Enhancing Safety in the Construction Workforce: A Comparative Study of Hands-On and Virtual Reality (VR) Training Methods

by

Kellie K. Jacob

A Dissertation
Submitted in Partial Fulfillment of the Requirements for the
Doctor in Education in Career and Technical Education Degree

Summer 2025
Style Manual Used: American Psychological Association, 7th Edition

Kellie K. Jacob 7/15/2025

Dissertation Author Signature | Date

Dr. Michael Selover, Chair | Date

Dr. Debbie Stanislawski, Committee Member | Date

Dr. Kevin Dietsche, Committee Member | Date

University of Wisconsin-Stout
Wisconsin's Polytechnic University

Dissertation Students: Please read the statements below and mark each box as "checked" to signify you have read and agree to each item. This page needs to be added on the page after your title page and completed prior to submitting your paper. It needs to be approved by the Graduate School.

Style Manual Used: American Psychological Association, 7th edition

☒ **I have adhered to the Graduate School Research Guide and have proofread my work.**
☒ **I understand that this research report must be officially approved by the Graduate School.**
Additionally, by signing and submitting this form, I (the author(s) or copyright owner) grant the University of Wisconsin-Stout the non-exclusive right to reproduce, translate, and/or distribute this submission (including abstract) worldwide in print and electronic format and in any medium, including but not limited to audio or video. If my research includes proprietary information, an agreement has been made between myself, the company, and the University to submit a thesis that meets course-specific learning outcomes and CAN be published. There will be no exceptions to this permission.
☒ **I attest that the research report is my original work (that any copyrightable materials have been used with the permission of the original authors), and as such, it is automatically protected by the laws, rules, and regulations of the U.S. Copyright Office.**
☒ **My dissertation chair has approved the content and quality of this paper.**

Abstract

The construction industry consistently ranks among the most dangerous occupational sectors in the United States, with specifically pipeline construction presenting heightened risks due to confined spaces, hazardous materials, and heavy machinery. This study compares traditional hands-on training with immersive virtual reality (VR) technology in response to the need for safer and more effective training methods. Through a true experimental design, the research evaluates knowledge retention, behavioral change, and learner perceptions by analyzing pre- and post-training assessments and survey responses from randomly assigned pipeline construction employees. Both training approaches yielded measurable improvements; however, hands-on training was associated with greater knowledge retention, while VR demonstrated stronger behavioral outcomes and higher participant satisfaction. Although statistical significance was not achieved, primarily due to a limited sample size, the practical differences suggest meaningful potential for integrating VR into future training strategies. The study concludes by recommending further exploration of hybrid training models that incorporate VR and hands-on training, aiming to provide a cost-effective, performance-driven training solution that reduces safety-related incidents in the construction workforce.

Acknowledgments

First and foremost, I extend my deepest gratitude to my grandmother, Evelyn L. Krug, whose lifelong dedication to education has been a profound inspiration to me. My passion for teaching and learning is a legacy I strive to uphold, just as she did. I hope her influence continues to be reflected in my work. Grandma, I hope your spirit finds pride in the path I've chosen. I love you.

I am also sincerely grateful to Dr. Michael Selover, Dr. Debbie Stanislowski, and Dr. Kevin Diestche for their invaluable guidance throughout this journey. Their wisdom, encouragement, and support have been instrumental in my success, and I truly appreciate their dedication. I also extend my heartfelt thanks to Cohort 10, particularly Ashley Der and Tyler Baeten, whose unwavering support provided strength and motivation when needed most.

I would also like to express my deep appreciation to Adam Day of the Northeast Gas Association for introducing me to Mike Rhodes of Precision Pipeline Solutions and for providing the opportunity to conduct research to advance safety in the pipeline industry. The commitment to progress makes a significant difference, and thanks to support, important steps toward a safer workforce can be realized. Thank you, Adam, Northeast Gas Association, Mike, and Precision Pipeline Solutions.

I also would like to extend my sincere gratitude to GTI Energy, Oberon Technology, and Paracosma for generously providing the technical equipment and software necessary to conduct this research. A special acknowledgment is owed to Mr. Ken Erhardt, CEO and Founder of Paracosma, for his mentorship throughout this process and his invaluable support in supplying the necessary technology. Your contributions played a pivotal role in the success of this study, and I am deeply grateful.

Finally, to my husband, Bill, and my children, Brady, Allie, and Brynn, thank you for your sacrifices, patience, and unwavering belief in me. Your love and support have been the foundation that allowed me to pursue and achieve this dream. I am endlessly grateful for your encouragement, and I share this accomplishment with each of you.

Table of Contents

List of Figures

Chapter I: Introduction

The construction industry continues to record high rates of accidents and fatalities, making it one of the most hazardous industries in the world (Waehrer et al., 2007). According to the U.S. Bureau of Labor Statistics (BLS; 2023), in 2021, nearly one in five workplace deaths occurred in the construction industry, and just over one-third of construction deaths were due to falls, slips, and trips. This accounted for 46.2% of all 2021 workplace fatalities (BLS, 2023). Specifically in the subsector of pipeline construction, incidents often result from hazards such as trench collapses, heavy machinery operations, and exposure to hazardous materials (Safe Training Online, n.d.). Proper training enables workers to identify and manage these unique hazards, including confined spaces near pipelines, exposure to toxic gases, trenching and excavation risks, heavy equipment operation dangers, welding, cutting hazards, and handling flammable materials (Safe Training Online, n.d.). Seo et al. (2021) stated that the current safety education and training programs have several problems and that the actual risks are not accurately reflected. Training effectively addresses the inexperience and lack of knowledge among construction workers, which are some of the most significant contributors to workplace accidents on construction sites (Shringi et al., 2023). In addition to being one of the most hazardous industry sectors to work for, the construction industry is known to be conservative and slow to innovation, including adopting emerging technologies (Von Heyl & Teizer, 2017). As modern information technology advances and equipment devices update, advanced training technologies, such as VR, have witnessed an increasing use and application in construction training (Li et al., 2024a).

VR can create cost-effective solutions for inherently dangerous tasks without real-world consequences, commonly assumed to lead to significantly better learning outcomes (Waehrer et al., 2007). However, Iqbal and Campbell (2023) state that there is a lack of research exploring these emerging technologies, such as research with kinesthetic learning or “hands-on learning" as a pedagogical approach. VR allows students to gain confidence, have repeated simulated exposures in a safe and equitable environment, and build competency in critical functions (Lee & Takenaka, 2022). This study aims to determine if VR improves training outcomes within the construction workforce compared to traditional hands-on training methods.

Statement of the Problem

According to the U.S. Bureau of Labor Statistics (2023), 5,486 fatal work injuries were recorded in the United States in 2022, a 5.7% increase from 5,190 in 2021. A worker died every 96 minutes from a work-related injury in 2022 (BLS, 2023). While training can be an effective solution to help mitigate fatalities and other safety-related incidents, the type of training that is most impactful has yet to be determined (Burke et al., 2006). Providing engaging and quality training to the workforce can ensure that tasks are performed effectively, hazards are identified, and the work is completed safely (Namian et al., 2016). While traditional training methods, such as hands-on training, have been considered the industry standard, VR offers the opportunity to train the workforce in an immersive, scalable, and safe environment that provides the opportunity to perform complex tasks without the traditional inherent risks (Vercelli et al., 2024). To fully understand the dynamics of training and the knowledge transfer to pipeline construction employees, a comparison of the effectiveness of VR training methods utilized for improving training outcomes compared to traditional hands-on methods within the pipeline construction workforce needed to be performed.

Purpose of the Study

This study aims to evaluate and compare the effectiveness of VR training methods compared to hands-on training methods to enhance training outcomes within the pipeline construction workforce. To achieve zero accidents, the construction industry is exploring various tools to improve safety management, training, and awareness (Salinas et al., 2022). This research focuses on pre- and post-training tests, performance evaluations, and surveys of the sample population within the pipeline construction industry. The primary objectives are to collect and analyze pre- and post-training tests and performance evaluations to determine whether sufficient evidence exists to answer the research questions. Additionally, the study aims to identify which training method is more effective in potentially reducing safety-related incidents in the pipeline construction industry.

Research Questions

The questions that guide this study are the following:

1. What specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, potentially resulting in a safer workforce?
2. How do perception, satisfaction, and engagement with training experience differ between VR and traditional hands-on training?
3. Which method influences and leads to a demonstrable behavior change in safely performing construction tasks, VR, or hands-on training?

Significance of the Study

Construction workers routinely encounter hazardous materials, confined spaces, and heavy equipment, significantly elevating the risk of workplace incidents. These conditions make practical training a regulatory requirement and a vital safeguard in promoting job site safety.

This study examines several key elements related to training effectiveness, with a critical focus on worker safety and the inherent risks faced during daily operations. By addressing these challenges through comparative training methods, the study underscores the importance of preparing the workforce to recognize hazards and respond appropriately in high-risk environments. This study directly addresses this crucial aspect by investigating potential improvements in training methods to enhance safety. Identifying the appropriate training methodology can yield higher knowledge retention, skill set development, and behavior modification, which are critical to optimizing training investments. Additionally, it has the potential to create a safety-minded culture while addressing the pipeline construction industry's critical need for innovative training solutions to enhance workforce protection.

This study will provide valuable insights into the perceptions, experiences, and perspectives of pipeline construction workers by employing a quantitative methods approach. This can help solidify how knowledge transfer occurs after VR training compared to traditional hands-on methods, which can lead to future training strategies that maximize safety awareness and behavior modification. It can also provide data on challenges with technology utilization and workers' acceptance of VR technology. Lastly, improving safety has been shown to lead to fewer injuries, illnesses, medical expenses, legal fees, and lost productivity, according to the Texas Department of Insurance (Texas Department of Insurance, 2024). This contributes to establishing a safety-conscious culture that engages in best practices within the construction workforce. This study will also contribute to the evidence of cost-effectiveness through VR utilization by potentially reducing the number of incidents on job sites. Reducing incidents saves lives and prevents injuries, improves employee efficiency, reduces project downtime, and lowers insurance premiums, which are significant benefits for construction companies (Zakari et al., 2025). Overall, this study has the potential to meaningfully contribute to improving training outcomes and, subsequently, safety in the construction industry by evaluating a promising advanced training technology that can provide valuable insights for training development.

Assumptions of the Study

The assumptions of this research study include:

1. The sample populations were willing to participate in the research study.
2. The sample populations provided honest feedback.
3. The sample populations understood the difference between traditional hands-on and VR training methods and the potential impact on safety.

Limitations of the Study

The limitations of this research study include the following:

1. The sample population survey results may not accurately represent the entire pipeline construction industry.
2. The sample populations may have shown biases based on personal preferences.
3. Sample populations may have varying levels of exposure to VR and traditional hands-on training.

Definition of Terms

The following is a list of terms that will be used throughout this paper:

Assessment

Knowledge test that provides objective measurements on safety and job-specific skills.

Construction Industry

A general term for the workforce performing skilled labor, primarily comprised of building or engineering projects (e.g., highways, pipelines, and utility systems).

Hands-on Training

Traditional methods of training without the aid of advanced technology.

Job Site

Any geographical location where construction activities are being performed.

Performance Evaluation

Performance evaluation (PE) utilizes a checklist for a series of steps related to a specific task for training.

Pipeline Construction Industry

A subsector of the construction industry that installs and maintains energy infrastructure.

Safety Training

Equips workers with the knowledge and skills to identify and avoid hazards on a job site.

Simulation

Safely imitates the action of a particular task without the risk of performing in a natural environment.

Subject Matter Expert

A subject matter expert (SME) is an individual with a vast amount of knowledge on a specific topic.

Standard/Regulation

A regulatory requirement established by a government agency that provides criteria for measuring whether employers are meeting specific compliance requirements.

Traditional Training Methods

Instructor-led instruction, lectures, PowerPoint, and hands-on practice in a physical classroom environment.

Virtual Reality

Virtual reality (VR) is a simulated three-dimensional environment where users can immerse themselves in a natural environment.

Workforce Development

An employer or third party that provides training to improve employees' job skills.

Chapter II: Literature Review

The construction industry is fundamentally dangerous due to the nature of the work being performed. It also has an extensively diverse and large workforce that experiences a vast number of safety-related accidents each year (Manning et al., 2020). Research has highlighted the cause of accidents within the construction industry due to employees' limited skills in safety topics and overall safety awareness (Le et al., 2015). According to the U.S. Bureau of Labor Statistics (2023), 5,486 fatal work injuries were recorded in the United States in 2022, a 5.7 % increase from 5,190 in 2021. In 2022, a worker died every 96 minutes from a work-related injury (BLS, 2023). While training can be an effective solution to help mitigate fatalities and other safety-related issues, the type of training that is most impactful has yet to be determined. To fully understand the dynamics of training and the knowledge transfer to construction employees, a comparison of the effectiveness of VR training methods utilized for improving training outcomes compared to traditional hands-on methods within the construction workforce needed to be performed.

This literature review will provide a detailed overview of safety within the construction industry, highlighting common safety hazards, industry statistics, and challenges. It will also discuss the importance of safety training, current methods, limitations, and the need for enhanced training approaches. It will also cover VR as an emerging safety training tool and its associated applications, benefits, and challenges. Hands-on training methods will also be discussed, including their effectiveness and comparison to VR and the barriers to hands-on training. The literature review will tie together this research with factors that affect training effectiveness, such as motivation, worker characteristics, and environmental factors.

Theoretical Frameworks

Two primary theoretical frameworks provide the groundwork for this research: the adult learning theory and Kolb's Experiential Learning Theory (ELT). The adult learning theory, also known as andragogy, examines the participation preferences of adult learners, the practical applications of real-world training, and the concept of self-directed learning. Andragogy aligns with construction education by enhancing learning outcomes to align with instructional strategies that meet the needs of adult learners (Austin, 2018). This study highlights that adult learners bring a wealth of diverse experiences and expectation levels to the training environment, which requires relevant and applicable training models that resonate with the learner (Austin, 2018). Austin (2018) continues to note that applying these principles will improve learner engagement, practical skill application, and overall training satisfaction.

The adult learning theory framework helps explore adult learners' participation preferences, real-world training applications, and self-directed learning (Loeng, 2020). It also applies to knowledge testing, performance evaluations, and post-testing perception surveys by capturing how adults learn through retaining, acquiring, and applying knowledge (Okano et al., 2018). Pre-tests allow the learner to address gaps in knowledge and focus on the relevant topics needed to achieve their goals, while post-tests allow the learner to obtain feedback on progress, which lends motivation to success (Harlen & Deakin Crick, 2003). It also establishes a firm baseline and provides measurable progress outcomes and is universally applicable to a post-testing perception survey by aligning with self-directed learning; it gauges the perceptions and effectiveness of the training methodology used (Harlen & Deakin Crick, 2003).

Kolb's ELT emphasizes learning through hands-on experiences that reinforce a deeper level of knowledge (Zahraee et al., 2023). The ELT framework has been successfully applied within the construction industry to achieve higher training outcomes (Zahraee et al., 2023). An example of this framework applied within the industry was presented at the 2023 Conference for Industry and Education Collaboration (Zahraee et al., 2023). Zahraee et al. (2023) integrated experiential learning components through a construction program to provide students with practical and field-based experience, collaborating with industry SMEs. The findings detailed enhanced practical skills and closed the gap between theoretical knowledge and real-world application. The ELT framework helps provide valuable insights into training methods by actively engaging in an experience, reflecting on it with feedback, and then applying what was learned through the four-stage learning cycle (McLeod, 2025).

Construction Industry Overview

The U.S. Bureau of Labor Statistics (BLS, 2023) defines the construction industry as establishments primarily constructing utilities, highways, or buildings. The Occupational Safety & Health Administration (OSHA, n.d.) the primary governing body for safety standards refers to the construction industry as a hazardous industry comprised of a wide range of multi-faceted activities that expose workers to severe hazards, such as trips, slips, and falls, unguarded machinery, being struck by heavy construction equipment, electrocution, and asbestos. While many standards and regulations govern the construction industry, this literature review will discuss specific regulations that frequently guide standard safety practices.

