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Improving Construction Site Safety by Incident Reporting Through Utilizing Virtual Reality

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Abstract

The construction industry consistently records one of the highest accident rates compared to other occupations, resulting in millions of workers suffering from construction-related injuries such as falls, trips, slips, and other causes. When an accident occurs, it is crucial to generate an incident report that details the causes of the accident, thereby aiding in the prevention of similar incidents in the future. Preparing an incident report requires understanding various factors, such as whether or not the safety protocols were followed, the sequence of events leading up to the accident, proper hazard identification, and the types of injuries sustained. Specific guidelines are also adhered to while preparing reports, which is challenging for young or inexperienced engineers working on construction sites. Virtual reality (VR) offers an excellent solution to this problem by allowing engineers to experience simulated conditions before preparing an actual incident report. This study aims to enhance the ability of civil engineers to create accurate incident reports using virtual reality. For this study, accident sites were simulated using data from Occupational Safety and Health Administration (OSHA) incident reports, and scenarios were developed on the Unity platform. Engineering students were recruited to evaluate virtual site conditions and produce incident reports that adhere to OSHA regulations. The input from the participants attests to the virtual reality platform's capability to facilitate the preparation of incident reports. Additionally, the platform's implementation in real-world construction sites could provide valuable training prospects for field engineers.

Keywords

Construction Hazard, Incident Report, Virtual Reality, OSHA training

Introduction

The construction industry experiences a disproportionately high number of accidents and injuries annually, standing out among various sectors. According to data from the U.S. Bureau of Labor Statistics, the construction and extraction occupations recorded the second-highest count of occupational fatalities, totaling 951 cases in 2021 [1]. Consequently, this positions the construction sector with the highest injury rate compared to other industries. In 2002, the construction industry incurred an estimated $11.5 billion in costs related to fatal and nonfatal injuries, accounting for 15% of the overall economic loss for all private industries [2]. The Bureau of Labor Statistics further reported a notable 8.9% increase in the total number of fatal work injuries across the United States in 2021, with a total of 5,190 recorded incidents [3]. This alarming trend underscores workplace accidents' significant economic impact and human toll.

However, it is crucial to acknowledge that the effects of workplace injuries extend beyond financial implications. The social and emotional burden on the families of affected workers cannot be quantified in monetary terms alone. Often, injured employees become dependent on physical and financial support for the rest of their lives, impacting their well-being and that of

their loved ones. Regulatory bodies like OSHA (Occupational Safety and Health Administration) and various organizations are committed to reducing accidents by implementing safety protocols and guidelines to combat these alarming statistics. Identifying potential hazards and systematically documenting factors that could lead to accidents in the future is a crucial skill in engineering. Although there are various methods for recording these hazards on construction sites or predicting potential accidents, mastering this skill requires time and expertise, which can pose challenges for young engineers starting their careers. As the demands of their profession become increasingly rigorous, newly graduated engineers often undergo intensive training for their job sites. Instilling a deep understanding of safety concerns within them is essential, as one of their critical responsibilities is preparing incident reports at construction sites. Virtual reality is emerging as an exceptional training tool to equip these budding engineers with the necessary expertise, offering a dynamic and immersive environment to hone their hazard identification and incident reporting skills.

The research paper presents a comprehensive Virtual Reality (VR) model designed to assist undergraduate and graduate students, especially in the field of civil engineering in understanding critical hazardous conditions that can occur on-site. The research employs a simulated environment to expose students to potential on-site hazards, increasing their comprehension of the complexities and risks involved. Additionally, the research explores the potential of using Unity 3D as a powerful platform for virtual training, providing students with the necessary skills to prepare professional reports in the field of site safety and incident management. By immersing trainees in a controlled yet realistic virtual environment, they can navigate, analyze, and respond to hazardous scenarios without experiencing real-world fatal consequences. This fosters a safe and cost-effective learning experience that is engaging and effective.

About OSHA Guidelines for Incident Reporting

The Occupational Safety and Health Administration (OSHA) is a pivotal federal agency in the United States dedicated to safeguarding the health and well-being of American workers. OSHA was established in 1970 under the Occupational Safety and Health Act and is indispensable in setting and enforcing workplace safety and health regulations across diverse industries. Its importance cannot be overstated, as it is the foundation of the nation's occupational safety framework. OSHA's mandate encompasses a multifaceted approach to workplace safety, including developing and enforcing stringent safety standards, comprehensive training and educational programs, compliance assistance for employers, and rigorous inspections to ensure adherence to safety protocols. By formulating and implementing safety regulations, OSHA is the guardian of workers' rights, advocating for safe and healthful working conditions. Its role is particularly critical in industries where employees are exposed to many hazards, such as construction, manufacturing, healthcare, and agriculture.

