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Enhancing Student Learning Experience by Incorporating Virtual Reality into Construction Safety and Risk Management Class

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For years, the construction industry was notorious for being slow in adopting new technologies. However, in the past decade, this trend started to change. Technologies such as building information modeling (BIM), drone, autonomous equipment, 3D printing, artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) were developed and used by the industry at a breakneck speed. While VR/AR technologies have been around for quite a long time, they have been gaining more attention by the AEC (Architecture, Engineering, and Construction) industry recently. These technologies have proven to benefit construction projects in many ways. From preconstruction to construction, they can add value and save time and money. One of the great advantages of these technologies is training for jobsite safety and hazard recognition. To create more interactive learning experience and prepare students for a rapidly changing industry, VR technology was utilized in Construction Safety and Risk Management class in the Construction Management program at Wentworth Institute of Technology. This paper describes how VR technology was incorporated as a pilot study into the class curriculum and provided students with a different and more engaging learning experience, as well as how it helped them learn the subject matter better.

Key Words: Virtual Reality (VR), Advanced Technologies, Jobsite Safety, Construction Management Curriculum, Construction Education.

Introduction

Traditional methods of construction safety education and certifications are based on lecturing or presenting information that requires students to passively learn the content (McCall et al. 2019). The incorporation of Virtual Reality (VR) and Augmented Reality (AR) technologies into education, provides a better opportunity to develop a better curriculum to promote active and collaborative educational methodologies. Active education is when the student is an active participant in the learning process; while collaborative is best explained as group work where the students work together to generate solutions to problems (McCall et al. 2019). These methods have been proven to be more effective over the lecture driven education (Fogarty et al. 2018). Using technology such as

VR/AR can help further expand both effective teaching styles and promote student engagement (Lucas 2018). This is especially relevant in the realm of recognizing unsafe actions and hazardous conditions on busy and dynamic construction sites.

While the classroom environment is a great medium for embedding the hard facts, specific OSHA regulations, and statistics associated with construction safety, it falls short on effectively engaging the students to recognize potential hazards in a real-world environment. Albert et al. (2014) reported that recent graduates were the least adept at identifying job site hazards and on average, they were only able to effectively recognize 43% of hazards in the construction environment. The ability for personnel to detect unsafe conditions directly correlates with an industry that is historically plagued with one of the leading fatality rates across industries (Albert et al. 2014). In the United States alone, the incident rates related to the construction industry are double that of the national industrial average (Rita and Man 2018). The low efficacy of safety trainings in the industry, that is leading one of the highest injury rates, creates a perfect domain for serious incidents to occur.

Increasing the effectiveness of construction safety training through the use of VR/AR technology will not only help to create a safe and more efficient work environment, but also gives employers very real monetary reasons to seek out this educational resource. Even minor incidents can lead to large expenditures in terms of both human and monetary capital. Small accidents can result in major bodily harm or even prove to be fatal. Studies have shown that an accident without a medical treatment on average costs 1,100 USD per worker and when medical treatment occurs, the costs escalate to 42,000 USD. If the mishap results in a fatality, then the cost is significantly greater at approximately 1,450,000 USD, in addition to the lost time and damage to moral which compound with the monetary determents (Pena, Ragan, and Kang 2019, National Safety Council 2021). VR technology provides an opportunity for the users to experience the hectic, fluid, and dangerous nature of construction sites without the risk of injury to self or others.

Literature Review

VR History:

While the terms VR and AR initially conjure images of modern labs and other technological advancements of the 21st century, VR has been around considerably longer than one would initially think. The very first application of VR developed by Morton Heilig in 1957 (Dumay, 2001). Heilig's design was the initial instance in which a simulation was able to successfully render three dimensional images that replicated real life physical environments (Li, 2018). Nearly a decade would follow before the first head mounted iteration would follow Heilig's model. Ivan Sutherland was the first to utilizes VR combined with a head mounted device (HMD) connected to a computer. By combining the real-life environments generated by the VR system with the HMD interface, Sutherland allowed individuals to see and experience the virtual world (Li, 2018). Initially access to VR systems were barred by lofty financial barriers which meant that the technology was only adopted by firms that were already well established (Delgado et al. 2020). Current VR/AR markets are rapidly growing with the estimated market size that continuously exceeds projections (Delgado et al. 2020). Fast forward to present day and VR is now more accessible than ever. Innovations across the broad spectrum of computer technologies have ensured that anyone can access to the power of VR with a smartphone and a cardboard box (Li, 2018).