Construction Industry Standards

OSHA’s 29 CFR 1926 regulates the broad overview of safety requirements within the construction industry, and the following are critical topics covered within safety training (OSHA, 1970):

- General Safety and Health Provisions (Subpart C) – This standard covers the general requirements for safety programs, inspections, and hazard communication.
- Personal Protective Equipment (PPE; Subpart E) – This standard requires employers to provide PPE such as safety vests, gloves, hearing protection, safety glasses, and respirators according to the hazards on each jobsite.
- Fall Protection (Subpart M) – This standard describes the requirements for fall protection for workers at heights above six feet.
- Excavation and Trenching (Subpart P) – This standard describes the requirements for protective systems for trenches greater than five feet in depth, inspections by competent persons, and safe egress methods.

Depending on the construction workers ' sub-industries, additional standards and regulations may be required. For example, according to the Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards (1970), 49 CFR Code 192 governs additional requirements for performing job-specific tasks and associated safety requirements within the pipeline industry. These standards/regulations are the foundational components for training, but the delivery method also needs to be explored to understand how the workforce retains and utilizes the skills taught.

Statistics in Construction

Whether the focus is on fatal injuries, death rate, or the number of non-fatal accidents in a calendar year, the construction industry has consistently ranked at the top of all categories (Mitchell, 2024). The construction industry is filled with high-risk work that has led to the highest number of deaths and injuries compared to any other industry within the United States

(Mitchell, 2024). The key statistics from the BLS (2023) on all fatal injuries in the construction industry are itemized below:

- In 2022, there were 1,069 fatal occupational injuries in the construction industry.
- In 2022, 19% of deaths in the U.S. workforce came directly from the construction industry.
- More than 65% of construction deaths are caused by falls, being struck by an object, electrocution, and being caught in/between incidents.

The non-fatal construction injury statistics show similarly alarming trends from the BLS (2023):

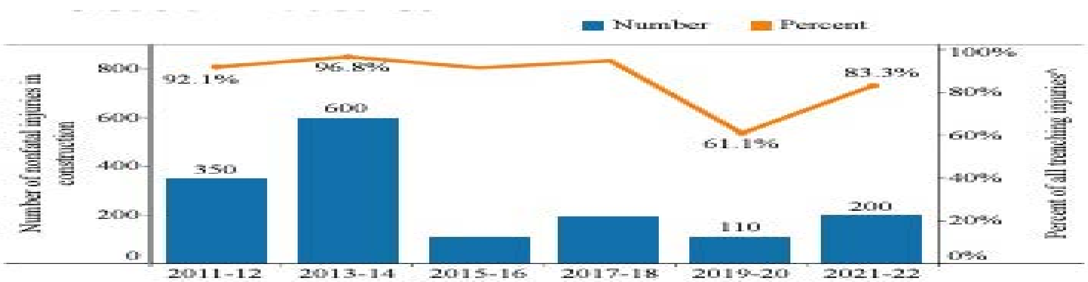
- In 2022, 169,600 non-fatal construction injuries and illnesses were reported, of which 42% required time away from work.
- The average number of days away from work due to an illness or injury was (11).
- The average number of hours full-time workers were absent due to illness or injury in 2022 was 24.2 million.

Additional key statistics from The Center for Construction Research and Training (CPWR) (2024) included the following:

- From 2011 to 2022, the number of fatal injuries increased by 39.8% in the construction industry.
- Fatal injuries primarily occurred among males (99.0%), 55 or older workers (31.1%), and Hispanic workers (37.4%) in 2022.
- The construction industry within the U.S. accounted for 85% of fatal trenching injuries from 2011 to 2021, as depicted in Figure 1, and 90% of non-fatal injuries from 2011 to 2022, as depicted in Figure 2.

Figure 1

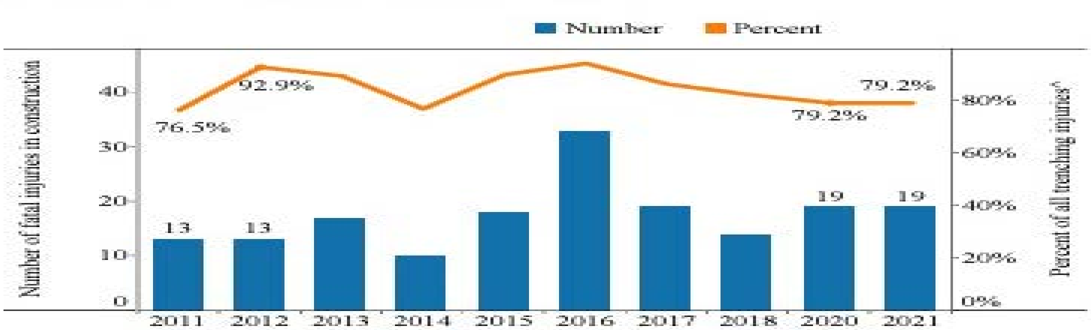
Fatal Trenching Injuries, 2011-2018, 2020-2021



Note. From *Trenching Injuries, Citations and Penalties in Construction* in The Center for Construction Research and Training (CPWR) Data Bulletin, May 2024. Data from the U.S. Bureau of Labor Statistics, 2022 Survey of Occupational Injuries and Illnesses. (https://www.cpwr.com/wp-content/uploads/DataBulletin-May2024.pdf). In the public domain.

Figure 2

Nonfatal Trenching Injuries, 2011-2022



Note. From *Trenching Injuries, Citations and Penalties in Construction* in The Center for Construction Research and Training (CPWR) Data Bulletin, May 2024. Data from the U.S. Bureau of Labor Statistics, 2022 Survey of Occupational Injuries and Illnesses. (https://www.cpwr.com/wp-content/uploads/DataBulletin-May2024.pdf). In the public domain.

These statistics highlight the unfortunate reality of injuries and fatalities within the construction industry. Significant risks, such as trips and falls, equipment incidents, and exposure to hazardous conditions at job sites, are all preventable accidents that accentuate the gap in the industry's current training approach (Nadhim et al., 2016). Improving the training methodology with more thorough, impactful, and engaging training, with methods such as immersive VR technology or enhanced hands-on simulations, could equip the industry to achieve its goal of zero incidents (Scorgie et al., 2024).

Jobsite Hazards in Construction

Globally, more than 60,000 workers are killed annually on job sites, and the underlying cause can be directly attributed to a lack of appropriate safety training and knowledge (Guo et al., 2024). Jobsite hazards are the actual risks a worker will encounter and can drastically alter the effectiveness of a safety training program if the workforce is not adequately prepared to mitigate them. Guo et al. (2024) believe construction safety should primarily focus on the worker's risk perception of a hazard, while Sanni-Anibire et al. (2020) believes that hazard identification and analysis are the most essential parts of focusing on safety performance, not perception. However, a hazard analysis cannot cover all causes of hazards/accidents that can be determined, as Sanni-Anibire et al. (2020) suggest.

Construction safety's central theme is ultimately accident prevention (Sanni-Anibire et al., 2020). This aligns with the current industry mantra to achieve zero incidents while operating at peak safety performance (Zwetsloot et al., 2017). This admirable goal requires a strong organizational commitment, strategy, and cultural shift toward safety as the number one priority. However, when hazards cannot always be seen or detected, the likelihood of an incident increases significantly (Zhu et al., 2023).

According to the National Safety Council (NSC, n.d.), in 2022, the total cost of work-related injuries in construction reached $167.0 billion, of which $50.7 billion is contributed to wage and productivity losses, $37.6 billion to medical expenses, $54.4 billion to administrative expenses, as well as $15.0 billion for employer’s uninsured costs. These statistics break down the cost per worker as $1,040, per medically consulted injury at $40,000, and per every death as $1,390,000 (NSC, 2024). The NSC estimates that 108,000,000 hours were lost due to work-related deaths and injuries and that 60,000,000 additional days will be lost in future years due to on-the-job deaths and permanently disabling injuries that occurred in 2022 (NSC, 2024).

Many studies have provided insight into the most critical jobsite hazards within the construction industry. Haslam et al. (2005) studied 100 construction accidents to identify the key contributing factors. The study found that 70% contributed to human error, 56% to equipment malfunctions, which included PPE, and 27% to improper use or condition of jobsite materials—another study conducted by Hamid et al. (2008) determined that the leading causes of accidents were worker negligence, failure to follow safety procedures, improper use or no use of PPE, poor site management, harsh outdoor conditions, lack of knowledge in workers' skills, and poor culture towards safety. While this study solidifies many job site hazards, it lacked a systematic categorization for data comparisons. Guo et al. (2024) contributed their findings of hazard exposure to falls from heights, strikes from equipment, electrocution, and mechanical injuries; however, Li et al. (2018) stated that the leading cause of all construction accidents, dealing with job site hazards, contributed to the unsafe behavior of construction workers. While these studies acknowledge many job site hazards, they lack the contextual basis for understanding why hazards occur. However, it does provide the framework for further research and development of future studies.

Barriers and Challenges to Safety in Construction

The construction industry is a highly complex and diverse environment that faces unique challenges within the context of job site safety (Le et al., 2015). One of the many barriers the industry faces is the challenge of illiteracy and language, which is a struggle for millions of Americans (Arcury et al., 2010). Schmidt (2022) noted alarming statistics from the U.S. Department of Education that show approximately 130 million adults in the U.S. have low literacy skills. This correlates to more than half of Americans between 16 and 74 (54%) reading below a sixth-grade level (Schmidt, 2022). Looking at this statistic from another vantage point, one out of every five adults cannot perform basic tasks such as filling out a job application or reading a news article. If this statistic applies to a typical construction crew of five (BLS, 2024), one crew member would struggle with basic reading and writing abilities. This will present various challenges in providing instructions, reading manuals or signs, and understanding other forms of written communication. These are all examples of barriers to effectively training individuals for their current jobs or advancements of skill sets. Furthermore, Demirkesen and Arditi (2015) argue that language barriers by non-English speakers are common in the construction industry and interfere with training. However, the difficulties caused by the language barrier in training are rarely investigated (Demirkesen & Arditi, 2015). It is imperative to adapt training to an employee's primary language to ensure there is an understanding of the training material and active participation in the training process (Estudillo et al., 2025).

Another significant barrier to safety for many companies is the financial burden linked to training and development. Safety training is adversely affected by limited training budgets and unpredictable product and technical innovations (Demirkesen & Arditi, 2015). The combined costs of initial and ongoing training and investments in new equipment, instructional materials, and qualified trainers can be prohibitively high for numerous organizations. The compatibility restraints between multiple technologies, data security, and privacy concerns also drive-up additional costs (Open Asset, 2024). Le et al. (2015) also explained that high accident rates significantly contribute to cost overruns and project delays, further driving up costs, which can put constraints on tight budgets.

An additional barrier is that the construction industry is projected to grow faster than the average industry for all occupations from 2023 to 2033 in the United States (BLS, 2024). This will create an average of 663,500 openings each year to address the employment growth, to replace workers who leave the industry due to retirement or career changes (BLS, 2024). Combating the worker shortage is one main area of contention, but companies additionally face skills shortages in the current workforce. The significant skills gap among employees stretches even broader in terms of technology and its practical uses, which slows down the adoption of technology and its intended use cases (Open Asset, 2024).

Hands-On Training in Construction

Traditional hands-on training methods are the current standard for most construction companies. This method is advantageous because it can be generalized and implemented broadly while reducing costs (Guo et al., 2024). Hands-on training is also often delivered to learners because well-established organizational processes align well with regulatory requirements and compliance (Stefan et al., 2023). It is also easy to organize training for the learner and can quickly be adapted to varying workforce and employee schedules. Hands-on training is typically administered through lectures, PowerPoint presentations, and physical equipment (Guo et al., 2024). It uses minimal resources, is cost-effective, and can quickly adapt depending on the scenario. Hands-on training allows a learner to use the tools needed to perform a task, which is hard to replicate in any other environment, including VR. This ultimately promotes a deeper understanding and better retention of safety procedures (Train Beyond, 2024). It also instills a high confidence level in the learner as they have practiced using the required tools. Hands-on training is the best approach for individuals who prefer to learn by doing because of the practical instruction (Demirkesen & Arditi, 2015). Instructors can also address weaknesses or important factors that the student might otherwise miss in an alternative format, with feedback readily accessible (Abdellatif, 2008). Hands-on training also encourages instructor engagement because, in other training settings, the learner may not feel compelled to seek guidance, allowing instructors to quickly provide real-time feedback and adapt to a learner's learning style (National Aviation Academy [NAA], n.d.). This also allows the learner to dissect and reassess the hands-on work, encouraging learners to work through obstacles they may encounter (NAA, n.d.).

Another advantage of hands-on training is that not everyone learns similarly. Hands-on training can be easily manipulated to meet the needs of a wide range of learning preferences. One study found that VR safety training is not necessarily for everyone, especially reflective, verbal, and global learners, who would benefit most from traditional hands-on methods (Guo et al., 2024). The same study also found that sensing and visual learners do not exhibit a specific preference for the training modalities and thus can choose traditional safety training methods, which can be cost-effective and easier to conduct. Hands-on training also encourages employee collaboration and may resonate with learners of different learning styles (NAA, n.d.). Kim et al. (2020) conducted a study comparing hands-on methods to VR training. Traditional hands-on methods significantly outperformed VR due to interactions with elements of the virtual simulation not being perceived appropriately. Furthermore, the study also identified realism as not a high priority within the program, and the interactions with avatars did have a perceived negative impact, as did the simulation of walking as a distractor.

Safety Benefits of Hands-On Training in Construction

A substantial amount of data indicates that using the actual tools to perform a task can yield high results. Hands-on training is a practical approach because it promotes real cases of safety training in construction and leads to a better training environment that considers workers' needs (Tezel et al., 2021). It also provides the transition from a training environment to the job site, reducing the physical and mental exhaustion that might otherwise occur (NAA, n.d.). It is common knowledge that repetitive tasks reduce the likelihood of errors, and a lack of training in equipment causes many workplace accidents (NAA, n.d.). Through sufficient hands-on training, learners can overcome the lack of training with tools and confidently perform assigned tasks.

Cost Benefits of Hands-On Training in Construction

Through practical skills, hands-on training can provide cost benefits by reducing the likelihood of errors, rework, and even accidents. While hands-on training can be administered to multiple people in a classroom, VR typically can only be administered one at a time due to the costs of technology, software, and hardware (Guo et al., 2024). Additionally, traditional hands-on methods can be administered anywhere at any time, while VR requires the use of the internet, computers, and headsets (Guo et al., 2024). In construction, many jobs will lack access to strong internet connections due to the location of a job site (Katiyar & Kumar, 2021). In these events, the only alternative is a traditional hands-on approach. Hands-on training also provides the opportunity for a high level of customization quickly (Deslauriers, 2024). Updating a VR program weekly, monthly, or even yearly may not be cost-effective. Hands-on training also allows customization to specific company procedures, reducing the need for additional supplementary training that may otherwise be needed with VR, as most out-of-the-box programs require supplemental training for company-specific tasks to meet internal procedures and state and federal requirements (Deslauriers, 2024).

Limitations of Hands-On Training in Construction

While hands-on training is widely acknowledged as an effective method, it is not without its limitations. Current hands-on training methods are subject to resource availability, including trainers, tools, equipment, weather, and the availability of students (Zhao & Ye, 2012). Albert et al. (2013) discovered that traditional training methods do not yield desirable levels of return because the training practices adopted rarely leverage the best training practices. Demirkesen and Arditi (2015) also highlighted the need for qualified trainers who actively work to improve the quality of training sessions. Additionally, having multiple instructors can lead to inconsistent training quality (Stefan et al., 2023). This could result in some learners understanding incorrect processes and procedures, leading to a safety incident. Hands-on is typically conducted with on-site safety briefings, lectures, and textbook learning (Shringi et al., 2023). The limitation of this methodology is within the broad approach to a lack of engagement, which does not allow for sufficient absorption of information that is critically needed for long-term information retention (Shringi et al., 2023). Additionally, traditional safety training is often intertwined with the construction process, often cut short by the need to get workers back in the field, reducing the effectiveness (Zhang et al., 2018).