One of OSHA's most potent tools is its authority to conduct inspections and enforce safety regulations. The prospect of regulatory inspections serves as a powerful incentive for employers to maintain safe workplaces, knowing that non-compliance can result in penalties and fines. This enforcement mechanism holds employers accountable and provides a safety net for workers, encouraging a culture of responsibility and diligence in upholding safety standards. To ensure safety, proper recordkeeping of incidents is very important [4]. Incident reports can help minimize injuries at the site in a significant way. Incident reporting involves the process of

documenting and communicating workplace accidents, near-misses, injuries, and other safety-related incidents. Its importance in reducing construction injuries at a worksite cannot be overstated. Timely and accurate incident reporting is crucial for identifying hazards, improving safety protocols, and preventing future accidents. By reporting incidents promptly, construction workers and employers can address root causes, implement corrective measures, and ensure a safer working environment. The sample format of the OSHA Near Miss Incident Form is available on the OSHA website [5]. When workers feel encouraged and safe to report incidents without fear of reprisal, it encourages open dialogue about safety concerns. Ultimately, this leads to improved hazard identification, early intervention, and a significant reduction in construction site injuries. In summary, incident reporting is a cornerstone of effective safety management in construction, as it not only fulfills regulatory requirements but also promotes a safer, more proactive work environment. So, the safety engineers must have ample knowledge about this reporting.

In the past, people have typically learned about OSHA training by reading handbooks or watching instructional videos. However, these methods lack interactive and immersive learning experiences. While they provide foundational knowledge, they may not offer practical insights that are essential for understanding on-site safety and incident reporting. Additionally, in-person training sessions can be expensive and time-consuming, challenging for small organizations or independent professionals. Virtual Reality (VR) is an exciting tool that offers a more engaging learning experience [6]. By immersing trainees in a realistic, interactive environment, they can navigate various scenarios and make decisions in a risk-free setting. However, the application of VR in the construction industry is still in its early stages, and researchers are working to integrate these technologies into safety training modules. Integrating VR into OSHA training modules requires a meticulous approach. It involves creating realistic, data-driven scenarios that adhere to OSHA guidelines and provide a comprehensive, immersive experience that closely mirrors real-world conditions. By exploring and integrating VR technologies into OSHA training modules, we can enhance site safety and ensure accurate, timely incident reporting in the construction industry.

Use of VR in the Construction Industry

The potential applications of VR in the field of civil and construction engineering are very promising. VR can be used for various purposes, including design visualization, construction management, safety training, academic learning, urban planning, and more. Many researchers are working hard to establish VR as a learning platform for students, as it can provide high-quality visualizations that can enhance the learning experience. For example, Chou et al. [7] used virtual reality to prepare a learning environment for teaching structural analysis in the traditional classroom and discover the limitations of VR in civil engineering education. VR models have also been used to educate students about construction, rehabilitation, and maintenance [8].

Crafting VR models is a complex process that demands technical excellence, extensive expertise, and substantial time investment. Unity proves to be an ideal platform in this endeavor. With its user-friendly interface and wide-ranging cross-platform capabilities, Unity is not just a game development tool but also a powerful tool for creating interactive 2D and 3D content, such as simulations and architectural visualizations [9]. Its continuous updates and robust community support have positioned it as a leading software for immersive digital experiences. In the field of

civil engineering education, Unity VR fosters the creation of interactive and captivating learning environments. For example, students can virtually venture through construction sites, gaining practical insights into site planning, topography, and project management—experiences that cannot be replicated by traditional teaching methods. Furthermore, VR simulations created with Unity can simulate dangerous scenarios, notably enhancing safety training. This hands-on methodology empowers future engineers with practical knowledge to manage real-world risks.

