likely to publish research where data is statistically significant (Smith, 2014). All of these types of bias will be avoided in the current research as much as possible to keep the integrity of the study intact.

3.9 Summary

This chapter covered the research methodology and other related areas. These include the theoretical framework, setting and participants, instrumentation, procedures, data processing and analysis, and ethical considerations. These areas cover what the study will be attempting to accomplish. They also cover how this will be done and give a background from previous research to validate the methodology.

CHAPTER 4. RESULTS

4.1 Introduction

This chapter will describe how the data was analyzed, along with how the data relates back to the research question, theoretical framework, and relevant previous research. The data that was collected was strictly quantitative, to directly compare traditional teaching methods in construction fall protection safety to Virtual Reality fall protection training modules. Data will first been analyzed from a perspective of the averages of all participants in the study. From here the more detailed analysis will be done using participants where the pre-test and post-test data was able to be matched to one another. The second part of the data analysis will be completed using a difference-in-differences method. This method was used to determine if there was a significant difference between the changes in scores from the pre-test to the post-test for each group. Test scores will be analyzed on a large group level for the tests as a whole and also on a per question basis. This was done to see if traditional education or Virtual Reality safety training was better suited for different topics within fall protection safety training. The data analyzed on the question by question basis will not use the difference-in-differences method but rather a three case basis to compare the two group's results.

4.2 Full Test Analysis

The first part of the analysis is to break the data down by group, while showing both the pre-test and post-test scores. From that point, the difference in score is presented as can be seen in Table 4. This is the statistic that will be used in the whole test analysis for the difference-in-differences method. After the collection of data, it was determined that question #6 was a faulty question, as all four of the multiple choice answers that were listed were correct answers. This question was removed from the final scores of both the pre-test and post-test to reduce the total number of questions from 24 down to 23. Seen below in Table 4, are the results of the pre-test and post-test scores, then the difference in score between the two of them by participant. This was the raw data that was used to further analyze the research to answer the research question.

Table 4.1 Full Test Results and Analysis

Group	Test Number	Pre-Test Score	Post-Test Score	Score Difference
1	19	0.565	0.87	0.305
1	21	0.652	0.87	0.218
1	29	0.696	0.652	-0.044
1	45	0.478	0.609	0.131
1	50	0.478	0.5	0.022
1	51	0.478	0.696	0.218
1	54	0.522	0.783	0.261
1	55	0.696	0.696	0.000
1	59	0.609	0.652	0.043
1	60	0.522	0.783	0.261
1	68	0.391	0.783	0.392
1	71	0.652	0.826	0.174
1	109	0.478	0.652	0.174
1	134	0.609	0.793	0.184
2	1	0.478	0.783	0.305
2	4	0.478	0.913	0.435
2	8	0.478	0.478	0.000
2	9	0.565	0.652	0.087
2	10	0.435	0.522	0.087
2	15	0.565	0.696	0.131
2	17	0.565	0.696	0.131
2	23	0.696	0.87	0.174
2	25	0.696	0.739	0.043
2	26	0.565	0.739	0.174

Table 4.1 continued

2	46	0.435	0.565	0.130
2	72	0.609	0.87	0.261
2	77	0.565	0.87	0.305
2	79	0.652	0.826	0.174
2	80	0.652	0.87	0.218
2	81	0.478	0.696	0.218
2	87	0.435	0.696	0.261
2	93	0.261	0.652	0.391
2	97	0.565	0.609	0.044
2	99	0.478	0.522	0.044
2	102	0.391	0.739	0.348
2	103	0.435	0.87	0.435
2	107	0.478	0.696	0.218
2	110	0.478	0.739	0.261
2	112	0.609	0.696	0.087
2	115	0.478	0.739	0.261
2	120	0.522	0.696	0.174
2	125	0.652	0.739	0.087

After the data was gathered, it was entered into IBM SPSS Statistics (SPSS). This is a common statistical tool that is often provided to students at research universities for research analysis. Data was analyzed to determine if there was a significant difference, in the difference of scores from the pre-test to the post-test scores, of each participant by group. To determine if the results were significant, the data analysis will use a P-value of .05. This is a standard significance level used for this type of research. Beyond the strictly numerical results of the research the data will be interpreted to understand the larger context of the research and analysis.