Criticisms of current hands-on training methodologies find that it is focused on a passive knowledge transfer pattern, which creates a passive atmosphere in receiving safety content without the appropriate interaction for getting the needed feedback (Burke et al., 2011). It is also very challenging to convey the importance of site hazards, such as chalkboards, PowerPoints, and paper tests, and the significance of the information being trained (Ge & Kuester, 2015). Additionally, Alsharef et al. (2020) noted the following list of shortcomings of traditional hands-on methods:

- poor design that lacks resources
- training does not inspire knowledge transfer
- improperly designed to address why employees fail
- does not promote an active learning environment
- low engagement training approach
- pedagogical approach versus an andragogical approach to deliver training
- generic and a lack of real-world experiences
- it may not be delivered in the employee’s preferred language
- many trainers are not educated on learning and skill acquisition theory

In many countries, safety training is taught through traditional hands-on classroom methods, but this has not sustained substantial results (He & Song, 2012). Additionally, when physically conducting traditional hands-on training, there is a risk that the worker may become exposed to hazards, which would be counterproductive to the training, employee, and workforce (Seo et al., 2021).

Virtual Reality (VR) Training

VR can be defined as a specific environment, situation, or experience embedded with computer technology to create realistic environments replicating an actual task (Seo et al., 2021). VR is achieved through a combination of special software and hardware that provides a high-resolution display and lens in a 3D view through each eye to create the illusion of depth. Through simulation fidelity, VR can transform learning safely and in cost-effective environments, leading to better learning outcomes (Cooper et al., 2021). In a true VR environment, an individual is equipped with a VR headset and hand controllers that interact with an alternate computerized reality that immerses users into a three-dimensional environment. This can also be done through a standard computer without the headset, but this is not considered a standard VR environment. Cooper et al. (2021) stated that some aspects of real environments are challenging to recreate within training; however, VR provides several opportunities to add sensory cues to simulate the real environment with visual, auditory, and occasionally haptic feedback.

VR in Construction Training

Traditional training methods, such as hands-on, can be tedious and lack engagement, but this can be changed by incorporating advanced virtual interactive technology (Le et al., 2015). Le et al. (2015) summarized the benefits of VR as follows:

- By utilizing experiential learning, students can identify hazards and practice emergency responses in a safe virtual environment.
- Active role-playing allows for synchronous and asynchronous collaboration to obtain real-time feedback and improve learning outcomes.
- Students can learn a wide variety of construction tasks that remarkably resemble the real world without the safety risk.

Train Beyond (2024) also found that VR achieves a 75% recall retention rate compared to traditional methods at 20%. They also found that on skill-based tasks, learners showed a 12% increase in precision and a 17% increase in completed tasks. Zhao and Ye found that completing the actual task in a simulated environment, such as VR, will obtain the most benefits for training (Zhao & Ye, 2012).

Safety Benefits of VR Training in Construction

Several studies have shown that accidents are caused by employee errors and misunderstandings of the tasks being performed, and the underlying cause is the lack of knowledge and practical experience in safety (Le et al., 2015). With advancements in technology, VR now allows a learner to fail safely, increasing the appeal of the technology (Stefan et al., 2023). Despite its number one priority, many studies have indicated that current safety training methods do not provide the required engagement, thus resulting in an ineffective knowledge transfer (Demirkesen & Arditi, 2015). To reduce injuries, an effective safety training program that can improve the workers' safety knowledge and practical experiences is needed (Le et al., 2015). Zhao and Ye (2012) stated that to improve construction safety, it must be done by simulating the actual task to "learn by doing" and that it would require the following factors:

- real-time experience of the simulated task
- collaborative role-playing exercises
- dialogic studying of materials and high social interaction on safety tasks

Safety education requires a theoretical foundation and an experiential one that reflects the inherent danger a worker may physically experience (Seo et al., 2021). Guo et al. (2024) agreed by describing VR technology as an advantage because it can simulate risky tasks without exposing users to actual hazards. VR programs contextualizing a real environment will deflect direct risks within the field (Seo et al., 2021). Additionally, the safety training has to be a practical approach, which depends on how it is structured within the organization, the instructor feedback, course content creation, and addressing any worker-related concerns with the training or technology (Demirkesen & Arditi, 2015).

Cost Benefits of VR Training in Construction

Many studies have indicated that accidents directly contribute to cost overruns and project delays (Le et al., 2015). A study conducted by Ho and Dzeng (2010) showed that every hour, three construction workers are injured or die, making it exceedingly difficult to quantify the loss of human capital and actual monetary value. According to research conducted by Abdellatif (2008), VR can alter how people learn by removing the barriers of geographical locations and ultimately lowering the cost compared to traditional training approaches. Oberon Technologies (n.d.) found similar results, with 30 – 70% being the average companies save when training with VR. That includes costs associated with technology, travel, and productivity loss experienced by the loss of work production. Train Beyond (2024) found the same statistical data in VR's cost-effectiveness and efficiency, at 30% to 70% in training cost savings compared to traditional training methods. They also found that VR can train the workforce four times faster without compromising effectiveness. Similarly, a study conducted in 2020 by PWC showed that employees completed VR up to 4 times faster than traditional training programs and 1.5 times faster than e-learning (PWC, n.d.).

> "VR can also be used for operation analysis, schedule optimization; an advance inspection of construction processes, equipment, materials, and so forth; pre-rehearsal and visualization of construction process simulation; and help review the rationality of construction process arrangement, thus optimizing the organization of construction plans, reducing problems such as collision and rework, effectively reducing cost and schedule loss, and helping to realize the sustainability of the construction process" (Li et al., 2024, p. 4).

Tyson, a large food producer, found that with VR, general safety and hazard awareness increased, and a 20% reduction in injuries and illnesses (Oberon Technologies, n.d.). With the advancements in VR, it is now affordable with consumer-grade technologies and provides a practical alternative that was previously difficult to achieve (Stefan et al., 2023).

Use of VR in Other High-Risk Industries

The construction industry is not the only high-risk industry that has explored the use of VR training. VR training is a compelling solution for the medical and aviation industries, where the real-life consequences are too grave to train personnel appropriately (Cooper et al., 2021). Many other industries use VR where scenarios and exercises are impractical, or the cost is too high (Cooper et al., 2021). There is little doubt that VR training has significantly reduced error rates and knowledge transfer in an authentic setting (Jacobs et al., 1990). In the medical industry, Cook et al. (2011) and his colleagues conducted a review of over 609 studies that encompassed 35,226 medical students. The review showed that VR training outperformed traditional training methods regarding knowledge, behaviors, and skills for patient outcomes. Similar findings were identified in a flight simulation training meta-analysis that showed higher VR training outcomes than traditional hands-on training methods (Jacobs et al., 1990). Several additional industries are utilizing the VR training framework, including the railroad, marine, and fire safety/prevention industries, primarily focused on evacuation simulations (Pedram et al., 2020).

Limitations of VR Training in Construction

While VR can fundamentally change the learning scope and create an engaging and effective teaching methodology, it has limitations. According to Le and Park (2012) the majority of VR solutions had the following limitations:

- offline modality without the use of instructors

- lack of interaction within the VR environment, creating a teamwork atmosphere
- limitation of space for students to engage in virtual activities

Cooper et al. (2021) described additional limitations, such as difficulty recreating vestibular or haptic cues to simulate the VR environment. Limitations also included VR training programs that are too generic for the task being performed, clear instructions on using the technology not being delivered in the employee's preferred language (Alsharef et al., 2020). Another primary concern is the accessibility through internal companies' IT protocols and the functionality to complete VR training on a tablet or phone. In addition, the high costs of development and production time to receive the desired training product, and the limitation of sense and presence in realism are valid concerns (Moore et al., 2019). Zhang et al. (2022) agreed, arguing that VR safety training is a mostly fixed training program with little flexibility, as the simulations can be expensive and time-consuming. Additional challenges that were identified in a research compilation of 90 leading papers included the following (Kim et al., 2020):

- Difficulties with the software and hardware.
- Challenging to integrate into a Learning Management System (LMS).
- Limitations with interactions in a VR setting.
- Physical side effects, including headaches, dizziness, and lethargy.

Although many studies have been conducted confirming the effectiveness of VR training programs, there is still a very low acceptance and user rate, indicating that there is still a lack of understanding of the technology and applicability of VR in training (M. Zhang et al., 2022).

Factors Affecting Training Effectiveness in Construction

Numerous factors influence the success of effective training programs, determining the success of achieving an organization's goals and enhancing the learner's experience. These factors are the individual learning characteristics, the culture within the organization, and, most importantly, the design and delivery of the training program. A study conducted by Le et al. (2015) interviewed students and civil engineers, which provided insight into the lack of current training methods that do not meet the expected level of safety knowledge specific to hands-on performance to prepare them for construction jobsites. Additionally, Saleh and Pendley (2012) discovered that current hands-on safety training methods have limited training effectiveness and do not adequately reach their targeted audience, nor solidify the work's importance. Several researchers have questioned the training effectiveness of widely accepted hands-on models because it does not yield desirable results (Alsharef et al., 2020). Identifying how workers perceive the training is critical in designing and deploying effective training models (Wilkins, 2011).

Contextual Factors in Construction

Contextual factors are vital in influencing the outcomes within specific training environments, such as the engagement and motivation of the worker, which play an integral role in knowledge retention and absorption. Facilitating training scenarios with higher knowledge preservation and the ability to apply the concepts to their work will motivate the workers during training (Rowen et al., 2022). Cultures grounded in consistency that reinforce the importance of safety can strengthen and motivate their workforce (Rowen et al., 2022). Motivation can easily be lost by inadequate training, high stress, job resources, and operational inefficiencies (Rowen et al., 2022). Additionally, VR training is recognized as immersing learners in a cognitive learning environment that increases motivation and drives desired training results (Zhao & Ye, 2012).

These factors provide a backdrop for how decisions are made and how training processes unfold, affecting the success and effectiveness of the training program. Additional factors include the ability to train in any weather, which is especially advantageous for companies in cold-weather climates (Zhao & Ye, 2012). However, some companies prefer to train outdoors in the elements as it prepares learners to be adaptable and resilient in many environmental conditions (NAA, n.d.). This can translate to better performance on jobsites since weather changes can significantly impact work tasks and are inevitable to avoid when working outdoors (NAA, n.d.). While some research shows that VR training can cause motion sickness and lethargy following a training session, Pedram et al. (2020) found that the level of sickness or lethargy in their study, which consisted of 284 sample populations, was very low. Cooper also found that the type of VR training program used, one of higher quality in graphics and sense of reality, significantly reduced motion sickness (2021). However, it was noted that using higher-quality VR programs will drive up the costs of VR training programs.

Another contextual factor to explore is the sample population's competence in using a VR program. Zhang et al. found that construction personnel may avoid using this type of technology because they do not consider themselves technologically apt (2022). It can also create cognitive overload and be counterproductive to the desired result (Kim et al., 2020). Additional factors included the high turnover rates within the construction industry. Due to this turnover, the industry is often called ‘transient’. Ortega and Marchante (2010) found that the transient nature of the workforce was a warranted factor to consider for its impact on the training process. When employees are continually trained or re-trained, it can drive up costs and result in project delays.

Need for Future Research Development

The need for future research development remains despite extensive efforts to reduce safety-related incidents, leaving an incomplete picture of the importance of utilizing advanced technologies to engage the workforce. The justification for this study shows that significant gaps still exist in utilizing advancements in training methods, such as VR, to improve training outcomes and ultimately lead to a safer workforce. Research Question One aims to discover what type of training, VR or traditional hands-on, is most effective in improving knowledge retention, ultimately resulting in a safer workforce. Evidence suggests that much of the construction industry training investments do not yield desirable returns or benefits or adapt to best practices identified in the broader research literature (Alsharef et al., 2020). There has not been an established, coherent, systematic framework that adequately captures all desired features and assessment criteria (Pedram et al., 2020). Zhang et al. argued that while many studies have researched various training methods, few have examined learner characteristics and how they affect any format (2022). Research question two also reinforced the gaps in those studies by determining which method influences and leads to a demonstrable behavior change: VR or hands-on training. Research question three addressed how perception, satisfaction, and engagement with a training experience differ between VR and traditional hands-on training. This has helped to fill the gaps identified by the studies of Pedram et al. and Zhang et al.

Another critical component overlooked is the overarching cost estimate of training resources for the entire industry to understand the economic impacts (Waehrer et al., 2007). When safety is the number one priority for many organizations, it is hard to put a price tag on effectively and efficiently training employees. This literature review helped quantify the cost and showed the added benefits of training with technological advancements. An additional gap identified is too much focus on implementing a VR program versus evaluating tasks and methods within VR training (H. Zhang et al., 2019). Additional studies focused more on the perceived level of immersion and presence within the VR environment. However, they failed to report training outcomes or the transfer of training from a virtual environment to a real-world scenario (Stothard et al., 2008). While McMahan, Schafrik, Bowman, Karmis, and Brune (2010) did report on the effectiveness of the training through pre- and post-testing, they did not conclude on the assessment of the training process or what factors affected the learning. This research addressed these concerns by focusing on the type of technology utilized based on prior research and adapting it to a systematic framework that would allow learners from varying backgrounds, cultures, and barriers to receive appropriate safety training. It authenticated these results through statistical analysis of the pre- and post-testing, which was identified as a significant gap.

Zhang et al. (2022) Also, users' acceptance and motivational factors for utilizing VR programs have not yet been fully explored. Sacks, Perlman, and Barak (2013) also noted a limitation in their study: 66 sample populations completed training in construction safety, with immediate pre- and post-testing one month later. They determined that while a significant advantage was identified with utilizing VR in construction tasks, they did not find the same improvements in general site safety, thus requiring further research. Kim et al. (2020) stated that the number of studies accounting for culture and personal backgrounds was severely limited and needed further exploration.

Summary

In summary, this literature review identified the growing need in the construction industry to improve safety training methods to mitigate safety-related incidents. While hands-on training has been recognized as the standard in the industry for its practical use cases and cost-effectiveness, emerging technologies such as VR offer innovative enhancements to address some limitations in removing hazards, learner motivation, and flexibility. However, clear gaps remained in comparing the effectiveness of these training methodologies within the workforce. This study aimed to investigate and compare the effectiveness of VR training methods for improving training outcomes compared to hands-on training methods within the construction workforce.

Chapter III: Methodology

This study aimed to evaluate the effectiveness of VR training methods compared to traditional hands-on training methods in enhancing training outcomes within the pipeline construction workforce. To achieve zero accidents, the pipeline construction industry is exploring various tools to improve safety management, training, and awareness (Salinas et al., 2022). This research focused on training observations, pre- and post-training tests, performance evaluations, and sample population surveys within the pipeline construction industry. The primary objectives were to collect and analyze pre- and post-training tests and performance evaluations to determine whether sufficient evidence existed to answer the research questions. Additionally, the study aimed to identify which training method, traditional hands-on or VR, was more effective in potentially reducing safety-related incidents in the pipeline construction industry. An online Microsoft survey assessed the sample population's confidence in applying safety skills, perceptions of training effectiveness, and overall impressions of the training methods used.

The methodology for this experimental design study focused on comparing the effectiveness of hands-on and VR training methods to enhance training outcomes. This section details the research design, data collection procedures, and analytical approach to determine the impact of two different training approaches on reducing safety-related incidents in the pipeline construction workforce.

To meet these objectives within the research, the following questions were developed:

1. What specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, ultimately resulting in a safer workforce?

2. How do perception, satisfaction, and engagement with a training experience differ between VR and traditional hands-on training?
3. Which method influences and leads to a demonstrable behavior change in safely performing construction tasks, VR, or hands-on training?