Methodology

This section details the methodology employed in the research to achieve the desired objectives and elicit positive feedback on learning, retention, and enjoyment from participants (as shown in Figure 1). The proposed research method involves collecting initial data from the Occupational Safety and Health Administration (OSHA) to compile comprehensive information on past accidents in construction sites. This data will serve as a foundational resource for creating a virtual scene using Unity 3D, where various incidents are meticulously replicated to provide an immersive and realistic VR experience. Participants will then be briefed on OSHA guidelines to ensure they are well-versed in the regulatory and safety norms prevalent in the construction industry, followed by an orientation session on VR technology to familiarize them with its operational aspects and potential applications in safety training. Once equipped with the necessary knowledge, participants will assess a virtual construction site, applying their understanding of OSHA guidelines to identify potential hazards and safety violations. They will then be required to complete a sample incident report based on their observations and insights from the virtual exploration. This exercise will pave the way for a comprehensive discussion where the reports will be analyzed, and participants will deliberate on the various aspects and outcomes of the virtual assessment. Finally, feedback will be solicited from the students to gain valuable insights into the efficacy of the methodology, the realism and educational value of the VR environment, and potential areas for improvement or further research in utilizing VR for safety training in the construction industry. This comprehensive approach facilitates an interactive learning experience and aims to enhance participants' proficiency in identifying, reporting, and mitigating potential safety hazards in real-world construction scenarios.

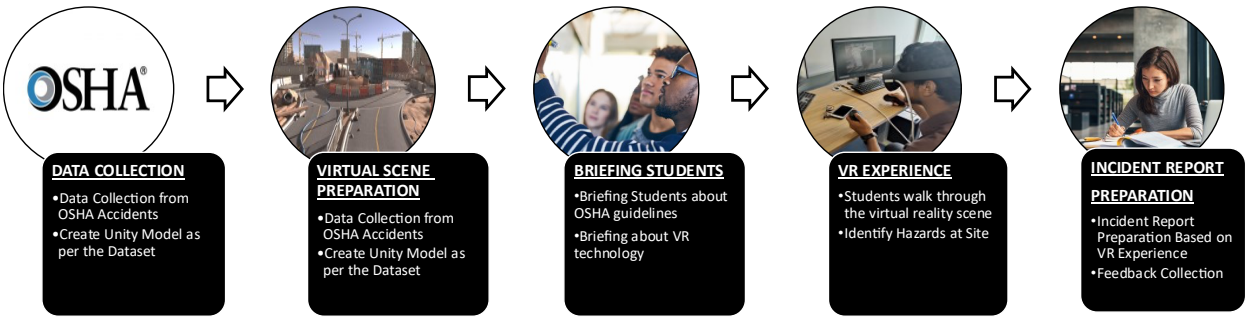

Figure 1: Research methodology

Experiment Design

The research experiment encompasses three activities, each contributing to the study's comprehensive approach. First, a 3D virtual reality model was meticulously crafted using the

Unity platform. Second, participants were equipped with a VR headset to fully immerse themselves in the 3D model, enabling them to navigate through simulated accident sites and engage with virtual scenarios. Finally, participants were requested to offer feedback, sharing their experiences, insights, and any potential challenges encountered during the VR experience.

3D Model Preparation

A 3D model was developed using Unity software for incident report training aimed at enhancing safety measures on construction sites. Extensive research was conducted to ensure accuracy by drawing from OSHA's archives to incorporate objects and scenarios that have historically led to accidents. The model produced a realistic virtual environment with common hazards, as showcased in Figure 2 of the documentation. Unity 3D models are more affordable and can be tailored to specific needs, in contrast to the costlier process of creating full-scale models using 3D cameras at actual construction sites, where hazards are deliberately introduced. Due to the limitations of the VR platform, static (or stationary) boundaries were used to define the construction site's area. In the static boundary mode, the user can use the headset while sitting or standing in place. This mode creates a default boundary area of 1 meter by 1 meter (3 feet by 3 feet) centered on the user. Although these boundaries are not visible, they help to sustain the user's immersion in the VR environment by outlining the explorable area and drawing attention to potential hazards. This virtual construction site model is an innovative safety training tool that enables workers to learn about and recognize safety hazards in a secure and controlled environment.