VR Feasibility:

The advent of VR was heavily influenced by entertainment purposes. As the technology of VR progressed, more utilization became available with more feasible cost. When looking to see if VR is feasible for educational pursuits, the cost and useability should be considered. The cost of VR systems ranges drastically depending on the system used. Google glasses, Oculus, Vive and others are on the market with a wide price range. The VR system used in this study was the Vive Pro, where the MSRP for the full kit is around 1,599 USD (Vive 2021). This price can increase if a compatible laptop is required. When comparing the cost of investing in the VR system to the monetary cost of a jobsite incident, the VR costs are negligible. The prevention of one accident without medical involvement is equivalent to the costs of a VR unit and prevention of more serious incidents which results in tremendous savings. The current generation of students have grown up inundated with technology. Studies have shown that VR maintains a high usability rating when using the System Usability Scale (SUS), which is a standardized questionnaire to help assess the user's perceived usability (Lewis 2018). The SUS average score is considered 68 and mirrors the standard letter grading system. VR experiments using students have obtained scores ranging from 75.50 to 81.25, which is considered above average (Lewis 2018; Pena et al. 2019). This demonstrates the student’s ability to use the VR system as an educational tool.

VR in Education:

VR use in education has been implemented in many industries. The industries use VR training to produce trainings that minimize risk and incidents. Notable industries are airlines, medicine, machining, welding, and mining. The ability to create and change scenarios that mimic the real-world situations, provides an opportunity to put participants in high-risk situations and practice the training protocols without any risk of injury or equipment damage (Kessler et al. 2020). Airlines have been using flight simulators to provide pilots with an extremely difficult simulations to help prepare for the worst-case scenarios. Mines within the UK and US have both adopted VR/AR use in training in case of disaster in mines. The results from these VR trainings have proven that participants have better performance at locating emergency exit routes (Li et al. 2020). The real-life situations that these simulations represent rarely occur in practice. In the rare chance an occurrence does happen, prior experience in a simulation helps produce appropriate responses of the involved parties, hopefully resulting in saving lives. Within the manufacturing industries, the improvements demonstrated a reduction in errors, task completion time, as well as an increase in viable experience from the VR training (Osti et al. 2020). Both nursing and mining industries have also integrated VR training in limited capacities to their training curriculums with the hopes of lowering incidents and increasing the amount of applicable experience that individuals have. When the training is expensive or has limited availability of material/equipment; VR provides a cost-effective tool to provide students with more realistic training experience prior to hands on training.

VR Benefits in Construction Education:

Utilizing VR in construction education has been limited by technology or the labor-intensive process if project specific models are used. The benefit of VR shines when generic programs are created to teach concepts that are difficult to envision through traditional teaching or 2-D models (Fogarty et al. 2018). Traditional teaching methods especially in safety are considered dry and yield minimum levels of engagement by students whereas VR brings excitement, participation, and interest into learning from the experience (McCall et al. 2019). After these new concepts are experienced with VR, the classroom setting allows for debriefing afterwards in collaborative manner to reinforce the knowledge. VR provides an opportunity for the user to interact with the subject matter which promotes active and collaborative learning. These types of learning methods have been shown to be more effective and provide better understanding and knowledge retention. Lucas (2018) showed that students who experienced VR in the academic setting were receptive to the use of VR and expressed their desire to see further use of the technology.

VR and Construction Safety:

The implementation of VR in the construction industry has been slower than other industries. As the technology of VR has been expanded so has the applications for use within construction and safety education (Froehlich et al. 2016). The industry within construction can use VR in many ways. For instance, VR/AR can help project team catch design flaws before construction begins or obtain project end-user comments. They can serve as virtual mockups and help with installation of high-end or complex finishes. They can also assist project managers with the sequencing elements in the project schedule or coordination of MEP (Mechanical, Electrical, and Plumbing) activities. Moreover, these technologies have shown great advantage for jobsite safety, heavy equipment operation, or offsite workforce trainings. The construction education is in its infancy stages utilizing VR as a teaching tool and still heavily relying on traditional instructional methods to teach safety. According to Pereira et al. (2018), there is a common trend of dissatisfaction and known ineffectiveness of the current OSHA safety courses. This area is where VR can be used to improve the traditional teaching style and move towards a system shown to provide a more retentive learning method. VR provides an immersive learning environment and can provide users with the sights of a typical construction site without the exposure to possible danger or coordination of a class site tour.