Research Methodology

The research methodology utilized for this study is a true experimental design. This design was selected to reinforce the validity of the pre- and post-test results by establishing a baseline assessment to compare to post-test results. True experimental designs emphasize the comparative data to interpret findings and increase the confidence that the outcomes are an accurate result instead of a function of extraneous variables or events (Gribbons & Herman, 1996). Wiersma and Jurs (2008) refer to this methodology as having a minimum of one variable that can be manipulated to determine the resulting effects. It also requires the sample population to be randomly assigned to make it a true experimental design. One particular study utilizing the true experimental design methodology assessed the effectiveness of strategies to reduce safety violations by randomly assigning control groups and comparing pre- and post-training tests with three months post-research, to see if there was a reduction in safety violations (van der Molen et al., 2015).

True experimental designs are the most accurate form of research due to the ability to perform statistical analysis on the data to either prove or disprove the hypothesis and establish the cause-and-effect relationship within a specified group (Kelkar, 2023). This design allowed for the authentication of the study by testing its validity by manipulating the independent variables to determine their effect on the dependent variable. True experimental designs emphasize comparative data to interpret findings and increase the confidence that the outcomes are accurate instead of a function of extraneous variables or events (Gribbons & Herman, 1996). Advantages of the true experimental design include the ability to control the variables, analyze the cause-effect relationship, set research boundaries, and increase the results' trustworthiness (Kelkar, 2023). Additionally, this design was selected due to the nature of the research, which involved performing pre- and post-tests with two randomized groups, and the strength of the design.

Setting

A typical day in pipeline construction consists of a crew of three to five individuals working on a job site in either an urban or rural area. The job responsibilities will vary depending on the scope of work, but the primary responsibility is building, installing, and/or maintaining pipeline infrastructure. This may include, but is not limited to, excavation, leak detection, locating, welding, fusing, coating, and installing pipe segments. Training can be conducted in the field or a simulated environment, such as a classroom setting.

Subject Selection

Northeast Gas Association (NGA) agreed to facilitate soliciting members to participate in the research study. They have a substantial membership pool and believed several companies would be willing to participate. (A. Day, personal communication, September 12, 2024). NGA contacted two pipeline construction contractors to gauge their interest in participating in this study: The DDS Companies and Precision Pipeline Solutions. Both companies agreed to participate in the research, and the following research requirements were discussed (W. Ackles, personal communication, September 18, 2024; M. Rhodes, personal communication, September 20, 2024):

- Participation in this study was voluntary and not a condition of employment.

- Each company selected sample populations based on the training needs.
- Sample populations would be exposed at a very low-risk threshold using VR.
- All sample populations would voluntarily sign a consent form.

Both companies agreed to provide 25 participants from their organization; however, DDS companies could not participate due to a change in leadership. The study included sample populations of varying sex, ethnicity, experience level, job roles, and age. Additionally, the subjects were from various construction project sites throughout the State of New York. The sample populations were selected based on the above criteria and then randomly assigned to the hands-on or VR group using a random name generator in Excel with a corresponding control number. Random assignment is considered the gold standard for experimental studies due to its rigor in achieving statistical control, which provides heightened precision by employing specific measures (Strale, 2024). This methodological rigor has contributed to a high degree of confidence in experimental treatments and is believed to mitigate selection bias and enhance generalizability (Strale, 2024).

Instrumentation

This study employed a range of instrumentation to assess training outcomes in a structured and reliable manner. Integrating multiple tools allowed for a comprehensive evaluation of participant knowledge, behavior, and perception, aligning directly with the study's objectives while meeting rigorous data collection and analysis standards. All materials, including the informed consent form, perception survey, and training procedures, were reviewed and approved by the University of Wisconsin–Stout Institutional Review Board (IRB) under an expedited review protocol for protecting human subjects granted February 11, 2025 (see Appendix A).

A proprietary test developed by GTI Energy was utilized to measure knowledge. This instrument was created by SMEs with decades of experience in safety procedures, hazard recognition, appropriate responses during outside leak investigations, and critical competencies in the pipeline construction industry. GTI Energy, a globally recognized training provider in the gas sector for over seventy years, maintains this content to ensure its continued relevance and quality (GTI Energy, n.d.). The assessment consisted of 20 task-specific multiple-choice questions, each worth one point. While an 80% score is typically required to pass, no minimum score was enforced in this study to compare pre- and post-test performance.

Behavioral performance was evaluated using a task-specific checklist in conjunction with the NGA, collaborating with gas industry SMEs. The performance evaluation focused on training and education while increasing public awareness of natural gas. The checklist assessed procedural accuracy during leak investigation tasks through hands-on performance or within a VR environment. The VR group used the Pico Neo immersive headset and handheld controllers running proprietary software co-developed by Oberon and GTI Energy to simulate realistic job site conditions. Participants completed tasks in a dedicated, pre-programmed VR space that mirrored the real-world testing environment. For the hands-on group, participants used industry-standard tools, including a Combustible Gas Indicator, bar hole, and PPE such as safety glasses, hard hats, and vests, under supervision from a qualified trainer. The evaluation process was identical across both groups, ensuring consistency and eliminating instructional bias. The maximum possible score was 20 points, with one point awarded per correctly completed step; traditionally, a pass/fail assessment required no passing threshold in this research to allow for comparison-based analysis.

The training phase followed an identical structure for both groups and was delivered by the same instructor using a PowerPoint-based presentation also created by GTI Energy. The hands-on group reinforced learning with physical tools, while the VR group engaged in simulated scenarios within the VR software. After training, participants repeated the knowledge and performance assessments to determine learning outcomes. Both groups were evaluated within the same controlled facility to ensure environmental consistency.

Following the post-training assessments, participants completed a Likert scale-based perception survey (see Appendix B) to capture feedback on training effectiveness and comfort level. This anonymous survey also included basic demographic questions, such as age, gender, current job title, and years of experience, and 15 7-point scale items assessing participant perceptions of the training method. Initially developed by Rensis Likert in the 1930s, the Likert scale provides a reliable method for measuring attitudes and experiences based on balanced, clearly worded statements (Formifyr, 2024). Formifyr (2024) notes that effective Likert items must be unambiguous and offer a symmetrical range of options to avoid bias and ensure valid responses. Two SMEs, A. Day and T. Stemrich, reviewed the survey instrument and confirmed its alignment with the research objectives and industry standards (A. Day, personal communication, March 3, 2025; T. Stemrich, personal communication, March 6, 2025).

Given the specialized and time-sensitive nature of the pipeline construction industry, a quantitative approach was selected to minimize disruption. Microsoft Forms was used to administer the surveys, supported by research indicating its effectiveness as a secure, user-friendly tool for collecting anonymous data (Cigliana et al., 2024). All survey responses and performance data were stored in encrypted digital formats, with personally identifiable information removed and stored separately. Only the researcher and dissertation chair, Dr.

Selover, had access to this information. While company management facilitated employee participation, they were not provided access to research data to preserve confidentiality and research integrity.

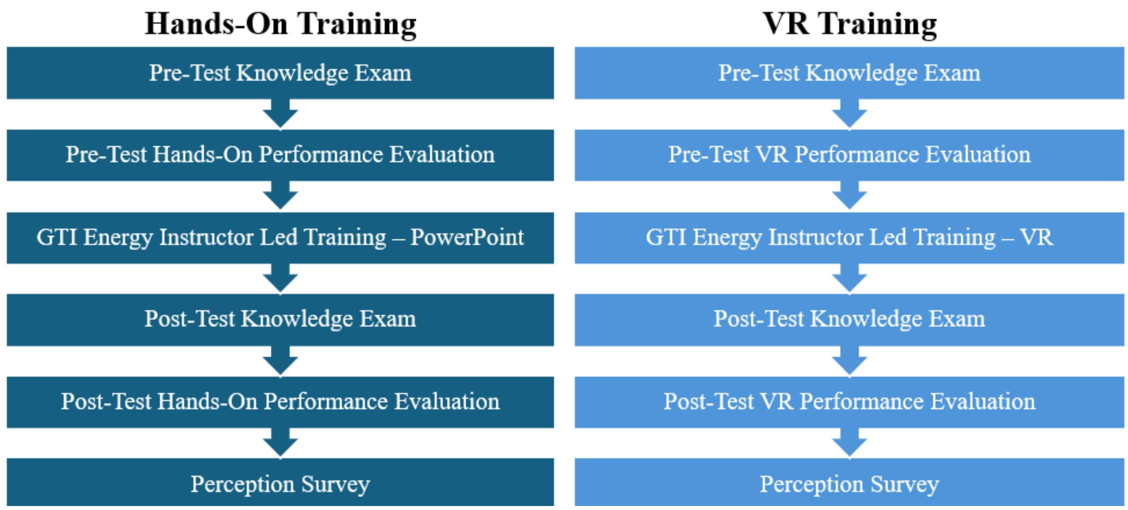
The survey design was based on Likert scale questions that intertwined with the adult learning theory by asking questions about preferred learning styles, relevance to experience, and motivation. In modern times, the Likert scale is one of the most common measurement methods for surveys (Baumeister et al., 2007). Jebb et al., (2021) also noted that Likert scales provide a simplified approach to measure unobservable constructs, as solidified in studies conducted by Clark and Watson (2019) and Hinkin (1998). They are used to gauge qualitative responses, such as general frequency and attitude toward a topic, which can be easily converted into quantitative data to be analyzed. (Baylor University, n.d.). “Recent studies show, however, that the reliability and validity of the data collected from these question types increases when using specifically a 7-category scale due to the increased spread of options to represent respondents’ viewpoints best” (Baylor University, n.d., para. 1). For this research, ELT has been utilized to test how VR training, over traditional hands-on training methods, could create safer environments for practicing high-risk activities that allow for errors without the physical consequences, and promote a higher level of knowledge transfer to the learner.

Data Collection Procedures

The data collection procedures used to collect and analyze data through pre- and post-training tests and performance evaluations determined whether sufficient evidence existed to answer the research questions. The following process was utilized as dipicted in Figure 3.

Figure 3

Process Flowchart



This process was selected due to the need to establish validity in the results by establishing a baseline. While this could potentially aid the sample populations in the baseline testing process, the population would still need the knowledge, skills, and ability to perform the task. The study aimed to identify the most effective training method for reducing safety-related incidents in the pipeline construction industry.

Pre-Test Cohort 1

The researcher arrived at Precision Pipeline Solutions in New Windsor, New York, on Wednesday, April 9th, at 8 a.m. The researcher was taken to a large training room, met with the two instructors, and reviewed the training procedures. The researcher ensured that adequate copies of the informed consent form, which is attached in Appendix C, were available and began testing the VR headsets and computers until noon. At noon, cohort one, which consisted of nine employees, entered the training room. The informed consent process was thoroughly detailed and passed out to each of the nine sample participants with pens. After all questions had been answered, each sample participant agreed to participate in the research. Upon collecting their forms, the researcher entered all nine names into Excel to randomly generate the participant numbers and control and experimental groups. Each participant was then informed of which test group they would participate in and split into two groups within the training room, five in the experimental group and four in the control group. Each participant was given a link to the Microsoft Forms pre-knowledge test to establish baseline results. Upon completion of the initial test, oral feedback was provided, and questions were answered. The control group then moved into the lab testing area to begin the initial hands-on test for leak investigation. The trainer utilized the Microsoft Forms performance checklist that I had previously emailed. The experimental group stayed in the main training room, and the trainer administered the same performance checklist while the participants completed the same procedures for leak investigation in VR. Again, oral feedback was provided. The testing process for both groups lasted approximately 1 hour.

Training Cohort 1

After completing the pre-tests, the control group rejoined the experimental group, and training commenced. GTI Energy's proprietary training on leak investigation was administered via PowerPoint. The control group reviewed the physical equipment periodically throughout the training, while the experimental group was shown the same equipment in VR. The training lasted approximately 1.5 hours for both groups.

Post-Test Cohort 1

Immediately after the training, the control and experimental groups completed identical post-knowledge tests administered from the previously emailed Microsoft Forms link. Upon completion, the control group returned to the lab, and the experimental group remained in the main training room to complete the performance evaluations in VR for a direct comparison with pre-test results, following the identical steps in the pre-testing procedure. Feedback was provided upon completion. This test lasted approximately 1 hour for both groups.

Survey Cohort 1

Upon completing all testing, each participant was emailed the perception survey via a Microsoft Forms link. All nine participants completed the survey, and the research for cohort one was concluded. The survey took approximately 15 minutes to complete from initial instruction to submission. The total research time was approximately four hours.

Upon completion of cohort one, cohort two immediately entered the training room. The procedures and steps to complete the training were identical between the two cohorts.

Pre-Test Cohort 2

At 4 p.m., cohort two, which consisted of eight employees, entered the training room. The informed consent process was thoroughly detailed and passed out to each of the eight sample participants with pens. After all questions had been answered, each sample participant agreed to participate in the research. Upon collecting their forms, the researcher entered all eight names into Excel to randomly generate the participant numbers and control and experimental groups. Each participant was then informed of which test group they would participate in and split into two groups within the training room, four in the experimental group and four in the control group. Each participant was then sent a link to the Microsoft Forms pre-knowledge test to establish baseline results. Upon completion of the initial test, oral feedback was provided, and questions were answered. The control group moved into the lab testing area to begin the initial hands-on test for leak investigation. The trainer utilized the Microsoft Forms performance checklist that I previously emailed. The experimental group stayed in the main training room, and the trainer administered the same performance checklist while the participants completed the same procedures for leak investigation in VR. Again, oral feedback was provided. The testing process lasted approximately 1 hour for both groups.

Training Cohort 2

After completing the pre-tests, the control group rejoined the experimental group, and training commenced. GTI Energy's proprietary training on leak investigation was administered via PowerPoint. The control group reviewed the physical equipment periodically throughout the training, while the experimental group was shown the same equipment in VR. The training lasted approximately 1.5 hours for both groups.

Post-Test Cohort 2

Immediately after the training, the control and experimental groups completed identical post-knowledge tests administered from the previously emailed Microsoft Forms link. Upon completion, the control group returned to the lab, and the experimental group remained in the training room to complete the performance evaluations in VR for a direct comparison with pre-test results, following the identical steps in the pre-testing. Feedback was provided upon completion. This test lasted approximately 1 hour for both groups.

Survey Cohort 2

Upon completing all testing, each participant was emailed the perception survey via a Microsoft Forms link. All eight participants completed the survey, and the research for cohort two was concluded. The survey took approximately 15 minutes to complete from initial instruction to submission. The total research time was four hours, completed by 8 p.m.

Data Analysis

The data analysis process evaluated whether hands-on or VR training data collected can be used to identify relationships, trends, or patterns. This approach allowed for deriving meaningful conclusions that support this research's objectives and questions. Statistics play a critical role in research by providing the tools necessary to collect, analyze, and interpret data to make informed decisions and draw valid conclusions from the data (Weihs & Ickstadt, 2018). Additionally, proper statistical methods ensure the experiments' reproducibility, a cornerstone of research (Kramer et al., 2019). As the International Journal of Data Science and Analytics highlights, statistics is fundamental in uncovering meaning within data and offering deeper insights (Weihs & Ickstadt, 2018). Detailed descriptions of study designs, data collection processes, and statistical analyses in research articles enable other researchers to replicate and build upon existing work, allowing advancement of knowledge (Kramer et al., 2019).