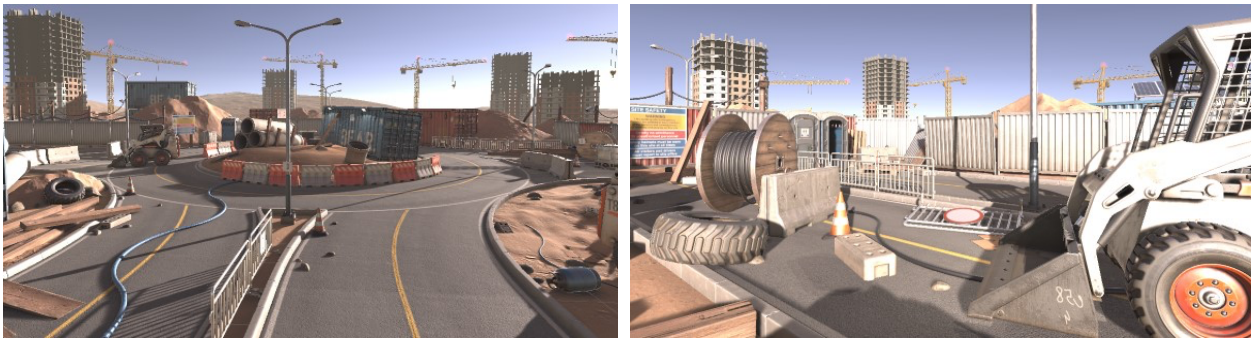

Figure 2: Designed construction site in VR for hazard identification/incident report preparation

Figure 3 presents several images captured from a 3D Unity-based construction site model, each showcasing specific hazardous conditions that could potentially result in workplace accidents. The pictures feature a coiled electric cable that poses a tripping hazard, a gas cylinder stored on its side, which could lead to leaks or explosions, and a broken fence that compromises site security and could give rise to unauthorized access or falling debris. Furthermore, a tilted roadblock is depicted as a subtle but dangerous obstruction, warning signs are obscured by equipment, thus failing to communicate potential dangers, and various obstacles are scattered on the roadway, significantly increasing the likelihood of trips and falls. Together, these images play an essential role in incident report training, highlighting the identification and correction of safety hazards on construction sites.

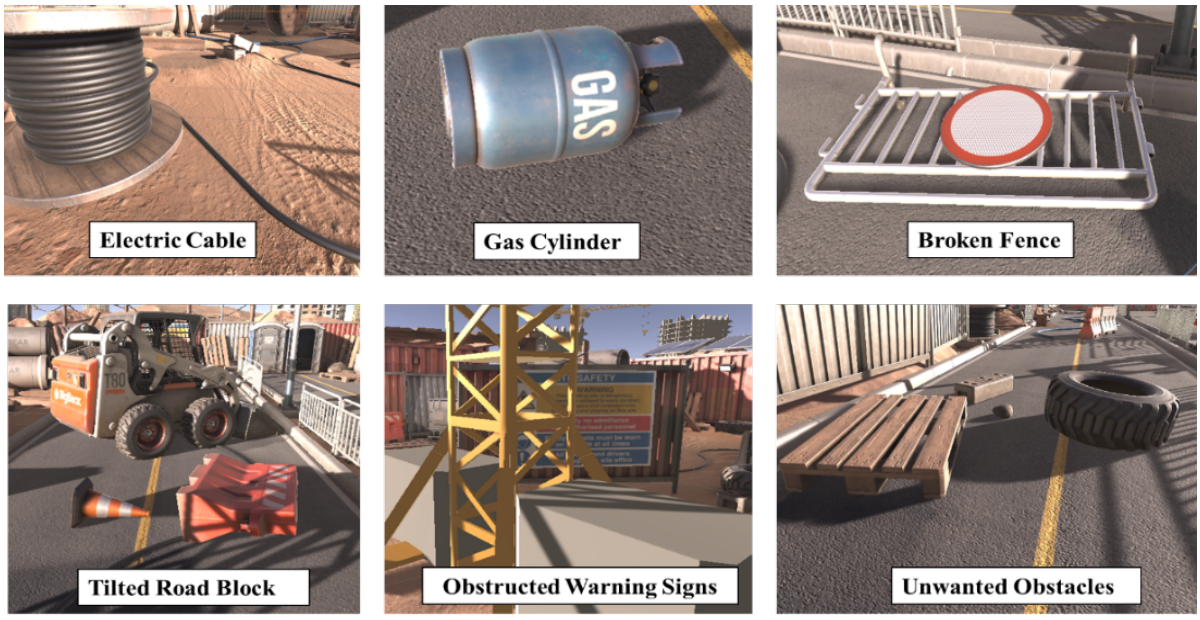

Figure 3: Hazardous conditions in the virtual construction site - This series of images from a 3D Unity model illustrates common safety hazards such as a loosely coiled electric cable, an improperly stored gas cylinder, a compromised fence, an unsteady roadblock, obstructed safety signage, and scattered obstacles on the roadway, all serving as key focus areas for incident report training to enhance on-site safety protocols