To begin the analysis, the difference in test scores was entered into an independent sample t-test analysis in SPSS. There were two distinct tables that the software presented as the results of the independent sample t-test. The first was the Group Statistics table and the second was the Independent Samples Test. The Group Statistic table gives basic information about the two groups results including, amount of participants in each group, the mean answer, as well as the standard deviation for each groups data. There are a few important interpretations that need to be made from this table. First the N-Value is the number of participants in each group. This is

Table 4.2 Group Statistics

Variable	Groups	N	Mean	Std. Deviation	Std. Mean Error
Difference	Group 1	14	0.1671	0.12497	0.0334
	Group 2	28	0.1959	0.119884	0.02265

important to note that the number of participants where their pre-test and post-test were able to be matched was limited to 14 for the Virtual Reality training group and 28 tests for the traditionally instructed group. From there the next two columns cover the mean and standard deviation for both groups. When comparing these, there is little difference between the two group's statistics. This is the first major indicator that there may not be a significant difference between the two groups improvement after instruction. To test specifically for statistical significance the next table produced by SPSS gives direct significance values.

Table 4.3 Independent Samples Test

		Levene's Test for Equality of Variances				
Variable		F	Sig.	t	df	Sig. (2-tailed)
Difference	Equal Variance Assumed	0	0.990	-0.724	40	0.474
	Equal Variance Not Assumed	0	0	-0.713	25.144	0.482

Table 4.3 continued

Independent Samples Test Cont.			
t-test for Equality of Means		95% Confidence Interval of the Difference	
Mean Difference	Std. Error Difference	Lower	Upper
-0.02879	0.03978	-0.10919	0.05162
-0.02879	0.04036	-0.11187	0.05430

When analyzing the Independent Samples Test shown above, the first thing that needs to be determined is which row, Equal Variance Assumed or Equal Variance Not Assumed, will be used for the analysis. To determine this, Levene's Test for Equality of Variances must be analyzed. If the significance value (Sig.) is greater than .05 then the row for Equal Variances Assumed must be used. In this case the significance value is .990, therefore the Equal Variances Assumed row will be used. From this point, there are two different parts of the table that show whether the difference of improvement between the two groups is significant. These parts are Significance (2-tailed) and the 95% confidence interval. Understanding the 2-tailed Significance statistic is simple, if the value of the statistic is greater than .05 then the result of the Independent t-test shows that there is no significant difference in the improvement in score by either group. In this case the P-Value that is given is .474, showing that the study found participants instructed with Virtual Reality Fall Protection Safety Training did not score significantly higher than participants who were instructed using traditional education methods. This is reinforced by the information presented in the 95% confidence interval. Due to the fact that the Lower end of the statistic falls under zero and the Upper end is above zero, then there is no way to say if one group or the other could be predicted, with enough statistical confidence, to score higher than the other. If the Lower and Upper were both negative and positive, then it would allow for the research to have confidence that one group would show a greater significant improvement over the other. This result at a broad level answers the research question when analyzing the results for the two group's tests. The larger implications of this result will be discussed in Chapter 5, to compare this result to that of previous research. The next step is to analyze the results on a question by question basis.

4.3 Question by Question Analysis

This method of analysis breaks down the pre-test and post-test answers on an individual question basis. Analyzing each question for each participant allows detection of differences by more detailed subject matter, under the larger blanket of fall protection education as a whole. As stated in Chapter 3, this analysis was completed on a three case basis. Table 3.1 covers each case in detail. For a brief review, the three cases are: Case 1; no change in score from the pre-test to the post-test either getting both right or both wrong, Case 2; improvement in score from the pre-test to the post-test, and Case 3; decrease in score from the pre-test to the post-test. These cases are looked at specifically on a per question basis. The analysis of each question in response to how many participants each fell into that case will be commented on in Table 7 below. After the data is presented in the table, certain important elements will be extracted and expanded upon in more detail. Again, the same as for the whole test analysis, question #6 was removed from the data due to the fact that all potential answers on the test were considered valid answers.