Research Methodology:

To examine the effectiveness of VR technology in teaching construction safety topics to college students, the Construction Safety and Risk Management class that was offered in Summer 2021 at Wentworth Institute of Technology with 17 Construction Management (CM) students was selected as pilot study. The experiment used the 3M Fundamentals of Fall Protection Virtual Training program (3M 2021) along with a Vive Pro Eye headset (Vive 2021) and a VR ready Razer laptop. The 3M virtual reality safety training activities were chosen since the company is one of the leaders in safety training and promoting safe practices in the construction industry. All the activities mimic the real scenarios that construction workers may experience in the field. The program includes four activities: (1) Check Site Hazards, (2) Check Anchorage Installations, (3) Erect Steel Beam, and (4) Install Corrugated Board (Figure 1).

Figure 1: 3M Fundamentals of Fall Protection Virtual Training Program

In this research, two separate quantitative data analyses were implemented following Delgado (2020) method to portray the relationship between the data collected and the experience of the participant. This allowed for multiple aspects of the experiment to be reviewed and contextualized. Each student was allotted 45 minutes to complete multiple VR activities. The sequence of activities was the same for each student and ordered from what was determined to be from least to most difficult interactions of VR. The first activity (Check Site Hazards) mirrors a site safety manager conducting a site safety walkthrough. This provided the students with basic VR movements and interactions with avatars, who represent different workforce personnel, to inspect and provide any missing PPE based on the activity being conducted. The second activity (Check Anchorage Installations) was the inspection of different fall protection anchorage points. This experience allowed the user to move around a construction site inspecting anchor points and connections for proper use, placement, and installation. The third scenario (Erect Steel Beam) provided a superb VR interaction experience. This scenario allowed the user to operate an ariel lift to a reach a steel beam. Once at the beam level, the user had to properly exit the lift bucket while complying with 100% tie off procedure and walk a few steps along the beam. Once in position at the end of the beam, a crane brought in another beam for connection to columns. The user had to guide the beam and secure it in place with bolts and a wrench. Once completed with beam, the user returned to the aerial lift to complete the scenario. The last scenario (Install Corrugated Board) focused on working in harmony with virtual coworkers to properly install a corrugated board while complying with safety protocols.

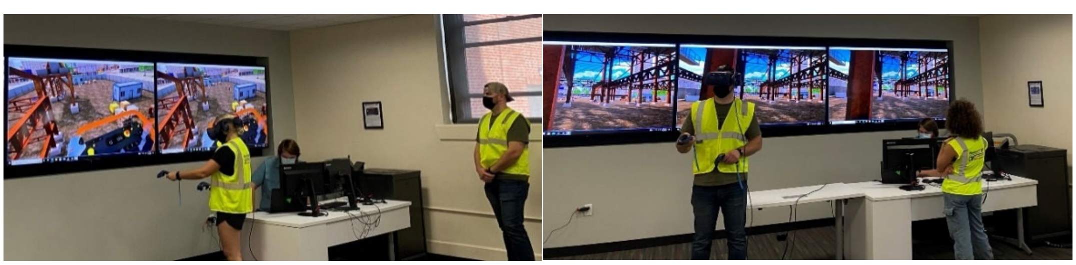

Figure 2: Students during the VR Training

The first quantitative analysis allowed for the identification of data trends from pre- and post- VR tests and the second one allowed for a numerical representation of the participants' opinions of the VR experience. In order to gauge the retention of information and knowledge learned from the VR experience, the time difference between pre- and post-VR tests were set to 3 weeks. The goal was to determine if the VR experience benefited the students academically, while also helping gauge the user's opinion on if the VR activities were beneficial. With these two data sets, it would be possible to examine whether (1) the VR learning activities improved students' test scores, (2) the VR was deemed beneficial learning approach by the students, and (3) the VR provided a significant improvement in the testing grades and was viewed positively by them. The quantitative data was gathered by giving the participating students two short tests at different times, one before and one after their VR experience. This allowed the pretest to be used as a baseline for the students' performance with the scores being compared between the two tests. To avoid biases, the students were not told that the quizzes and VR experience were related. Also, students were not informed about either of the tests to minimize biases associated with possible study before the tests.