Research Question 1 Statistical Analysis

For Research Question 1, the statistical software Jamovi was used to analyze the measurement of change in knowledge retention for each participant to ensure alignment with the research question: which specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, potentially resulting in a safer workforce. The data was then compared for the change across both training types, which required analyzing pre- and post-test knowledge scores per individual and then at a group-level comparison to identify the individual improvements. To run this data analysis, the researcher ensured that the data for the pre-test and post-test were labeled as continuous and the training type as nominal. The data was then imported, and a Computed Variable was computed. The new field was named knowledge gain, and the following formula was entered: = posttest – pretest. The new column reflected the change in raw scores for each participant between the pre- and post-test scores. An independent sample t-test was conducted by setting the dependent variable to the newly created knowledge gain field and grouping variable by training type. Descriptive statistics measured the mean difference with a 95% confidence interval and the effect size for knowledge tests. Welch's t-test and the Mann-Whitney U test were used to determine any significant difference in data. Shapiro-Wilk and Levene's tests were also used to determine if the knowledge gain followed a normal distribution and if the variance among the knowledge gain scores was equal across the two training groups. These tests determined if one group improved more than the other using the independent t-test, whether the difference was statistically significant, and whether the difference was practically meaningful.

Research Question 2 Statistical Analysis

For Research Question 2, the statistical software Jamovi analyzed which method influences and leads to a demonstrable behavior change in safely performing pipeline tasks, VR, or hands-on training. The results were ensured by labeling the pre- and post-performance test data as continuous and the training type as nominal. Again, the data was imported, a Computed Variable was computed, and it was labeled behavior change with the following formula: = posttest - pretest. This provided the behavior change column to reflect the statistical value of the results and assist in analyzing whether traditional or VR led to a more significant behavior modification. An independent t-test was conducted to analyze the mean difference in training outcomes between hands-on and VR training groups. The dependent variable was the behavior change, and the grouping variable was the training type. The assumption and requirement for this data was that the dependent variable and the test scores must be continuous. It also required normal distribution within each group and the testing of homogeneity of variances using

Levene's Test and the Mann-Whitney U test. Descriptives, effect size, and confidence interval at 95% were also conducted. The data sources were the pre- and post-testing performance evaluations completed using simulated tasks. The standard of $p < 0.05$ was applicable in this dataset to balance Type I errors.

Research Question 3 Statistical Analysis

Lastly, for Research Question 3, the statistical software Jamovi analyzed how perception, satisfaction, and engagement with training experiences differ between VR and traditional hands-on training. The study results were analyzed by ensuring the Likert scale survey data variables of training type were listed as nominal and the survey questions as continuous. The data was imported, and again, an independent t-test was conducted. The dependent variables were perception, satisfaction, and engagement of the training type completed, and the grouping variable was the training type. It also required normal distribution within each group and the testing of homogeneity of variances using Levene's Test, Welch's T-tests, and the Mann-Whitney U test. Descriptives, mean difference, effect size, and confidence interval at 95% were also conducted. The data sources were the fifteen survey questions administered post-training. The standard of $p < 0.05$ was applicable in this dataset to balance Type I errors. Assumption tests and Shapiro-Wilk and Levene's tests were also used. The assumption and requirement for this data was that it contained all the values for accurate data.

Limitations

Identifying this research's limitations is essential to ensuring the generalizability of the findings and maintaining integrity. Sample population-related limitations include selection bias, as the entire sample does not accurately reflect the entire construction industry. This sample reflects pipeline construction work instead of one of many other sub-groups, so randomization of the sample populations was necessary. The sample populations had a wide range of experience and skill sets. This inevitably led some sample populations to have more knowledge of construction practices and safety procedures, and testing may not reflect new knowledge learned from training, but rather that of prior experience. To account for this, a pre-test was utilized to establish a baseline and then compared to the post-test for research validity. Limitations also include a smaller sample size. Although seventeen participants participated in this study, the sample size is not statistically significant to generalize the findings to the construction industry. This is due to several factors, including the wide range of sub-trades within the industry, each with varying levels of worker expertise, differing scopes of work, and diverse job-site environments with changing safety risks. Additionally, VR and hands-on training are two completely distinct ways of training. VR favors depth perception and understanding of technology use, while hands-on is a physical interaction with real tools. This could result in varying degrees of knowledge transfer between the two approaches. A follow-up assessment could be done in future research where both groups receive the same level of exposure to both training methods, and those results can then be compared. Training environmental limitations are also factored in due to the controlled nature of the research, as it does not fully replicate the work being performed on a job site. The sample populations may perform higher in a controlled environment, potentially inflating the training effectiveness. To combat this, the tasks simulated the conditions encountered in the field as closely as possible, with physical equipment for the control group and a robust VR program for the experimental group. VR may initially show higher test scores due to the novelty of the technology. This could prematurely show added benefits to the technology, but long-term results would decipher the sustainability.

Summary

Chapter 3 summarizes the subject selection process, how the instrumentation for the study was used, data analysis, and limitations of this research. The concentration was on analyzing the data to determine if there was a statistical difference in training methodology between hands-on and VR training to improve training outcomes and reduce safety-related incidents within the construction industry. Chapter 4 will continue with an in-depth exploration of the research results.

Chapter IV: Presentation of the Findings

This study aimed to evaluate the effectiveness of VR training methods compared to hands-on training methods in enhancing training outcomes within the pipeline construction workforce. To achieve zero accidents, the pipeline construction industry is exploring various tools to improve safety management, training, and awareness (Salinas et al., 2022). This research focused on training observations, pre- and post-training tests, performance evaluations, and sample population surveys within the pipeline construction industry. The primary objectives were to collect and analyze pre- and post-training tests and performance evaluations to determine whether sufficient evidence existed to answer the research questions. Additionally, the study aimed to identify which training method, traditional hands-on or VR, was the most effective for potentially reducing safety-related incidents in the pipeline construction industry. An online Microsoft survey assessed the sample population's confidence in applying safety skills, perceptions of training effectiveness, and overall impressions of the training methods used.

Research Questions

The questions that guided this study are the following:

1. What specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, potentially resulting in a safer workforce?
2. Which method influences and leads to a demonstrable behavior change in safely performing pipeline tasks, VR, or hands-on training?
3. How do perception, satisfaction, and engagement with training experience differ between VR and traditional hands-on training?

This chapter will provide the results of the true experimental design study and an in-depth analysis of the results as they pertain to each of this study's research questions.

Demographics

The control group had eight participants, whereas the experimental group had nine. The 17 participants included 16 males and one female. This provided a diversified sample of varying age, sex, and experience. The demographics obtained are itemized in Table 1 below:

Table 1

Training Demographics

Training Type	Gender	Age Range	Job Role
Traditional	Female	46-55	Supervisor
Traditional	Male	66+	Training
Traditional	Male	56-65	VP
Traditional	Male	36-45	Field Supervisor
Traditional	Male	56-65	Leak Survey Tech
Traditional	Male	46-55	Project Manager
Traditional	Male	56-65	Laborer
Traditional	Male	26-35	Laborer
VR	Male	46-55	Project Manager
VR	Male	56-65	Laborer
VR	Male	56-65	Training
VR	Male	56-65	Project Manager
VR	Male	46-55	Operator
VR	Male	36-45	Project Manager
VR	Male	36-45	Foreman
VR	Male	26-35	Gas Tech
VR	Male	36-45	Trainer

Findings

This section reports the quantitative findings from the research study, which investigated the impact of hands-on and virtual reality (VR) training methods on improving safety outcomes in the pipeline construction industry. The analysis focuses on measurable variables and outcomes such as knowledge retention, incident identification, and task performance, using statistical analysis to compare the effectiveness of the two training methods. These results provide data-driven insight into how each method influences safety-related behaviors and competencies.

Research Question 1 Findings

The interpretation of the findings for the question, what specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, potentially resulting in a safer workforce, shows statistically no significant difference in knowledge gains between the two groups, as depicted in Figure 4.

Figure 4

Knowledge Retention by Training Type

							95% Confidence Interval				95% Confidence Interval	
		Statistic	df	p	Mean difference	SE difference	Lower	Upper		Effect Size	Lower	Upper
Knowledge Gain	Student's t	1.08 ᵃ	15.0	0.299	1.24	1.15	-1.21	3.68	Cohen's d	0.523	-0.483	1.50
	Welch's t	1.03	8.96	0.331	1.24	1.20	-1.48	3.96	Cohen's d	0.510		
	Mann-Whitney U	30.0		0.589	1.000		-2.00	4.00	Rank biserial correlation	0.167		

Note. H_a $\mu_{\text{Control Group - Knowledge}} \neq \mu_{\text{Experimental Group - Knowledge}}$

ᵃ Levene's test is significant (p < .05), suggesting a violation of the assumption of equal variances

The control group's mean knowledge gain was 4.13 compared to the experimental group's 2.89. However, the median for both groups was 3.0, which indicated that the control group had higher levels of variability in the recorded responses (SD = 3.18 vs 1.27) as seen in Figure 5.

Figure 5

Knowledge Gain per Group

	Group	N	Mean	Median	SD	SE
Knowledge Gain	Control Group - Knowledge	8	4.13	3.00	3.18	1.13
	Experimental Group - Knowledge	9	2.89	3.00	1.27	0.423

The independent t-test data indicated a p-value of 0.299, which showed a 29.9% chance that the results occurred randomly. Therefore, there is no statistically significant difference in knowledge gain. This is further reinforced with a 95% confidence interval (-1.21, 3.68), which includes 0, which cannot rule out the possibility of no real difference within the data. Welch's t-test, with a p-value of 0.331 and a similar confidence interval of (-1.48, 3.96) and Cohen's d of 0.510 again showed no significance, but did reinforce the moderate effect size. The violation of equal variances with Levene's test of $p = 0.008$ justifies this correction. The Mann-Whitney U test provided a result of 30.0 and a p-value of 0.589, an effect size of 0.167, and a confidence interval of (-2.00, 4.00). This again confirms the previous two tests with no significant difference. Two assumption tests were employed: Shapiro-Wilk (Normality) with a result of $W = 0.958$ with a p-value of 0.587, which can be seen in Figure 6. This confirmed the normality assumed.

Figure 6

Normality Test on Knowledge Gain per Group

Normality Test (Shapiro-Wilk)

	W	p
Knowledge Gain	0.958	0.587

Note. A low p-value suggests a violation of the assumption of normality

Levene's (Equal Variance) was also run, as shown in Figure 7. It shows a result of F = 9.49 with a p-value of 0.008, indicating that the assumption was violated, making Welch's t-test the appropriate method for testing.

Figure 7

Levene's Test on Knowledge Gain per Group

Homogeneity of Variances Test (Levene's)

	F	df	df2	p
Knowledge Gain	9.49	1	15	0.008

Note. A low p-value suggests a violation of the assumption of equal variances

In summary, while the control group showed more significant knowledge improvement, the difference cannot be considered statistically significant. The moderate effect size suggests that the traditional training methods have a higher potential to be more effective, but the sample size prevented the results from reaching statistical significance.

Research Question 2 Findings

Interpreting the findings for the question of which method influences and leads to a demonstrable behavior change in safely performing pipeline tasks: VR or hands-on training, Figure 8 shows that the experimental group (VR) showed on average better improvement, but with a smaller sample size, the result is not conclusive.

Figure 8

Behavior Change in Training Groups

							95% Confidence Interval				95% Confidence Interval	
		Statistic	df	p	Mean difference	SE difference	Lower	Upper		Effect Size	Lower	Upper
Behavior Change	Student's t	-0.947	15.0	0.359	-0.917	0.968	-2.98	1.15	Cohen's d	-0.460	-1.43	0.536
	Mann-Whitney U	29.0		0.524	-1.000		-3.00	1.00	Rank biserial correlation	0.194		

The behavior change was measured using only the hands-on application for each group, and scores were compared individually to measure the change. Group descriptive statistics were performed, and the mean change indicated that the experimental group had a greater improvement (1.67) than the control group (0.75). The median also supported this data, with the experimental group at (1.00) and the control group at (0.50). Standard deviations were nearly identical, indicating that the variability amongst both groups was nearly similar. The independent sample t-tests also found that the data was not statistically significant with a p-value of 0.359 and a mean difference of -0.917. The 95% confidence interval of (-2.98, 1.15), which includes 0, cannot rule out the possibility of no real difference within the data. The effect size of d = -0.460, a moderate effect size, indicates practical importance, even though the data is not statistically significant. The Mann-Whitney U test provided a result of 29.0, a p-value of 0.524, and an effect size of 0.194. This again confirms no statistically significant difference. Two assumption tests were employed: Shapiro-Wilk (Normality) with a result of W = 0.962 with a p-value of 0.661, and Levene's test, which can be seen in Figure 9. This confirmed the normality assumed.

Figure 9

Normality Test on Behavior Change per Group

Normality Test (Shapiro-Wilk)

	W	p
Behavior Change	0.962	0.661

Note. A low p-value suggests a violation of the assumption of normality

Levene's (Equal Variance) was also run, as seen in Figure 10. It shows the result of F = 0.023 with a p-value of 0.881. This indicates that the variances are equal, the assumptions for the t-test are satisfied, and the results are valid.

Figure 10

Levene's Test on Behavior Change per Group

Homogeneity of Variances Test (Levene's)

	F	df	df2	p
Behavior Change	0.0230	1	15	0.881

Note. A low p-value suggests a violation of the assumption of equal variances

In summary, although the experimental group showed a more significant average improvement, the difference cannot be stated as statistically significant. However, the moderate effect size does suggest there is real-world relevance to the data, and with a larger sample size, this could reveal statistical significance.

Research Question 3 Findings

Table 2 interprets the findings regarding how perception, satisfaction, and engagement with an experience differ between VR and traditional hands-on training, segregated by domain. The domains covered the effectiveness of learning experiences (Q1-Q4), engagement and motivation (Q5-Q7), satisfaction and recommendation (Q8-Q9), ease of use and comprehension (Q10-Q12), and application and future training (Q13-Q15).

Table 2

Perception Survey

Question number	Domain	Question
1	Effectiveness of learning experience	The learning experience I completed was effective in helping me comprehend safety procedures.
2	Effectiveness of learning experience	The learning experience covered real-world safety risks in my job.
3	Effectiveness of learning experience	The learning experience assisted in hazard recognition.
4	Effectiveness of learning experience	The learning experience was an effective method to teach proper use of equipment and tools.
5	Engagement & motivation	I felt engaged and excited to learn throughout the learning experience.
6	Engagement & motivation	The learning experience has motivated me to work more safely.
7	Engagement & motivation	I feel confident applying the skills I learned in my job.
8	Satisfaction & recommendation	I am satisfied with the quality of the learning experience I received.
9	Satisfaction & recommendation	I would recommend a co-worker to complete this learning experience.
10	Ease of use & comprehension	The learning experience was user-friendly.
11	Ease of use & comprehension	The learning experience increased my overall safety awareness.
Question number	Domain	Question
13	Application & future training	Additional learning experiences in the same format would benefit me and my company.

14	Application & future training	The learning experience directly applied to the work I perform.
15	Application & future training	The learning experience allowed me to practice performing tasks with minimal risk to my safety.

Figure 11 shows that independent sample t-tests, Welch's t-tests, and Mann-Whitney U tests were conducted across the fifteen Likert-scale questions.