This experiment assesses students' ability to identify construction hazards and report incidents in a virtual reality (VR) environment. According to OSHA guidelines, four types of near-miss or close-call incidents have been created to accomplish this. The incidents are commonly referred to as “Near Miss”, “Safety Concern”, “Safety Idea” and “Others”. A “Near Miss” is an incident where no property was damaged and no personal injury was sustained, but where, given a slight shift in time or position, damage and injury easily could have occurred. On the other hand, “Safety Concern” refers to any condition or practice in the workplace that could potentially cause injury or illness to employees or lead to property damage.

The “Safety Idea” is a proposal made by employees or management to improve workplace safety, potentially reducing the risk of accidents or enhancing existing safety measures. The “Others” category is typically used for incidents or situations that do not neatly fit into the other specified categories but still relate to workplace safety or health concerns. As indicated in Figure 4, the majority of incidents, numbering 5, fall into the 'Near Miss' category, which underscores the importance of identifying and reporting these types of incidents in VR training. Additionally, 'Safety Ideas' are highlighted with four incidents, emphasizing the significance of proactive measures. 'Safety Concerns' and 'Other Hazards' are also represented with three incidents each, providing participants with a comprehensive range of safety-related scenarios to navigate.

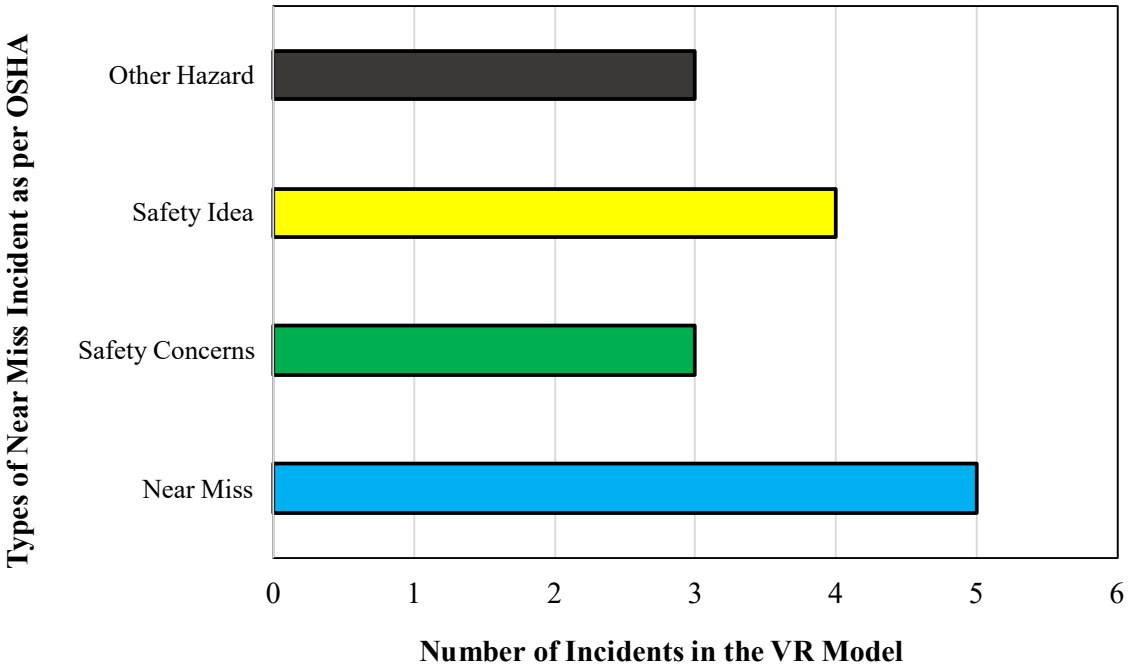

Figure 4: Total number of incidents used in the VR model

Student participation

For this study, a group of 12 graduate and undergraduate students were carefully chosen from various academic backgrounds to ensure a thorough evaluation of safety protocols. A brief information about the participants is shown in the table 1:

Table 1: Participant demographics in the experiment

Study Level	**Major**	Male Participants	Female Participants
Graduate	Computer Science	4	0
	Civil Engineering	1	1
	Industrial Engineering	2	0
	Electrical Engineering	2	1
Undergraduate	Civil Engineering	1	0

Before the virtual reality (VR) walkthrough, participants attended a 20-minute session to gain an understanding of the exercise's objectives and expectations. Once briefed, students donned VR headsets and embarked on a comprehensive tour of a 3D construction site model developed with Unity software. The virtual environment was designed to challenge students to identify and report potential hazards, such as misplaced equipment and unsafe working conditions, that could lead to accidents on an accurate construction site. This exercise aimed to enhance their knowledge of site safety and evaluate the effectiveness of VR training in identifying and preventing hazards.