Table 4.4 Case Based Question by Question Analysis

Question: Employees on a walking/working surface with an unprotected side or edge that is ________ or more above a lower level must be protected from falling by the use of guardrail systems, safety net systems, or personal fall arrest systems.				
Answer: 6 Feet				
Question #1				Comments: This question tests one of the most common pieces of fall protection knowledge. Many participants may have known this from previous experience.
Group	Case 1	Case 2	Case 3	
Group 1	12	2	0	
Group 2	11	1.5	1.5	
Question: The top-rail of a guardrail system must be able to withstand a force of _______ pounds.				
Answer: 200 Pounds				
Question #2				Comments: This is an question that connects to a physical thing on a construction site, giving a good visual for VR training.
Group	Case 1	Case 2	Case 3	
Group 1	8	4	2	
Group 2	10.5	2	1.5	
Question: If wire rope is used for top-rails on a guardrail system, then it must be flagged at intervals of ________ or less with high-visibility material.				
Answer: 6 Feet				
Question #3				Comments: This question saw large amounts of improvement from both groups. This is a somewhat detailed question that many participants would most likely not have had previous knowledge on.
Group	Case 1	Case 2	Case 3	
Group 1	6	5	3	
Group 2	7.5	5.5	1	
Question: When should you inspect the components of personal fall-arrest, restraint, or positioning-device systems for damage or excessive wear?				
Answer: Before and after each use				
Question #4				Comments: This was a large topic in both traditional and VR instruction, leading to similar amounts of improvement.
Group	Case 1	Case 2	Case 3	
Group 1	12	2	0	
Group 2	10.5	2.5	1	

Table 4.4 continued

Question: True or False: Do not use a personal fall-arrest system that has arrested a fall unless a competent person has determined that the system is safe to use.				
Answer: False				
Question #5				Comments: This question is worded somewhat poorly possibly leading participants to be confused over the intended answer.
Group	Case 1	Case 2	Case 3	
Group 1	10	2	2	
Group 2	8.5	4	1.5	
Question: When inspecting snap-hooks, which of the following defects should be looked for?				
Answer: Cracks, excessive wear, and corrosion				
Question #7				Comments: There is a large section of module 2 in the VR training that goes over this question. Possibly giving more detailed instruction on the topic.
Group	Case 1	Case 2	Case 3	
Group 1	11	2	1	
Group 2	12.5	0.5	1	
Question: The anchor point (where you hook your lanyard) must be able to support _____________.				
Answer: 5,000 Pounds				
Question #8				Comments: Both groups saw marked improvement on this question. Similar to question #3 this is a detailed number that participants would mostly likely not have previous knowledge on.
Group	Case 1	Case 2	Case 3	
Group 1	7	7	0	
Group 2	7.5	5.5	1	
Question: When using a harness and lanyard for fall protection, what is the minimum allowable distance (in feet) from the anchorage point to the lower surface?				
Answer: 18.5 Feet				
Question #9				Comments: This question requires some small amounts of calculation to determine the distance. Some participants may have rushed through this leading to many scores remaining the same.
Group	Case 1	Case 2	Case 3	
Group 1	12	2	0	
Group 2	10	3	1	

Table 4.4 continued

Question: Keep your lanyard (including retractable lanyards) within a ______ cone of the anchor point in order to minimize the swing fall hazard.				
Answer: 30°				
Question #10				Comments: Both groups saw marked improvement on this question. Similar to question #3 and #8 this is a detailed number that participants would mostly likely not have previous knowledge on.
Group	Case 1	Case 2	Case 3	
Group 1	6	7	1	
Group 2	8	5	1	
Question: True or False: It is safe to stand on the top two steps of a step ladder as long as you do not have to reach to high.				
Answer: False				
Question #11				Comments: Almost every participant showed no improvement on this question. This is a common standard even outside of construction leading to many participants having previous knowledge.
Group	Case 1	Case 2	Case 3	
Group 1	14	0	0	
Group 2	13.5	0.5	0	
Question: What should you do if you find a broken ladder?				
Answer: Mark or tag it as broken and taken out of service				
Question #12				Comments: While important this question relies on the common sense of the participants to know the correct answer.
Group	Case 1	Case 2	Case 3	
Group 1	14	0	0	
Group 2	14	0	0	
Question: Your ladder is supported by a point 24 feet above the ground. How far from the wall should use at the base of the ladder to get the correct ladder slope?				
Answer: 6 Feet				
Question #13				Comments: Again questions that are more detail oriented parts of fall protection see greater improvement overall in both groups.
Group	Case 1	Case 2	Case 3	
Group 1	6	8	0	
Group 2	6.5	6.5	1	