Figure 11

Behavior Change by Group Type

		Statistic	df	p	Mean difference	SE difference	95% Confidence Interval Lower	95% Confidence Interval Upper		Effect Size
Q1: Effectiveness of Learning Experience	Student's t	-0.268	15.0	0.792	-0.1111	0.414	-0.994	0.771	Cohen's d	-0.130
	Welch's t	-0.266	13.83	0.794	-0.1111	0.418	-1.010	0.787	Cohen's d	-0.130
	Mann-Whitney U	35.0		0.958	-2.82e-5		-1.000	1.000	Rank biserial correlation	0.0278
Q2: Effectiveness of Learning Experience	Student's t	-0.664	15.0	0.517	-0.1667	0.251	-0.701	0.368	Cohen's d	-0.323
	Welch's t	-0.661	14.47	0.519	-0.1667	0.252	-0.705	0.372	Cohen's d	-0.322
	Mann-Whitney U	30.0		0.535	-1.01e-5		-1.000	3.76e-5	Rank biserial correlation	0.1667
Q3: Effectiveness of Learning Experience	Student's t	-0.273	15.0	0.788	-0.0694	0.254	-0.611	0.472	Cohen's d	-0.133
	Welch's t	-0.274	14.83	0.788	-0.0694	0.254	-0.611	0.472	Cohen's d	-0.133
	Mann-Whitney U	33.5		0.822	-2.45e-5		-1.000	5.82e-5	Rank biserial correlation	0.0694
Q4: Effectiveness of Learning Experience	Student's t	-0.243 [a]	15.0	0.812	-0.0833	0.344	-0.816	0.649	Cohen's d	-0.118
	Welch's t	-0.235	10.77	0.819	-0.0833	0.355	-0.867	0.700	Cohen's d	-0.116
	Mann-Whitney U	36.0		1.000	1.23e-5		-1.000	1.000	Rank biserial correlation	0.0000
Q5: Engagement & Motivation	Student's t	-1.181	15.0	0.256	-0.2917	0.247	-0.818	0.235	Cohen's d	-0.574
	Welch's t	-1.178	14.62	0.257	-0.2917	0.248	-0.820	0.237	Cohen's d	-0.573
	Mann-Whitney U	25.5		0.267	-1.97e-5		-1.000	5.04e-5	Rank biserial correlation	0.2917
Q6: Engagement & Motivation	Student's t	0.542	15.0	0.596	0.3333	0.615	-0.977	1.643	Cohen's d	0.264
	Welch's t	0.552	14.67	0.589	0.3333	0.604	-0.957	1.624	Cohen's d	0.266
	Mann-Whitney U	32.5		0.762	8.56e-5		-1.000	2.000	Rank biserial correlation	0.0972
Q7: Engagement & Motivation	Student's t	-0.648	15.0	0.527	-0.1944	0.300	-0.834	0.445	Cohen's d	-0.315
	Welch's t	-0.665	13.71	0.517	-0.1944	0.292	-0.823	0.434	Cohen's d	-0.319
	Mann-Whitney U	28.0		0.415	-3.27e-5		-1.000	5.21e-5	Rank biserial correlation	0.2222
Q8: Satisfaction & Recommendation	Student's t	-1.181	15.0	0.256	-0.2917	0.247	-0.818	0.235	Cohen's d	-0.574

Note. H_a $\mu_{Traditional} \neq \mu_{VR}$

[a] Levene's test is significant ($p < .05$), suggesting a violation of the assumption of equal variances

							95% Confidence Interval			
		Statistic	df	p	Mean difference	SE difference	Lower	Upper		Effect Size
	Welch's t	-1.178	14.62	0.257	-0.2917	0.248	-0.820	0.237	Cohen's d	-0.573
	Mann-Whitney U	25.5		0.267	-1.97e−5		-1.000	5.04e-5	Rank biserial correlation	0.2917
Q9: Satisfaction & Recommendation	Student's t	-1.792	15.0	0.093	-0.6528	0.364	-1.429	0.124	Cohen's d	-0.871
	Welch's t	-1.718	9.43	0.118	-0.6528	0.380	-1.506	0.201	Cohen's d	-0.851
	Mann-Whitney U	20.5		0.097	-1.000		-1.000	4.35e-5	Rank biserial correlation	0.4306
Q10: Ease of Use & Comprehension	Student's t	0.247	15.0	0.808	0.1111	0.450	-0.849	1.071	Cohen's d	0.120
	Welch's t	0.252	14.42	0.805	0.1111	0.441	-0.833	1.055	Cohen's d	0.121
	Mann-Whitney U	35.0		0.959	1.61e-5		-1.000	1.000	Rank biserial correlation	0.0278
Q11: Ease of Use & Comprehension	Student's t	0.278	15.0	0.785	0.1250	0.450	-0.835	1.085	Cohen's d	0.135
	Welch's t	0.275	14.06	0.787	0.1250	0.454	-0.848	1.098	Cohen's d	0.134
	Mann-Whitney U	31.5		0.661	7.41e-6		-1.000	1.000	Rank biserial correlation	0.1250
Q12: Ease of Use & Comprehension	Student's t	1.181	15.0	0.256	0.3889	0.329	-0.313	1.091	Cohen's d	0.574
	Welch's t	1.208	14.15	0.247	0.3889	0.322	-0.301	1.079	Cohen's d	0.581
	Mann-Whitney U	26.0		0.315	1.36e-5		-2.45e−5	1.000	Rank biserial correlation	0.2778
Q13: Application & Future Training	Student's t	-0.224	15.0	0.826	-0.0694	0.310	-0.730	0.591	Cohen's d	-0.109
	Welch's t	-0.229	14.38	0.822	-0.0694	0.304	-0.719	0.580	Cohen's d	-0.110
	Mann-Whitney U	32.0		0.705	-3.55e−5		-1.000	1.000	Rank biserial correlation	0.1111
Q14: Application & Future Training	Student's t	-1.289	15.0	0.217	-0.8472	0.657	-2.248	0.553	Cohen's d	-0.627
	Welch's t	-1.260	12.19	0.231	-0.8472	0.672	-2.309	0.615	Cohen's d	-0.619
	Mann-Whitney U	25.0		0.283	-1.000		-3.000	1.83e-5	Rank biserial correlation	0.3056
Q15: Application & Future Training	Student's t	-1.108	15.0	0.285	-0.4444	0.401	-1.299	0.411	Cohen's d	-0.538
	Welch's t	-1.092	13.28	0.294	-0.4444	0.407	-1.322	0.433	Cohen's d	-0.534

Note. H_a $\mu_{Traditional} \neq \mu_{VR}$

[a] Levene's test is significant ($p < .05$), suggesting a violation of the assumption of equal variances

The effectiveness of the learning experience (Q1-Q4) was not statistically significant due to the sample size and effect size. The mean difference across all four questions in chronological order: -0.11, -0.17, -0.7, and -0.8 also showed no statistically significant difference. However, the small effect sizes indicated similar perceived effectiveness across both training methods. Engagement and motivation (Q5-Q7) demonstrated that the control group reported slightly higher engagement in question five with a moderate effect size of *d* = -0.57 but did not reach statistical significance 0.256. Question seven also reported a slightly higher engagement and motivation with the control group, with a mean difference of -0.19 but a small effect size of *d* = -0.32. However, the experimental group scored slightly higher on question six with a mean difference of +0.33, but again with a small effect size of *d* = 0.26. The training's satisfaction and recommendation (Q8-Q9) showed that, while not statistically significant, VR participants were more likely to recommend the training. It also suggested that due to the large effect size of *d* = -0.87, it was a meaningful practical difference, almost approaching statistical significance with a p-value of 0.093. Ease of use and comprehension (Q10-Q12) indicated the VR training was perceived with a slight advantage as being more user-friendly and comprehensive. However, again, none of these tests reached statistical significance. Application and future training (Q13-Q15) showed small and moderate effect sizes, indicating potentially meaningful differences. VR participants rated the applicability and future use slightly higher than the traditional training methods, especially in question 14.

Two assumption tests were employed: Shapiro-Wilk (Normality), which showed that most variables violated normality, indicating non-normal data, as seen in Figure 12.

Figure 12

Normality Test by Domain

Normality Test (Shapiro-Wilk)

	W	p
Q1: Effectiveness of Learning Experience	0.860	0.015
Q2: Effectiveness of Learning Experience	0.754	< .001
Q3: Effectiveness of Learning Experience	0.685	< .001
Q4: Effectiveness of Learning Experience	0.819	0.004
Q5: Engagement & Motivation	0.833	0.006
Q6: Engagement & Motivation	0.870	0.022
Q7: Engagement & Motivation	0.849	0.010
Q8: Satisfaction & Recommendation	0.833	0.006
Q9: Satisfaction & Recommendation	0.824	0.004
Q10: Ease of Use & Comprehension	0.899	0.066
Q11: Ease of Use & Comprehension	0.773	< .001
Q12: Ease of Use & Comprehension	0.913	0.111
Q13: Application & Future Training	0.790	0.001
Q14: Application & Future Training	0.903	0.077
Q15: Application & Future Training	0.879	0.031

Note. A low p-value suggests a violation of the assumption of normality

As seen in Figure 13, Levene's Test assumptions indicated that almost all questions passed, except question four, with a value of $p = .044$, where the equal variance is not assumed.

Figure 13

Levene's Test by Domain

Homogeneity of Variances Test (Levene's)

	F	df	df2	p
Q1: Effectiveness of Learning Experience	0.0951	1	15	0.762
Q2: Effectiveness of Learning Experience	0.8824	1	15	0.362
Q3: Effectiveness of Learning Experience	0.2762	1	15	0.607
Q4: Effectiveness of Learning Experience	4.8529	1	15	0.044
Q5: Engagement & Motivation	0.1106	1	15	0.744
Q6: Engagement & Motivation	3.1513	1	15	0.096
Q7: Engagement & Motivation	3.1932	1	15	0.094
Q8: Satisfaction & Recommendation	0.1106	1	15	0.744
Q9: Satisfaction & Recommendation	1.5673	1	15	0.230
Q10: Ease of Use & Comprehension	1.2814	1	15	0.275
Q11: Ease of Use & Comprehension	0.3725	1	15	0.551
Q12: Ease of Use & Comprehension	0.3151	1	15	0.583
Q13: Application & Future Training	1.5401	1	15	0.234
Q14: Application & Future Training	2.9685	1	15	0.105
Q15: Application & Future Training	0.1823	1	15	0.675

Note. A low p-value suggests a violation of the assumption of equal variances

Summary

In summary, this chapter discussed the true experimental design study results and the Likert-scale survey results of 17 individuals working in the pipeline construction industry. These findings provided a foundational level of understanding of how traditional and VR training methods in the pipeline construction industry influence safety knowledge and behavior, perception, satisfaction, and engagement outcomes. In the final chapter, a deeper dive and interpretation of the data will be discussed, as well as an interpretation of the findings and their practical implications.

Chapter V: Discussion, Conclusion, and Recommendations

This study aimed to evaluate the effectiveness of VR training methods compared to traditional hands-on training methods to enhance training outcomes within the pipeline construction industry. To achieve zero accidents, the pipeline construction industry is exploring various tools to improve safety management, training, and awareness (Salinas et al., 2022). This research focused on training observations, pre- and post-training tests, performance evaluations, and sample population surveys within the pipeline construction industry. The primary objectives were to collect and analyze pre- and post-training tests and performance evaluations to determine whether sufficient evidence existed to answer the research questions. Additionally, the study aimed to identify which training method, traditional hands-on or VR, was the most effective for potentially reducing safety-related incidents in the pipeline construction industry. An online Microsoft survey assessed the sample population's confidence in applying safety skills, perceptions of training effectiveness, and overall impressions of the training methods used.

The next section of this chapter will present the results of the quantitative analysis comparing the effectiveness of hands-on and virtual reality (VR) safety training methods within the pipeline construction industry. This chapter builds upon those findings by interpreting the results and the relevant literature introduced in chapters one and two. It also aims to provide insight into the implications of training method effectiveness, knowledge retention, behavior change, and participant experience. This chapter also outlines the conclusions drawn from the study and offers recommendations for future research and use within pipeline construction safety training.

Discussion

This section will discuss recommendations based on the study's results and existing literature on construction safety training. It will also explore potential explanations for the observed trends and limitations, and suggest future research to enhance safety in the pipeline construction industry.

Research Question 1

Research questions 1 asked, “What specific type of training, VR or traditional hands-on, is most effective in improving knowledge retention, potentially resulting in a safer workforce?” This research question was answered through the results obtained from pre- and post-knowledge test scores compared across the control and experimental groups. While the control group demonstrated a greater average gain (M = 4.13) than the experimental group (M = 2.89), the difference did not meet statistical significance (p = 0.299). While the control group did show a slight advantage, the variability amongst responses, combined with a small sample size, may have limited the statistical power of this research.

The findings related to research question 1 align with prior literature highlighting the strengths and limitations of both hands-on and virtual reality (VR) training approaches. Traditional hands-on training has been widely utilized in the construction industry due to its practical nature and tool-based application, which promotes a deeper understanding of safety procedures (Guo et al., 2024; NAA, n.d.). This method benefits learners who prefer physical interaction with their environment and allows immediate instructor feedback (Demirkesen & Arditi, 2015). However, as noted in the literature, hands-on training can be limited by inconsistent instruction quality, logistical challenges, and risks associated with real-world exposure (Alsharef et al., 2020; Stefan et al., 2023). On the other hand, VR training offers a scalable, immersive environment where learners can repeatedly engage with realistic tasks without facing actual hazards (Le et al., 2015; Zhao & Ye, 2012). Though VR has shown strong potential for increasing engagement and recall through simulation-based learning, its effectiveness can vary depending on the learner's familiarity with technology and the quality of the VR design (Kim et al., 2020; Zhang et al., 2022). These findings reinforce the need for a balanced approach to training, leveraging the realistic advancements in technology and adaptability of hands-on methods while exploring the enhanced retention benefits that VR may offer under the right conditions.

Research Question 2

Research questions 2 asked, "Which method influences and leads to a demonstrable behavior change in safely performing pipeline tasks, VR, or hands-on training?" Research question 2 compared the behavioral performance of the pre- and post-tests to identify if a performance increase could be identified. This data revealed that the experimental group experienced a higher mean improvement (M = 1.67) than the control group (M = 0.75). Again, the results were not statistically significant (p = 0.359), but the moderate effect size (Cohen's d = -0.46) indicated that VR training may yield practically relevant improvements in safe task performance. Both normality and variance assumptions were met, which supported the validity of the t-test used.

In evaluating research question 2, the findings suggest that both VR and traditional hands-on training methods contributed to measurable improvements in safety-related behaviors, with the VR group showing slightly greater behavioral change. This outcome supports previous studies indicating that immersive environments can strengthen skill acquisition by repeatedly allowing learners to practice tasks in a simulated setting without real-world risk (Le et al., 2015;

Stefan et al., 2023). VR's interactive nature encourages trial-and-error learning, which is highly effective in high-risk industries where mistakes in the field could lead to serious consequences (Seo et al., 2021). However, traditional hands-on training remains valuable, especially for tasks requiring muscle memory and fine motor skills, as it mirrors actual jobsite conditions (NAA, n.d.; Train Beyond, 2024). The statistical difference in behavioral change between the groups was not significant; however, the moderate effect size suggests that VR has promising benefits in improving task performance and safety. These results reinforce the need to consider both the nature of the tasks being taught and the learning preferences of the workforce when selecting training methods (Guo et al., 2024; Kim et al., 2020). This will ensure that training for real-world scenarios is safe and provides learners with the best possible experience, which they will retain.

Research Question 3

Research questions 3 asked, "How do perception, satisfaction, and engagement with training experience differ between VR and traditional hands-on training?" While this survey did not indicate statistically significant differences in perception, satisfaction, or engagement, there were many indications, from moderate to large effect sizes, favoring VR. Willingness to recommend the training (Q9), comprehension (Q12), and future training applicability (Q14) suggest that VR has practical advantages even in the absence of statistical significance. Although not statistically conclusive, these findings suggest VR training is perceived favorably and may enhance learner motivation and satisfaction.

The findings for research question 3 highlight that while no statistically significant differences were observed between the groups, participants who completed the VR training consistently reported higher levels of satisfaction, comprehension, and willingness to recommend the training. These results are consistent with prior literature suggesting that immersive learning environments foster greater engagement and motivation, especially when learners feel actively involved in the training process (Zhao & Ye, 2012; Rowen et al., 2022). VR training environments, which simulate real-world scenarios and allow for repeated practice in a risk-free space, are often perceived as more modern, efficient, and relevant, specifically among workers comfortable with technology (Zhang et al., 2022). However, it is important to acknowledge that hands-on training resonates well with many learners, especially those who value tactile interaction and personal guidance from instructors (Demirkesen & Arditi, 2015; Guo et al., 2024). While individual preferences and technological familiarity may influence perception, the data suggests that VR holds meaningful potential for enhancing user experience in training when implemented effectively. These findings underscore the importance of aligning training methods with task objectives and learner engagement strategies to maximize impact.