Feedback from participants

Following the walkthrough experience, students were asked to complete a questionnaire based on the "OSHA Near Miss Incident Form". This form indirectly addressed the questions necessary to prepare an incident report for a construction site and allowed the determination of hazard identification accuracy among the participants.

Results and Discussion

According to the findings presented in Figure 5, students who utilized a Virtual Reality (VR) walkthrough for a construction site demonstrated a remarkable ability to recognize various types of near-miss incidents. Out of the 12 students who participated in the study, 10 of them (which amounts to roughly 83%) accurately identified the events that could lead to accidents. Additionally, 11 students (about 92% of the participants) were able to pinpoint significant safety issues in line with OSHA standards. Notably, 9 students (about 75% of the total students) suggested practical safety measures, reflecting their proactive approach to safety. Furthermore, 8 students (about 67%) were able to identify other varieties of near-miss incidents, indicating their comprehensive understanding of potential hazards in construction. These results suggest that VR walkthroughs are a highly effective tool for improving safety awareness and the ability to detect and respond to near-miss incidents in construction environments.

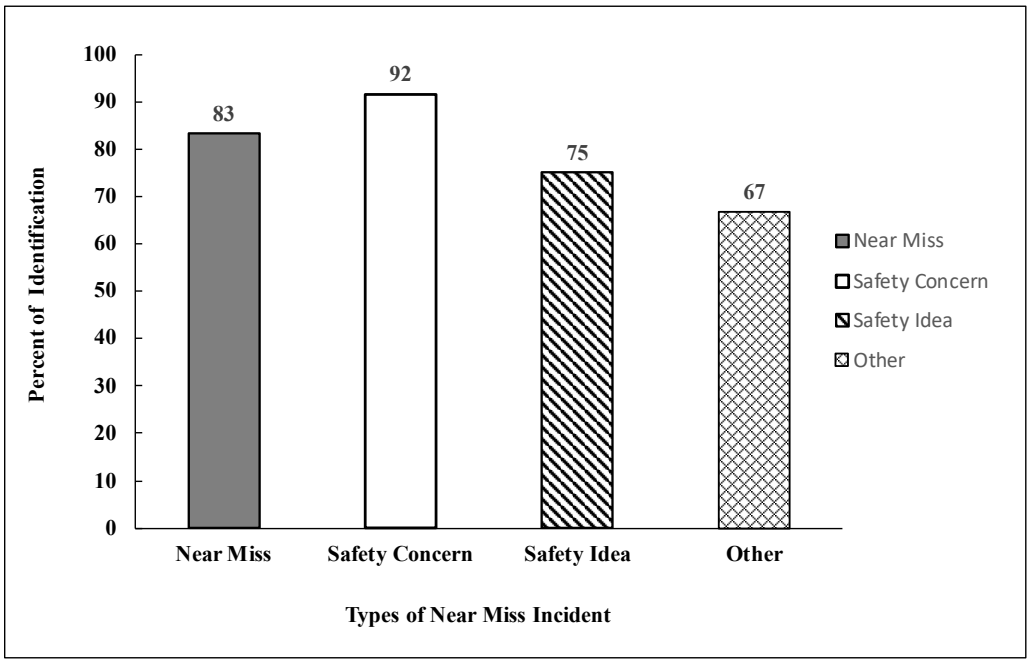

Figure 5: Participant's near miss incident identification performance

In Figure 6, the results of student interactions with a VR construction environment where different types of safety concerns are presented. The data indicates that a remarkable 92% of students (11 in total) demonstrated the effectiveness of the VR platform in enhancing their ability to identify and categorize unsafe safety acts. These students could accurately spot unsafe acts on the virtual site through observation and reasoning, despite having no prior experience in the construction field. This finding highlights the innate human capability to recognize danger and the potential of VR to enhance hazard awareness. The study also found that approximately 83%

of the participants (10 students) had the necessary skills to gauge risk levels by analyzing the layout and distribution of hazards, a vital skill for proactive risk management. Additionally, 75% of the students (9 in total) were able to identify unsafe or unsuitable equipment, indicating a good understanding of its role in safety. However, the study also revealed that only 58% of students (7 in total) could accurately identify improper machinery operation, suggesting a need for more practical learning to address this shortfall. Lastly, around 75% of students (9 in total) were proficient at evaluating the virtual conditions against OSHA standards, demonstrating an understanding of regulations and their practical application. These results emphasize the value of immersive learning in safety training and highlight the need for further practical experience to improve student performance.