Table 4.4 continued

Question: When using/setting up/dismantling/moving ladders or scaffolding, what is the minimum distance you should stay away from overhead power lines that are less than 50kV?				
Answer: 10 Feet				
Question #14				Comments: This is another question where strong visuals can be used to help reinforce the answer to the question leading to a higher improvement rate for the VR training.
Group	Case 1	Case 2	Case 3	
Group 1	8	5	1	
Group 2	11	3	0	
Question: An extension ladder must extend _______ above the landing to provide a handhold for getting on and off the ladder.				
Answer: 3 Feet				
Question #15				Comments: Almost every participant showed no improvement on this question. This is a common standard even outside of construction leading to many participants having previous knowledge.
Group	Case 1	Case 2	Case 3	
Group 1	11	2	1	
Group 2	11.5	1.5	1	
Question: True or False: cross bracing can be used when climbing onto scaffolding.				
Answer: False				
Question #16				Comments: There were very frew cases of improvement on this question. This would seem to be due to either common knowledge or previous experience.
Group	Case 1	Case 2	Case 3	
Group 1	13	1	0	
Group 2	11.5	1.5	1	
Question: For OSHA regulations, fall protection (i.e guardrails or harnesses & lanyards) is required on scaffolding when working height reaches _____________.				
Answer: 10 Feet				
Question #17				Comments: This result was surprising as this was another topic that benefits from strong visuals, however in this case the participants receiving traditional instruction improved at over 3 times the rate of the participants of VR training.
Group	Case 1	Case 2	Case 3	
Group 1	9	3	2	
Group 2	4.5	9.5	0	

Table 4.4 continued

Question: When selecting a ladder based on its duty rating, which is NOT taken into consideration?				
Answer: Duration the worker will occupy the ladder				
Question #18				Comments: This question saw little improvement from either group.
Group	Case 1	Case 2	Case 3	
Group 1	13	1	0	
Group 2	10	2.5	1.5	
Question: Ladders or other safe means of access are required to access scaffolding which is more than _______ in height.				
Answer: 2 Feet				
Question #19				Comments: This question saw little improvement from either group.
Group	Case 1	Case 2	Case 3	
Group 1	11	1	2	
Group 2	13	1	0	
Question: Scaffolds with a height to base ratio of more than _______must be restrained from tipping.				
Answer: 4 to 1				
Question #20				Comments: Both groups saw a good amount of improvement on this question. This is another detailed topic that many participants would now have previous knowledge on.
Group	Case 1	Case 2	Case 3	
Group 1	8	5	1	
Group 2	8	5	1	
Question: At what height do roofers need fall protection?				
Answer: 6 Feet				
Question #21				Comments: This question saw VR training participants improve markedly over traditional instruction participants for unknown reasons.
Group	Case 1	Case 2	Case 3	
Group 1	8	6	0	
Group 2	10	0.5	3.5	

Table 4.4 continued

Question: True or False: OSHA allows the use of Safety Monitors on low-sloped roofs (less than 4 vertical to 12 horizontal slope) instead of guardrails, personal fall arrest systems, or safety nets.				
Answer: True				
Question #22				Comments: This topic saw the traditional participants improve at double the rate of VR training. This was one of the very last topics covered in the VR training, participants may have become less invested in the training at this point in time.
Group	Case 1	Case 2	Case 3	
Group 1	5	4	5	
Group 2	5	8	1	
Question: For OSHA regulations, warning flags can be used to mark the perimeter of low-sloped roofs. What is the minimum distance from the edge that the warning line can be located if mechanical equipment IS NOT being used on the roof?				
Answer: 6 Feet				
Question #23				Comments: This topic saw the traditional participants improve at double the rate of VR training. This was one of the very last topics covered in the VR training, participants may have become less invested in the training at this point in time.
Group	Case 1	Case 2	Case 3	
Group 1	9	3	2	
Group 2	7	6	1	
Question: For OSHA regulations, warning flags can be used to mark the perimeter of low-sloped roofs. What is the minimum distance from the edge that the warning line can be located if mechanical equipment IS being used on the roof?				
Answer: 10 Feet				
Question #24				Comments: This again shows that the most improvement is seen in detail oriented questions. There was a greater amount of improvement in the traditional instruction group for unknown reasons.
Group	Case 1	Case 2	Case 3	
Group 1	9	5	0	
Group 2	5.5	8	0.5	

One of the most surprising and unexpected trends that presented itself in the data was for several questions, the amount of participants that fell into Case 1 heavily outweighed the number of participants that were in Case 2 and Case 3 combined. This points to a few different outcomes. Case 1 is achieved by seeing no improvement in score, due to this any participant with prior knowledge of the subject for a question will generally score in Case 1. The other way to score in Case 1 is for the participant to answer the question wrong on both the pre-test and post-test. This shows that whichever method that they were instructed in, did not see them retain the information presented. As would be suspected Case 3 saw the lowest amount of tallies. Participants second guessing themselves or misunderstanding the question are the two most likely causes of scoring in Case 3. The results of the data for the whole group analysis would make one think that that almost every case would have the same amount of marks, this was not true as each group saw improvement on different questions from one another. For the analysis, if there was a spread in the results for Case 2 by more than two points, it was concluded that there was some reasoning that one group saw a higher rate of improvement rate than the other. This did not occur for most questions. More specific trends and unexpected outcomes of the question by question analysis will be covered in Chapter 5.