Conclusion

The results of this study revealed that both traditional and VR training methods contributed to improved knowledge and behavior modification among pipeline construction workers. While traditional training did show a slightly greater increase in knowledge retention, VR training led to more noticeable improvements in how participants performed safety-related tasks. Regarding how the training was experienced, participants viewed both methods positively. However, those in the VR group expressed a stronger sense of engagement, comprehension, and willingness to recommend the training to others.

VR provides numerous benefits for enhancing safety in the construction industry. It prioritizes learner engagement in an immersive setting that provides hands-on simulations without the real-world risks, associated with traditional training methods. It also allows for repeated attempts and immediate feedback in critical areas such as hazard recognition within a controlled environment. This can lead to better behavioral outcomes and improved knowledge transfer and retention, as demonstrated in this study. Additional studies, such as the one conducted by Scorgie et al. (2024), confirm that VR training enhances retention, increases learner productivity and engagement, and promotes a deeper understanding of safety and job-specific tasks. VR is also cost-effective, reducing travel, productivity loss, and training materials/equipment costs. As training programs continue to evolve, they must meet the needs of the modern workforce, and VR provides that opportunity. Overall, the findings suggest that while traditional training remains effective, VR training offers valuable advantages that cannot be replicated with traditional training methods in behavioral impact and learner experience. VR can be strategically implemented to improve engagement and behavioral change, while traditional methods remain essential for tactile skill building. Stakeholders can support this shift by promoting innovation within training standards and VR as a powerful risk-reduction tool.

Recommendations for Research and Future Action

Based on this study's findings and limitations, several recommendations are proposed to enhance training practices and guide future development of pipeline construction training programs. First, expanding the sample size with participants from various pipeline companies throughout the United States would significantly improve the results. This would also provide a more thorough understanding of training effectiveness across a wide range of diverse work environments. Future studies could also explore the possibility of implementing a hybrid training model that incorporates the practicality of traditional training methodology with VR for high-risk tasks. This would provide advantages in high-risk scenarios without the inherent risk and danger associated with many pipeline construction tasks. While both training formats positively impacted learning outcomes, hands-on training remains vital for reinforcing skills, while VR shows tremendous promise in behavior modification and learner satisfaction. While the sample size had limited statistical findings, the real-world implications are clear. A hybrid approach may offer the best of both worlds and could be key to advancing jobsite safety across the construction industry. Additionally, a more in-depth analysis of VR acceptance across various backgrounds could provide highly effective training designs.

Lastly, conducting a long-term study into the lasting effects of traditional and VR training methodologies would also be advantageous. It would provide more clarity, perception, and insight into knowledge retention with behavioral changes over time. Finally, assessing the cost-effectiveness of various training methods and aligning those with industry standards can help support the integration of advanced training technologies. This could contribute to creating standardized, technologically enhanced safety and task training programs that are both practical and scalable. Additionally, the return on investment is invaluable to ensure the workforce has been trained to meet rigorous standards and, above all else, safely. Ultimately, these efforts can lead to a safer workforce, reduced job site incidents, and significantly improve overall training effectiveness across the pipeline construction industry.

References

Abdellatif, R. (2008). Distance learning in secondlife: A virtual critique. *Submission Categories*. https://www.academia.edu/76455693/Distance_Learning_in_SecondLife_A_Virtual_Crit

Albert, A., Hallowell, M., & Kleiner, B. (2013). Enhancing construction hazard recognition and communication with energy-based cognitive mnemonics and a safety meeting maturity model. *Journal of Construction Engineering and Management*, *140*(2). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000790

Alsharef, A., Albert, A., Jaselskis, E., & Bhandari, S. (2020). Construction safety training: Barriers, challenges, and opportunities. In M. E. Asmar, D. Grau, & P. Tang (eds.), *Construction research congress 2020: Safety, workforce, and education* (pp. 547–555). https://doi.org/10.1061/9780784482872.059

Arcury, T. A., Estrada, J. M., & Quandt, S. A. (2010). Overcoming language and literacy barriers in safety and health training of agricultural workers. *Journal of Agromedicine*, *15*(3), 236–248. https://doi.org/10.1080/1059924X.2010.486958

Austin, R. B. (2018, June 23-July 27). *Tailoring construction management instruction to the emerging adult learner* [Conference Session]. 2018 ASEE Annual Conference & Exposition, Salt Lake City, UT. https://doi.org/10.18260/1-2--31040

Baumeister, R. F., Vohs, K. D., & Funder, D. C. (2007). Psychology as the science of self-reports and finger movements: Whatever happened to actual behavior? *Perspectives on Psychological Science*, *2*(4), 396–403. https://doi.org/10.1111/j.1745-6916.2007.00051.x

Baylor University. (n.d.). *Academy for teaching and learning: Attitudinal questions and Likert scales*. Retrieved March 3, 2025, from https://atl.web.baylor.edu/teaching-guides/researching-teaching-and-learning/attitudinal-questions-and-likert-scales

Burke, M. J., Salvador, R. O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., & Sonesh, S. (2011). The dread factor: How hazards and safety training influence learning and performance. *Journal of Applied Psychology, 96*(1), 46–70. https://doi.org/10.1037/a0021838

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., & Islam, G. (2006, February). Relative effectiveness of worker safety and health training methods. *American Journal of Public Health*, *96*(2), 315–324. https://doi.org/10.2105/AJPH.2004.059840

Cigliana, K. A., Gray, T., & Gower, G. (2024). Improving marking effectiveness and feedback provision in an OSCE assessment using Microsoft forms: A pilot study in sport and exercise therapy. *Research in Learning Technology*, *32*. https://doi.org/10.25304/rlt.v32.3097

Clark, L. A., & Watson, D. (2019). Constructing validity: New developments in creating objective measuring instruments. *Psychological Assessment*, *31*(12), 1412–1427. https://doi.org/10.1037/pas0000626

Cook, D. A., Hatala, R., Brydges, R., Zendejas, B., Szostek, J. H., Wang, A. T., Erwin, P. J., & Hamstra, S. J. (2011). Technology-Enhanced Simulation for Health Professions Education: A Systematic Review and Meta-analysis. *JAMA*, *306*(9):978–988.

Cooper, N., Millela, F., Cant, I., White, M. D., & Meyer, G. (2021). Transfer of training—Virtual reality training with augmented multisensory cues improves user experience during training and task performance in the real world. *PLOS ONE*, *16*(3), Article 0248225. https://doi.org/10.1371/journal.pone.0248225

Demirkesen, S., & Arditi, D. (2015, July). Construction safety personnel's perceptions of safety training practices. *International Journal of Project Management*, *33*(5), 1160–1169. https://doi.org/10.1016/j.ijproman.2015.01.007

Deslauriers. (2024, July 15). *The benefits of on-site training*. https://deslinc.com/blog/on-site-training-construction-service

Estudillo, B., Forteza, F. J., & Carretero-Gómez, J. M. (2025, February). Effectiveness of training in reducing accidents in construction companies. *Journal of Safety Research*, *92*, 283–291. https://doi.org/10.1016/j.jsr.2024.12.005

Formifyr. (2024, September 2024). *How to make a likert scale a step-by-step guide for survey design*. https://formifyr.com/blog/how-to-make-a-likert-scale/

Ge, L., & Kuester, F. (2015, July). Integrative simulation environment for conceptual structural analysis. *Journal of Computing in Civil Engineering*, *29*(4). https://doi.org/10.1061/(ASCE)CP.1943-5487.0000405

Gribbons, B., & Herman, J. (1996). True and quasi-experimental designs. *Practical Assessment, Research, and Evaluation*, *5*(1), 14. https://doi.org/10.7275/FS4Z-NB61

GTI Energy. (n.d.). *Training overview*. https://www.gti.energy/training-events/training-overview/

Guo, X., Liu, Y., Tan, Y., Xia, Z., & Fu, H. (2024, December). Hazard identification performance comparison between virtual reality and traditional construction safety training modes for different learning style individuals. *Safety Science*, *180*, 106644. https://doi.org/10.1016/j.ssci.2024.106644

Hamid, A. R. A., Majid, M. Z. A., & Singh, B. (2008). Causes of accidents at construction sites. *Malaysian Journal of Civil Engineering*, *20*(2). https://doi.org/10.11113/mjce.v20.15769

Harlen, W., & Deakin Crick, R. (2003). Testing and motivation for learning. *Assessment in Education: Principles, Policy & Practice*, *10*(2), 169–207. https://doi.org/10.1080/0969594032000121270

Haslam, R., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., & Duff, A. R. (2005, July). Contributing factors in construction accidents. *Applied Ergonomics*, *36*(4), 401–415. https://doi.org/10.1016/j.apergo.2004.12.002

He, X., & Song, L. (2012, April). Status and future tasks of coal mining safety in China. *Safety Science*, *50*(4), 894–898. https://doi.org/10.1016/j.ssci.2011.08.012

Hinkin, T. R. (1998). A brief tutorial on the development of measures for use in survey questionnaires. *Organizational Research Methods*, *1*(1), 104–121. https://doi.org/10.1177/109442819800100106

Ho, C.-L., & Dzeng, R.-J. (2010, September). Construction safety training via e-Learning: Learning effectiveness and user satisfaction. *Computers & Education*, *55*(2), 858–867. https://doi.org/10.1016/j.compedu.2010.03.017

https://jamanetwork.com/journals/jama/fullarticle/1104300

Jacobs, J. W., Prince, C., Hays, R. T., & Salas, E. (1990, July 1). *A meta-analysis of the flight simulator training research*. Defense Technical Information Center. https://apps.dtic.mil/sti/citations/ADA228733

Jacobsen, E. L., Solberg, A., Golovina, O., & Teizer, J. (2021). Active personalized construction safety training using run-time data collection in physical and virtual reality work environments. *Construction Innovation*, *22*(3), 531–553. https://doi.org/10.1108/CI-06-2021-0113

Jebb, A. T., Ng, V., & Tay, L. (2021, May 3). A review of key Likert scale development advances: 1995–2019. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.637547

Katiyar, A., & Kumar, P. (2021). A review of Internet of Things (IoT) in construction industry: What is experimental design? *International Journal of Advanced Science Computing and Engineering*, *3*(2), 65–72. https://doi.org/10.62527/ijasce.3.2.53

Kelkar, G. (2023, March 15). *What is experimental design? A comprehensive guide for 2023*. Emeritus. https://emeritus.org/blog/product-design-innovation-what-is-experimental-design/

Kim, J., Zornnetr, P., Korlapati, S., Sargsyan, N., Akula, S., Wei, X., & Seals, C. D. (2020). *Evaluating the effectiveness of virtual reality construction safety training and lessons learned* [Conference session]. Creative Construction E-Conference 2020 (Virtual conference), 42–49. https://doi.org/10.3311/CCC2020-074

Kramer, M. H., Paparozzi, E. T., & Stroup, W. W. (2019, September). Best practices for presenting statistical information in a research article. *HortScience*, *54*(9), 1605–1609. https://doi.org/10.21273/HORTSCI13952-19

Le, Q. -T., & Park, C. -S. (2012, August 20-23). *Construction safety education model based on second life* [Conference session]. IEEE International Conference on Teaching, Assessment, and Learning for Engineering, Hong Kong, China . https://doi.org/10.1109/tale.2012.6360336

Le, Q. T., Pedro, A., & Park, C. S. (2015). A social virtual reality-based construction safety education system for experiential learning. *Journal of Intelligent & Robotic Systems*, *79*, 487–506. https://doi.org/10.1007/s10846-014-0112-z

Lee, Y.-C. J., & Takenaka, B. P. (2022). Extended reality as a means to enhance public health education. *Frontiers in Public Health*, *10*, 1040018. https://doi.org/10.3389/fpubh.2022.1040018

Li, H., Fang, S., Chen, L., Menadue, V., & Martin, S. (2024a). Extended reality (XR)—A magic box of digitalization in driving sustainable development of the construction industry: A critical review. *Sustainable Development*, *32*(3), 2830-2845. https://doi.org/10.1002/sd.2818

Li, S., Wang, Q.-C., Wei, H.-H., & Chen, J.-H. (2024b). Extended reality (XR) training in the construction industry: A content review. *Buildings*, *14*(2), 414. https://doi.org/10.3390/buildings14020414

Li, X., Yi, W., Chi, H.-L., Wang, X., & Chan, A. P. C. (2018, February). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, *86*, 150–162. https://doi.org/10.1016/j.autcon.2017.11.003

Loeng, S. (2020, January). Self-directed learning: A core concept in adult education. *Education Research International*, *2020*(1), Article 3816132, 1-12. https://doi.org/10.1155/2020/3816132

Manning, J., B., Liu, J., & Redding, L. W. (2020, January). *Is virtual reality safety training making the construction industry safer?* [Conference Session]. Creative Construction E-Conference 2020 [Virtually held]. https://doi.org/10.3311/CCC2020-062

McLeod, S. (2025). *Kolb's learning styles & experiential learning cycle*. Simply Psychology. https://www.simplypsychology.org/learning-kolb.html

Mitchell, E. (2024, June 18). *2024 construction safety statistics [USA]*. Corfix. https://www.corfix.com/blog/2024-construction-safety-statistics-usa/

Moore, H. F., Eiris, R., Gheisari, M., & Esmaeili, B. (2019). Hazard identification training using 360-degree panorama vs. virtual reality techniques: A pilot study. In Y. K. Cho, F. Leite, A. Behzadan, and C. Wang (eds.) *Computing in civil engineering2019: Visualization, information modeling, and simulation*, (pp. 55–62). https://doi.org/10.1061/9780784482421.008

Nadhim, E., Hon, C., Xia, B., Stewart, I., & Fang, D. (2016). Falls from height in the construction industry: A critical review of the scientific literature. *International Journal of Environmental Research and Public Health*, *13*(7), 638. https://doi.org/10.3390/ijerph13070638

Namian, M., Albert, A., Zuluaga, C. M., & Behm, M. (2016, December). Role of safety training: Impact on hazard recognition and safety risk perception. *Journal of Construction Engineering and Management*, *142*(12). https://doi.org/10.1061/(asce)co.1943-7862.0001198

National Aviation Academy. (n.d.) *5 key benefits of hands-on training*. https://www.naa.edu/benefits-of-hands-on-training/

National Safety Council. (n.d.). *Work injury costs—Injury facts*. https://injuryfacts.nsc.org/work/costs/work-injury-costs/

Oberon Technologies. (n.d.) *ROI of virtual reality training*. https://www.oberontech.com/featured-offers/roi-of-virtual-reality-training/

Occupational Safety & Health Administration. (1970). Regulations standard 29 C.F.R. § 1926. U.S. Department of Labor. https://www.osha.gov/laws-regs/regulations/standardnumber/1926

Occupational Safety & Health Administration. (n.d.). *Construction industry*. U.S. Department of Labor. https://www.osha.gov/construction

Okano, K., Kaczmarzyk, J. R., & Gabrieli, J. D. E. (2018). Enhancing workplace digital learning by use of the science of learning. *PLOS ONE*, *13*(10), Article 0206250. https://doi.org/10.1371/journal.pone.0206250

Open Asset (2024, May 10). *Construction technology: 16 building technologies driving the future*. Open Asset. https://openasset.com/blog/construction-technology/

Ortega, B., & Marchante, A. J. (2010). Temporary contracts and labour productivity in Spain: A sectoral analysis. *Journal of Productivity Analysis*, *34*(3), 199–212. https://doi.org/10.1007/s11123-010-0185-z

Pedram, S., Palmisano, S., Skarbez, R., Perez, P., & Farrelly, M. (2020, August). Investigating the process of mine rescuers' safety training with immersive virtual reality: A structural equation modelling approach. *Computers & Education*, *153*, 103891. https://doi.org/10.1016/j.compedu.2020.103891

PWC. (n.d.). *PWC's study into the effectiveness of VR for soft skills training*. https://www.pwc.co.uk/services/technology/immersive-technologies/study-into-vr-training-effectiveness.html