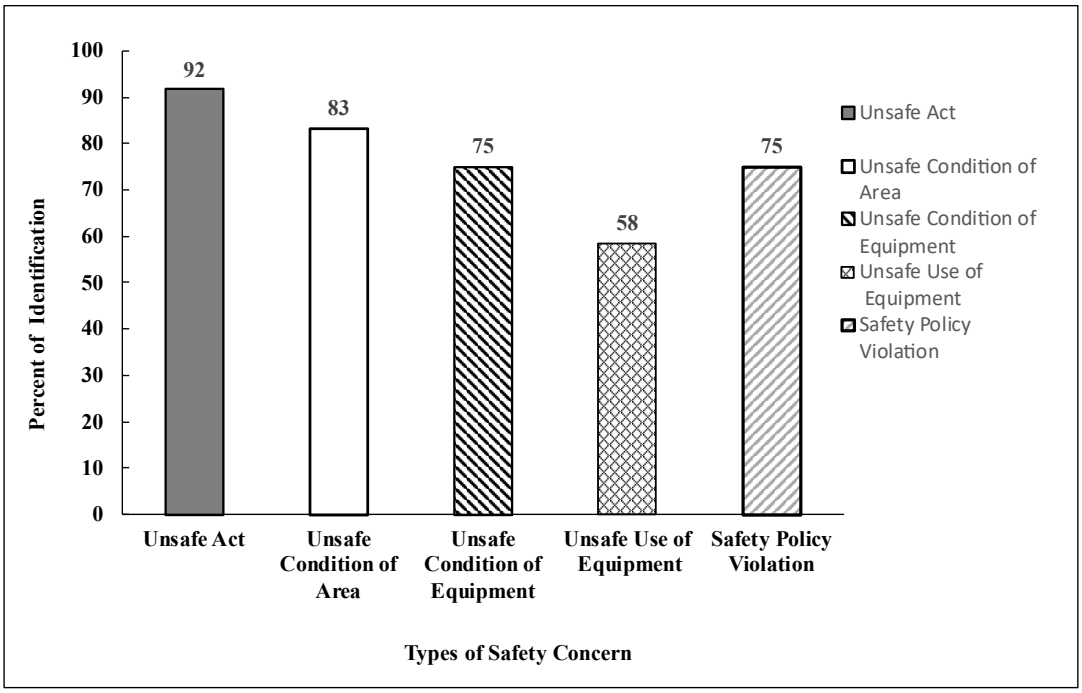

Figure 6: Participants' performance in identifying different types of safety concerns

Conclusion

This research aimed to explore the feasibility of creating a training platform for engineering students, enabling them to identify site hazards to generate incident reports that comply with OSHA standards. The study evaluated the students' abilities to detect and address potential hazards in a construction environment, specifically within a VR simulation. The evaluation criteria included the effectiveness of hazard identification and the integration of these observations into comprehensive reports. However, the researchers encountered a few limitations. For example, implementing static boundaries in the VR model was necessary, but it may have limited the students' interaction with the virtual environment. To address this issue, the authors suggest implementing room-scale boundaries (room-scale allows drawing boundaries in the user's physical space using the touch controller), which would create a more realistic and engaging simulation, potentially leading to more meaningful participant responses. The authors also acknowledge that the small sample size might have restricted the insights gained from the

study. A larger and more diverse group of participants could generate a more comprehensive range of data, ultimately enhancing the validity and relevance of the research findings. Moreover, the authors recommend extending the scope of the study beyond students to professional engineers. This approach would offer a dual perspective, combining students' fresh, academic viewpoint with seasoned professionals' practical, field-based experience. Such an approach contributes significantly to the study's robustness, providing a more nuanced comprehension of the training platform's effectiveness and its potential impact on real-world engineering practices. By addressing these aspects, future research could pave the way for more sophisticated VR-based training methodologies customized to meet the evolving demands of construction site safety and incident reporting.

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