For the question by question analysis the research question is answered in three different ways, for different questions. First, in some cases the improvement in scores for each group is the same or similar. Second, for some questions participants in the Virtual Reality training group saw a notable improvement over participants who were given traditional education in fall protection. Lastly, the remaining question participants of the traditional education group saw a notable improvement over participants in the Virtual Reality training group. These three scenarios cover the results of each of the 23 questions that were used for the question by question analysis.

4.4 Summary

Chapter 4 completed the analysis over the data that was collected for the research. It was analyzed using two different methods. First, for the whole test, the difference in differences method was used. This was done using a statistical analysis software to determine if the result of the data was significant. After this the data was analyzed on a question by question basis. This was done to see if either of the two groups improved more in specific subject areas. The data was interpreted from a strictly numerical perspective, into a tangible way to understand the findings of the research. Finally, the answer to the research question was presented for each analysis method. Moving into the final chapter, the interpretation of the data will be used to further analyze results and make conclusions over the data. This will be done by identifying different patterns and themes that are found throughout the data for each analysis method.

CHAPTER 5. ANALYSIS AND SYNTHESIS

5.1 Introduction

Chapter 5 will be an analysis and synthesis of information provided in the first four chapters of the master's thesis. This chapter will also include a discussion, analyzing the results. Chapter 5 will also cover how data collection methods may have had an impact on the results and analysis along with other unanticipated factors that may have impacted the research. Finally, commentary will be made on findings from the data that were not anticipated and also potential areas or topics for future research on this subject.

5.2 Discussion

The discussion over the research will cover the data collected in three different ways. First, whole group averages and general baselines will be identified. This was done to begin to see initial trends in the data before analysis software was used. Second, the data will be looked at from a whole test perspective, covering the average change in score for the two groups. This is separate from whole group as it isolates and compares the difference in improvement for each group. Finally, data will be interpreted on a question by question and subject basis. The question by question analysis was only completed for participants who's pre-test and post-test could be matched. This will show if one group or the other saw more improvement in certain subject areas. Also, this will can help to determine if some subject areas need more or less coverage in the training or classroom lectures.

5.2.1 Baseline Data

Table 8 below covers the baseline data for all participants of the study. To begin the study there were 140 total participants that completed the pre-test. From this point, participants were asked to volunteer and participate in the Virtual Reality training modules as one of the requirements for the IRB exemption that was given for this research. There were two groups for this research, participants that took part in the Virtual Reality training will be referred to as Group 1 and participants who received traditional instruction will be referred to as Group 2. There were 24 participants that volunteered to be part of Group 1. Of this number, 2 participants in Group 1 did not complete the training giving Group 1 an attrition rate of 8.33%. The remaining participants (116) made up Group 2 for the traditional educational portion. For Group 2, only 96 of the 116 participants completed the post-test. This gave Group 2 an attrition rate of 17.24%. These rates are important to the research due to the fact that if they are too high it may limit the type or overall ability to complete statistical analysis over the data. The attrition rates for this research were not high enough for this to occur. However, beyond this for the statistical analysis, participant's pre-tests and post-tests could only be used if they could be matched together. This occurred for only 14 participants in Group 1 and 28 participants in Group 2.

Table 5.1 Overall Test Data

Overall Test Data					
Pre-Test		VR Post-Test		Traditional Post-Test	
AVG	0.533	AVG	0.701	AVG	0.704
High	0.792	High	0.875	High	0.917
Low	0.208	Low	0.500	Low	0.417
Median	0.542	Median	0.729	Median	0.708

As can be seen in Table 8 above the final overall average score for each group had a final difference of .03%, .701 for Group 1 and .704 for Group 2. While this cannot be tested for significance because of the inability to match a pre-test to a post-test, it does show that both groups did learn and retain a significant amount of the information presented to their group. This is also a first indication when looking at the data that there is no significant difference between the increases in score of the two groups.

5.2.2 Difference-in-Differences Test Analysis

The difference-in-differences analysis method compares the difference of a condition, in this case the score of the pre-test and post-test, before and after a treatment is applied. Then, the two different groups score differences are compared through the use of independent t-tests to determine if the difference between them is significant or not. From there, the research question is answered in reference to the significance or insignificance of the data that was analyzed.