Rowen, A., Grabowski, M., & Russell, D. W. (2022). The impact of work demands and operational tempo on safety culture, motivation and perceived performance in safety critical systems. *Safety Science*, *155*, 105861. https://doi.org/10.1016/j.ssci.2022.105861

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics*, *31*(9), 1005–1017. https://doi.org/10.1080/01446193.2013.828844

Safe Training Online. (n.d.). *Pipeline construction safety training in the United States*. https://safetraining.com/pipeline-construction-safety-training-in-the-united-states

Saleh, J. H., & Pendley, C. C. (2012). From learning from accidents to teaching about accident causation and prevention: Multidisciplinary education and safety literacy for all engineering students. *Reliability Engineering & System Safety*, *99*, 105–113. https://doi.org/10.1016/j.ress.2011.10.016

Salinas, D., Muñoz-La Rivera, F., & Mora-Serrano, J. (2022). Critical analysis of the evaluation methods of extended reality (XR) experiences for construction safety. *International Journal of Environmental Research and Public Health*, *19*(22), 15272. https://doi.org/10.3390/ijerph192215272

Sanni-Anibire, M. O., Mahmoud, A. S., Hassanain, M. A., & Salami, B. A. (2020, January). A risk assessment approach for enhancing construction safety performance. *Safety Science*, *121*, 15–29. https://doi.org/10.1016/j.ssci.2019.08.044

Schmidt, E. (2022, March 16). *Reading the numbers: 130 million American adults have low literacy skills, but funding differs drastically by state.* APM Research Lab. https://www.apmresearchlab.org/10x-adult-literacy

Scorgie, D., Feng, Z., Paes, D., Parisi, F., Yiu, T. W., & Lovreglio, R. (2024, March). Virtual reality for safety training: A systematic literature review and meta-analysis. *Safety Science*, *171*, 106372. https://doi.org/10.1016/j.ssci.2023.106372

Seo, H. J., Park, G. M., Son, M., & Hong, A.-J. (2021). Establishment of virtual-reality-based safety education and training system for safety engagement. *Education Sciences*, *11*(12), 786. https://doi.org/10.3390/educsci11120786

Shringi, A., Arashpour, M., Golafshani, E. M., Dwyer, T., & Kalutara, P. (2023). Enhancing safety training performance using extended reality: A hybrid delphi–AHP multi-attribute analysis in a type-2 fuzzy environment. *Buildings*, *13*(3), 625. https://doi.org/10.3390/buildings13030625

Stefan, H., Mortimer, M., Horan, B., & Kenny, G. (2023, July). Evaluating the preliminary effectiveness of industrial virtual reality safety training for ozone generator isolation procedure. *Safety Science, 163*, 106125. https://doi.org/10.1016/j.ssci.2023.106125

Stothard, P., Mitra, R., & Kovalev, A. (2008). Assessing levels of immersive tendency and presence experienced by mine workers in interactive training simulators developed for the coal mining industry. *SIMTECT 2008.* https://espace.curtin.edu.au/handle/20.500.11937/13717

Strale F., Jr. (2024, September 30). Examining the efficacy of control groups in achieving statistical control: A critical look at randomized controlled trials. *Cureus*, *16*(9), Article e70562. https://doi.org/10.7759/cureus.70562

Texas Department of Insurance. (2024). *The costs of not providing OSHA training*. https://www.tdi.texas.gov/tips/safety/oshatraining.html

Tezel, A., Dobrucali, E., Demirkesen, S., & Kiral, I. A. (2021). Critical success factors for safety training in the construction industry. *Buildings, 11*(4), 139. https://doi.org/10.3390/buildings11040139

The Center for Construction Research and Training. (2024, May). *Trenching injuries, citations and penalties in construction* (Data Bulletin). https://www.cpwr.com/wp-content/uploads/DataBulletin-May2024.pdf

Train Beyond. (2024, April 2). *VR safety training: Modern vs. traditional in-person methods*. https://www.trainbeyond.com/vr-safety-training-modern-alternative-to-in-person-methods/

Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards, 49 C.F.R § 192. (1970). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-192?toc=1

U.S. Bureau of Labor Statistics. (2023, May 01). *TED: The Economoics Daily: Construction deaths due to falls, slips, and trips increased 5.9 percent in 2021*. https://www.bls.gov/opub/ted/2023/construction-deaths-due-to-falls-slips-and-trips-increased-5-9-percent-in-2021.html

Van der Molen, H. F., Den Herder, A., Warning, J., & Frings-Dresen, M. H. W. (2015). National evaluation of strategies to reduce safety violations for working from heights in construction companies: Results from a randomized controlled trial. *BMC Public Health, 16*, Article 19. https://doi.org/10.1186/s12889-016-2693-x

Vercelli, G., Iacono, S., Martini, L., Zardetto, M., & Zolezzi, D. (2024). *From risk to readiness: VR-based safety training for industrial hazards* (Version 1). arXiv. https://doi.org/10.48550/ARXIV.2412.13725

Von Heyl, J., & Teizer, J. (2017, July). Lean production controlling and tracking using digital methods. In *Proceedings of the 25th Annual Conference of the International Group for*

Lean Construction, Heraklion, Greece (pp. 127–134). https://doi.org/10.24928/2017/0238

Waehrer, G. M., Dong, X. S., Miller, T., Haile, E., & Men, Y. (2007, November). Costs of occupational injuries in construction in the United States. *Accident Analysis & Prevention*, *39*(6), 1258–1266. https://doi.org/10.1016/j.aap.2007.03.012

Weihs, C., & Ickstadt, K. (2018). Data Science: The impact of statistics. *International Journal of Data Science and Analytics, 6*(3), 189–194. https://doi.org/10.1007/s41060-018-0102-5

Wiersma, W., & Jurs, S. (2008. *Research methods in education*: *An introduction* (9th ed.). Pearson.

Wilkins, J. R. (2011). Construction workers' perceptions of health and safety training programs. *Construction Management and Economics, 29*(10), 1017–1026. https://doi.org/10.1080/01446193.2011.633538

Zahraee, A., Zhang, C., Pratt, D., & Chandramouli, C. V. (2023, February 8-10). *Vertical integration of experiential learning in construction curriculum with industry collaboration* [Conference Session]. 2023 CIEC, Charleston, South Carolina. https://doi.org/10.18260/1-2-1110-48796

Zakari, M., Akomah, B. B., Nkomo, W. M., Abilgah, T., & Thwala, W. D. (2025). Impact of safety training and communication on construction project productivity: Case study of cape coast. *Journal of Civil Engineering Frontiers*, *6*(1), 11–17. https://doi.org/10.38094/jocef60197

Zhang, H., He, X., & Mitri, H. (2019). Fuzzy comprehensive evaluation of virtual reality mine safety training system. *Safety Science*, *120*, 341–351. https://doi.org/10.1016/j.ssci.2019.07.009

Zhang, L., Wei, W., Bai, C., Gao, Y., & Zhang, Y. (2018). Exploiting clustering manifold structure for hyperspectral imagery super-resolution. *IEEE Transactions on Image Processing*, *27*(12), 5969-5982. https://doi.org/10.1109/TIP.2018.2862629

Zhang, M., Shu, L., Luo, X., Yuan, M., & Zheng, X. (2022). Virtual reality technology in construction safety training: Extended technology acceptance model. *Automation in Construction*, *135*, 104113. https://doi.org/10.1016/j.autcon.2021.104113

Zhao, D., & Ye, Y. (2012). Using virtual environments simulation to improve construction safety: An application of 3D online game-based training. In W. Deng (ed.) *Future Control and Automation: Lecture Notes in Electrical Engineering* (Vol. 172, pp. 269–277). Springer. https://doi.org/10.1007/978-3-642-31006-5_33

Zhu, M., Li, G., Huang, Q., Li, D., & Du, J. (2023). Analysis of eye movements of workers in safe and unsafe behaviors using a video-based method. *International Journal of Occupational Safety and Ergonomics*, *29*(1), 254–262. https://doi.org/10.1080/10803548.2022.2035087

Zwetsloot, G. I. J. M., Kines, P., Wybo, J.-L., Ruotsala, R., Drupsteen, L., & Bezemer, R. A. (2017, January). Zero accident vision-based strategies in organizations: Innovative perspectives. *Safety Science*, *91*, 260–268. https://doi.org/10.1016/j.ssci.2016.08.016

Appendix A

IRB Approval Letter

University of Wisconsin-Stout
Wisconsin's Polytechnic University

INSTITUTIONAL REVIEW BOARD

Office of Research and Sponsored Programs

Robert S. Swanson Learning Center #201

715-232-4042

irb@uwstout.edu

Date: February 5, 2025

PI: Kellie Jacob

Department: TEACHING LEARNING & LEADERSHIP, GRADUATE STUDENT

Re: Initial - IRB-FY2025-125

Enhancing Safety in the Construction Workforce: A Comparative Study of Hands-On and Virtual Reality (VR) Training Methods

Dear Kellie Jacob,

In accordance with Federal Regulations, your project, *Enhancing Safety in the Construction Workforce: A Comparative Study of Hands-On and Virtual Reality (VR) Training Methods*, was reviewed on February 5, 2025 by a member of the University of Wisconsin-Stout Institutional Review Board and was approved under Expedited Review in accordance with Federal Policy for the Protection of Human Subjects (45 CFR 46). This project is hereby approved for one year from the official approval date. If a renewal is needed, it is to be submitted at least 10 working days prior to the expiration date.

Responsibilities for Principal Investigators of IRB-approved research:

1. **No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.**
2. **All unanticipated or serious adverse events must be reported to the IRB.**
3. **All protocol modifications must be approved prior to implementation unless they are intended to reduce risk.**
4. **All protocol deviations must be reported to the IRB.**
5. **All recruitment materials and methods must be approved by the IRB prior to being used.**

6. **Research which involves financial compensation to participants must follow appropriate UW-Stout payment procedures.**
7. **Consent forms must adhere to UW-Stout IRB standards and indicate that the research has been approved by the UW-Stout IRB as required by federal regulations (see UW-Stout IRB consent form templates for more details).**
8. **Federal regulations require IRB review of ongoing projects on an annual basis.**
9. **Any modifications to the approved study must be submitted for review through Cayuse IRB. All approval letters and study documents are located within the Study Details in Cayuse IRB.**

Thank you for your cooperation with the IRB and best wishes with your project. If you have questions, please contact the IRB office at irb@uwstout.edu or by phone 715-232-4042, and your question will be directed to the appropriate person.

Sincerely,

Michael Mensink, Ph.D.; IRB Chair

University of Wisconsin-Stout Institutional Review Board

Appendix B

Perception Survey

Demographic Questions

What is your gender?

- Male
- Female
- Prefer not to answer

What is your age range?

- 18-25
- 26-35
- 36-45
- 46-55
- 56-65
- 66 +

What is your current job role?

- Laborer
- Operator
- Foreman
- Project Manager
- Other

What is your industry experience level?

- <1 year
- 1 – 5 years
- 6 – 10 years
- 11 - 15 years
- 16 – 20 years
- 20 + years

What is your familiarity with new training technology such as VR?

- None
- Minimal
- Moderate

- High

How many hours do you work a week on average?

- <40 hours
- 40 – 49 hours
- 50 – 59 hours
- 60 + hours

How comfortable are you with reading and writing in the language of the training materials?

- Not comfortable
- Slightly comfortable
- Neutral
- Comfortable
- Very comfortable

Survey Questions

Scale: Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

Q1: The training method was effective in helping me comprehend safety procedures.

Q2: The training method covered real-world safety risks in my role.

Q3: The training method assisted in hazard recognition.

Q4: The training was an effective method to teach proper use of equipment and tools.

Q5: I felt engaged and excited to learn throughout the training session.

Q6: The training has motivated me to work safer.

Q7: I feel confident applying the skills I learned in my job duties.

Q8: I am satisfied with the quality of training I received.

Q9: I would recommend a co-worker to complete this training method.

Q10: The training was user-friendly.

Q11: The training increased my overall safety awareness.

Q12: I was able to comprehend the training material with ease.

Q13: Additional training in the same format would benefit me and my company.

Q14: The training directly applied to the work I perform.

Q15: The training allowed me to practice performing tasks with minimal risks to my safety.

Appendix C

Informed Consent for Research Participation

Study Title:	Enhancing Safety in the Construction Workforce: A Comparative Study of Hands-On and Virtual Reality (VR) Training Methods

Researcher Name	**Department**	**Contact Information**
Kellie Jacob	UW Stout/TLL	jacobk3708@my.uwstout.edu

Faculty Advisor	**Department**	**Contact Information**
Dr. Michael Selover	UW Stout/TLL	seloverm@uwstout.edu

Overview of the Research Study

Participation invitation:	You are invited to participate in the research study described below. Your participation is entirely voluntary, and you may stop your participation or withdraw from the study at any time and for any reason. If you choose to not participate or to stop your participation, there will be no negative consequences to you. Your decision to participate or not in this study will not change your relationship with the researchers or the University of Wisconsin-Stout.
Who can participate in this study:	Construction personnel who are required to complete periodic safety training as part of their employment and regular job duties.
Study description:	While training can be an effective solution to help avoid fatalities and other safety incidents, the type of training that is most impactful has

	yet to be determined. To maximize the efficacy of training and knowledge transfer, a comparison of training methods, their outcomes, and participants' perceptions of the training will be conducted.
What you will be asked to do:	Participants will attend task training as directed by their supervisor in one of two different delivery methods. A knowledge check will be performed both before and after training, and a survey regarding participant opinions about the training will be conducted after the training is complete.
Time commitment:	Approximately 3 hours
Participation risks:	The researcher(s) anticipate minimal risk to participants in this study. While no significant discomfort is expected, there remains a slight possibility of experiencing minor physical side effects, such as headaches, dizziness, or lethargy if using the virtual reality training method.
VR process:	If you are randomly selected for participation in the VR training, you will utilize a Pico Neo IIII headset with two hand controllers. You will place the headset on independently with oral instruction from the researcher. You will interact in a virtual reality environment, performing a leak investigation task in a large, empty training room.
What will be done to minimize your participation risks:	The study environment will be optimized for comfort, including proper ventilation and scheduled breaks to prevent fatigue. Participants will receive clear safety guidelines and be closely monitored throughout the study to address any discomfort promptly.
Participation benefits:	The primary benefit of this study is its contribution to testing new technology to enhance safety within the construction workforce. By

	evaluating innovative training methods, the study seeks to provide valuable insights that can help improve workplace safety standards and reduce jobsite hazards.

Confidentiality and Data Protection

Who will have access to your data:	The researcher, Kellie Jacob, and Chair, Dr. Michael Selover of UW Stout.
Data protection and future use:	All data will be stored electronically in an encrypted file to ensure compliance and ethical standards. Additionally, all personally identifiable information will be removed from documentation and stored separately.

Protection of Human Research Subjects

If you have questions about this study, please contact:	Kellie Jacob, UW Stout/TLL, jacobk3708@my.uwstout.edu Dr. Michael Selover, UW Stout/TLL, seloverm@uwstout.edu
If you have concerns about this study or your rights as a participant, please contact:	Institutional Review Board Chair University of Wisconsin-Stout Robert S. Swanson Learning Center #207 715-232-4042 irb@uwstout.edu
Your right to withdraw:	Your participation in this study is entirely voluntary. You may choose not to participate or to stop the study or survey without any adverse consequences to you. However, should you choose to participate and later wish to withdraw from the study, there may be no way to identify your data after it has been

	submitted. If you are participating in an anonymous survey, once you submit your responses, the data cannot be linked to you and cannot be withdrawn.
UW-Stout IRB approval statement:	This study has been reviewed and approved by the University of Wisconsin-Stout's Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations for human subjects research as required by federal law and UW-Stout policies.

Consent Statement

I agree to participate in this study and understand that I may stop my participation or withdraw my consent at any time during active participation.

□ **YES** □ **NO**

____

Print Name

____

Sign Name