The data that was collected for this research ultimately showed that there was not a significant difference between the improvement in scores of the Virtual Reality training and traditional education groups. This conclusion, is different from the majority of previous research which shows that Virtual Reality educational tools are generally more effective than traditional methods. For this research there are a few reasons that the conclusions do not match the results of previous research. To begin, this is the first time that these Virtual Reality fall protection training modules have had data collected from them to test the effectiveness of the tool for teaching. This might have led to inefficiencies in the modules themselves and the way that they were presented to the participants. In future rounds of testing of the Virtual Reality modules, it could benefit the training to tweak the process somewhat. Two major changes that could be made would be to break the Virtual Reality training into two sessions and also provide participants with some printed information to take home based on parts of the training they deem to be important. Another major part of this research that was not able to be tested, due to the time constraints on the study, was long-term retention of information. After the training was completed by the participants, all post-tests were then completed within a week of instruction. Testing the information after several months' time had passed would be another indicator to determine if one educational method was more effective than the other. Through different iterations of testing on the training modules and a longer testing period results may become more consistent with the findings of previous research on the subject

5.2.3 Case Based Question by Question Analysis

This part of the discussion covers the data collected on a case based question by question analysis. The questions were not tested to see if there was a significant difference between the groups, for the three cases using t-tests or other methods using statistical software. To start, there were 8 questions where Case 2 (0-1 improvement in score) was within one score either way for the two groups. Another interesting trend for the majority of questions, saw more scores remain the same, falling under Case 1, rather than improving. Questions 11 and 12 saw this to an extreme

Table 4.4 Case Based Question by Question Analysis #11

<table>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5">Question: True or False: It is safe to stand on the top two steps of a step ladder as long as you do not have to reach to high.</td></tr>
<tr><td colspan="5">Answer: False</td></tr>
<tr><td colspan="4">Question #11</td><td rowspan="4">Comments: Almost every participant showed no improvement on this question. This is a common standard even outside of construction leading to many participants having previous knowledge.</td></tr>
<tr><td>Group</td><td>Case 1</td><td>Case 2</td><td>Case 3</td></tr>
<tr><td>Group 1</td><td>14</td><td>0</td><td>0</td></tr>
<tr><td>Group 2</td><td>13.5</td><td>0.5</td><td>0</td></tr>
</table>

Table 4.4 Case Based Question by Question Analysis #12

Question: What should you do if you find a broken ladder?				
Answer: Mark or tag it as broken and taken out of service				
Question #12				Comments: While important this question relies on the common sense of the participants to know the correct answer.
Group	Case 1	Case 2	Case 3	
Group 1	14	0	0	
Group 2	14	0	0	

extent, with all but one participant's score remaining the same. Overall between the two groups the questions that saw the highest increase in score, were on the subject of fall protection for roofers. Each of the four questions that covered fall protection for roofers saw one group or the other show a sizeable improvement over the other. Question 21 was the most drastic with Group 1 improving

Table 4.4 Case Based Question by Question Analysis #21

Question: At what height do roofers need fall protection?				
Answer: 6 Feet				
Question #21				Comments: This question saw VR training participants improve markedly over traditional instruction participants for unknown reasons.
Group	Case 1	Case 2	Case 3	
Group 1	8	6	0	
Group 2	10	0.5	3.5	

6 to .5 over Group 2. For the remaining three questions covering fall protection for roofers, Group 2 saw the greater amount of improvement. This result for the questions over fall protection for roofers leading to the idea that, even within fall protection studies the information should be broken down in depth into smaller subject areas. This would allow for a better understanding of which subjects under fall protection many benefit more from one instruction method over the other.

Overall both sets of analysis do not show that one group saw a significant improvement over the other. The results show that both methods of analysis achieved similar results for each research group. There are a wide range of factors that could affect the results. Many of these are unforeseen variables that were encountered or uncovered, either during data collection or shortly after completing data collection.

The first of these was a variable that was anticipated, but could not be accounted for with the test group. The variable is that students at this level of education have become accustomed to and understand how to learn in a traditional education setting. The participants would have limited to no experience learning in a virtual environment, thus potentially negatively affecting the scores of Group 1.

The next variable occurred due to an unanticipated change in the class schedule. This change to the original class schedule placed an official test for the class to take place the following week after the post-test was taken. Some participants may have already began to study the information for the class test over the subject matter. This would have positively affected their scores increasing the overall average for Group 2.

During several sessions of the Virtual Reality training, the HMD malfunctioned forcing the participant to take a break and give time for the headset and training program to be reset. This caused an abrupt disruption to the training that could break the focus of the participant. This could lead to them possibly retaining less information from that specific module. On the other hand despite this, the Virtual Reality training does offer a one on one training opportunity for the participants. In previous research it is shown that this type of instruction has a positive impact on the participant.

The last unknown variable that impacted the study was previous knowledge on fall protection safety of the participants. It was known that some participants may have had some previous knowledge due to prior work experience and other education. However, this impact would seem to have been much greater than anticipated. This was due to some of the data from the question by question analysis. All of these different variables had an impact on the research and the data that was collected for the study. Understanding that these variables were present and how they effected the research will be crucial to future research efforts.

5.3 Critical Evaluation of Study

This study over Virtual Reality education in Construction Fall Protection Safety was able to answer the research question presented earlier in the thesis. The research was done using strictly quantitative data to test if one instruction method was more effective at teaching participants the content. One of the areas that could have been greatly improved upon was the collection and matching of the participant's pre-tests and post-tests. Being granted an exemption by the IRB for the research did allow for the study to be completed in a timely manner. However, it did require that no personal information of the participants be collected. This made matching the pre-tests and post-tests much more difficult. The research covers whether one instructional method was more effective at teaching the participants the content, however, due to time constraints, the study was not able to test knowledge retention which is important to educational studies. The last piece of the study that could make a large difference, was that the participant group came from the same relative demographic. It may have benefitted the research to expand the participant group to a wider range of demographics. Overall, the research did reach a conclusion and answered the research question that was presented.

5.4 Future Research and Direction

This study was one of the first pieces of research to test Virtual Reality training for fall protection safety in construction. While the research question was relatively simple, throughout the research process literature review, theoretical framework, methodology, data collection, and data analysis many other relevant questions were brought to light. The first of these was about long term retention. The results from the two groups in this study were relatively similar but in previous research Virtual Reality has been shown to be effective in the long term, due to its visuals and one on one instruction. Testing the long term retention of the information presented in the Virtual Reality training modules is an important step in the process. The next area for future research is to understand if Virtual Reality training or traditional methods are more effective by subject within fall protection safety. Some of this could be seen through the question by question analysis. However, a more detailed, comprehensive study could be completed to understand this better. Finally this same research could be done but a third group added into the study. Introducing a mixed methods education group may provide the best improvement scores. This could take all the benefits found from both Virtual Reality training and traditional education methods to provide an overall improved take on construction safety training as a whole. This research study concluded that there is neither group saw a significant amount of improvement in test score over the other when comparing Virtual Reality training to traditional education methods for fall protection safety in construction. This was the conclusion after reviewing previous literature, developing a framework and methodology, collecting data, and analyzing the data. There are many areas that this study could be improved upon and other similar areas for other future research to be conducted.

5.5 Summary

This research study concluded that there is neither group saw a significant amount of improvement in test score over the other when comparing Virtual Reality training to traditional education methods for fall protection safety in construction. This was the conclusion after reviewing previous literature, developing a framework and methodology, collecting data, and analyzing the data. There are many areas that this study could be improved upon and other similar areas for other future research to be conducted.

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APPENDIX A. PRE-TEST AND POST-TEST

Pre-Test

Level II Evaluation Plan –fall protection basics, harnesses/lanyards, ladders, scaffolding, flat roofs

Questions 1-24 Instructions- CIRCLE the best answer to the following multiple-choice or true/false questions:

1. Employees on a walking/working surface with an unprotected side or edge that is ________ or more above a lower level must be protected from falling by the use of guardrail systems, safety net systems, or personal fall arrest systems.
   a) 2 feet
   b) 6 feet
   c) 8 feet
   d) 12 feet

2. The top-rail of a guardrail system must be able to withstand a force of _______ pounds.
   a) 50 pounds
   b) 100 pounds
   c) 150 pounds
   d) 200 pounds

3. If wire rope is used for top-rails on a guardrail system, then it must be flagged at intervals of ________ or less with high-visibility material.
   a) 6 feet
   b) 10 feet
   c) 15 feet
   d) 20 feet

4. When should you inspect the components of personal fall-arrest, restraint, or positioning-device systems for damage or excessive wear?
   a) Once a week
   b) Once a day
   c) Before and after each use
   d) As needed or directed

5. True or False: Do not use a personal fall-arrest system that has arrested a fall unless a competent person has determined that the system is safe to use.

6. Which of the following should be looked for when inspecting harness webbing?
    a) Frayed edges
    b) Cracks, breaks, rough or sharp edges
    c) Loose, bent or broken grommets
    d) Stiffness and cracking

7. When inspecting snap-hooks, which of the following defects should be looked for?
    a) Cracks, excessive wear, and corrosion
    b) Broken fibers and pulled stitches
    c) Chemical damage
    d) Cuts and burns

8. The anchor point (where you hook your lanyard) must be able to support ______________.
    a) 2 times your body weight (safety factor of 2)
    b) 200 pounds
    c) 4 times your body weight (safety factor of 4)
    d) 5000 pounds

9. When using a harness and lanyard for fall protection, what is the minimum allowable distance (in feet) from the anchorage point to the lower surface?
    a) 6 feet
    b) 8 feet
    c) 10 feet
    d) 18.5 feet

10. Keep your lanyard (including retractable lanyards) within a ______ cone of the anchor point in order to minimize the swing fall hazard.
    a) 30°
    b) 45°
    c) 60°
    d) 90°

11. <u>True or False</u>: It is safe to stand on the top two steps of a step ladder as long as you do not have to reach to high.

12. What should you do if you find a broken ladder?
    a) Try to fix it
    b) Mark or tag it as broken and taken out of service
    c) You can use it, but only for a few minutes

13. Your ladder is supported by a point 24 feet above the ground. How far from the wall should use at the base of the ladder to get the correct ladder slope?

a) 2 feet
b) 4 feet
c) 6 feet
d) 8 feet
e) 12 feet

14. When using/setting up/dismantling/moving ladders or scaffolding, what is the minimum distance you should stay away from overhead power lines that are less than 50kV?
    a) 5 feet
    b) 6 feet
    c) 8 feet
    d) 10 feet

15. An extension ladder must extend _______ above the landing to provide a handhold for getting on and off the ladder.
    a) 1 foot
    b) 2 feet
    c) 3 feet
    d) 6 feet

16. True or False: cross bracing can be used when climbing onto scaffolding.

17. For OSHA regulations, fall protection (i.e guardrails or harnesses & lanyards) is required on scaffolding when working height reaches _____________.
    a) 4 feet
    b) 6 feet
    c) 10 feet
    d) 12 feet
    e) 15 feet

18. When selecting a ladder based on its duty rating, which is NOT taken into consideration?
    a) Worker's weight
    b) Weight of the tools needed for the task
    c) Weight of the materials needed for the task
    d) Duration the worker will occupy the ladder

19. Ladders or other safe means of access are required to access scaffolding which is more than ______ in height.
    a) 2 feet
    b) 3 feet

c) 4 feet
d) 6 feet
e) 10 feet

20. Scaffolds with a height to base ratio of more than _______must be restrained from tipping.
    a) 3 to 1
    b) 4 to 1
    c) 5 to 1
    d) 6 to 1

21. At what height do roofers need fall protection?
    a) 6 feet
    b) 10 feet
    c) 15 feet
    d) 30 feet

22. True or False: OSHA allows the use of Safety Monitors on low-sloped roofs (less than 4 vertical to 12 horizontal slope) instead of guardrails, personal fall arrest systems, or safety nets.

23. For OSHA regulations, warning flags can be used to mark the perimeter of low-sloped roofs. What is the minimum distance from the edge that the warning line can be located if mechanical equipment **IS NOT** being used on the roof?
    a) 2 feet
    b) 4 feet
    c) 6 feet
    d) 8 feet
    e) 10 feet

24. For OSHA regulations, warning flags can be used to mark the perimeter of low-sloped roofs. What is the minimum distance from the edge that the warning line can be located if mechanical equipment **IS** being used on the roof?
    a) 2 feet
    b) 4 feet
    c) 6 feet
    d) 8 feet
    e) 10 feet

--- END OF TEST---

APPENDIX B. TEST ANSWER KEY

Answer Key

1. B; 6 feet
2. D; 200 pounds
3. A; 6 feet
4. C; Before and after each use
5. False
6. Omitted; All answers correct
7. A; Cracks, excessive wear, and corrosion
8. D; 5000 pounds
9. D; 18.5 feet
10. A; 30^{o}
11. False
12. B; Mark or tag it as broken and taken out of service
13. C; 6 feet
14. D; 10 feet
15. C; 3 feet
16. False
17. C; 10 feet
18. D; Duration the worker will occupy the ladder
19. A; 2 feet
20. B; 4 to 1
21. A; 6 feet
22. True
23. C; 6 feet
24. E; 10 feet