Results:

The pre- and post-VR tests had a max score of 70 points and of the 17 students participating, 15 showed improvements (Figure 3). To perform the statistical analysis, the test scores' scale adjusted from 70 to 100 to reflect standard grading system for the course. As illustrated in Figure 3, student 17 missed the post-VR test and student 13 scored lower than the pre-VR test. The analysis of all the participants showed an increase in test scores of 8 points, reflecting an improvement from 86% to 94%. When the data on student 17 was removed, it did not impact the results. This data suggests that the VR activities improved the students' knowledge of proper PPE required for construction activities based off their testing. Later, the two-sample t-test was performed at 5.0% level of significance (α= 0.05) and since the ratio of variances of two samples were less than 2, equal variances was assumed (Table 1). The statistical analysis showed a significant difference between the two samples with the P-Value of 0.000099.

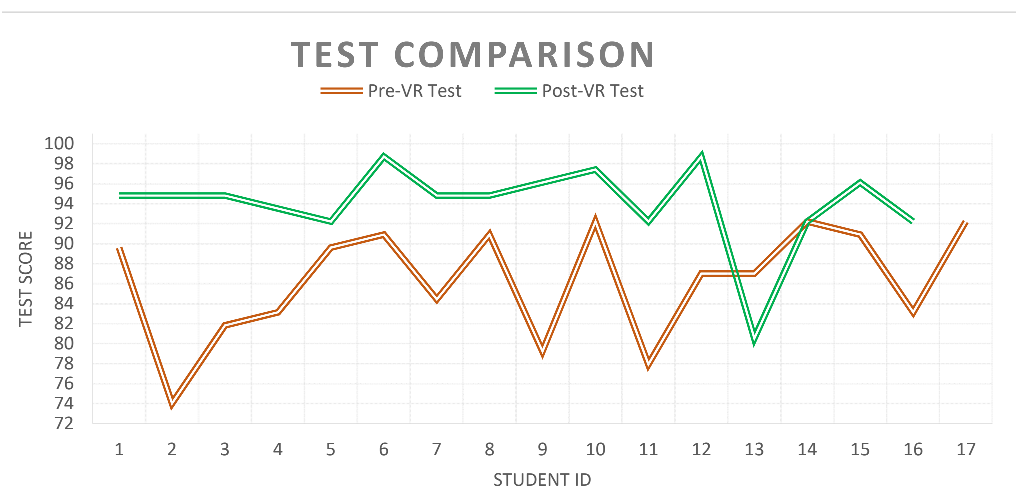

Figure 3: Comparison of Pre-VR and Post-VR Test Scores

Table 1: t-Test Analysis Results

t-Test: Two-Sample Assuming Equal Variances	*Pre-VR Test Score*	*Post-VR Test Score*
Mean	86.25	93.99
Variance	31.63	17.51
Observations	17	16
Pooled Variance	24.80	
Hypothesized Mean Diff.	0	
df	31	
t Stat	-4.464480	
P(T<=t) one-tail	0.000050	
t Critical one-tail	1.695519	
P(T<=t) two-tail	0.000099	
t Critical two-tail	2.039513	

Table 2: Survey Questions & Results

Number	**Question**	**Min**	**Max**	**Mean**	**Mode**	**Std. Deviation**
1	The VR experience was not difficult to use.	10	12	11.40	12	0.74
2	The navigation of the VR experience did not take away from the ability to learn.	10	12	11.40	11	0.63
3	The VR experience encouraged critical thinking.	10	12	11.27	11	0.70
4	The VR experience provided a better understanding of possible site safety issues.	10	12	11.53	12	0.64
5	The VR experience was a good use of learning time.	10	12	11.27	11	0.70
6	I would like to see more VR used in my education.	10	12	11.20	11	0.77
7	The VR experience will be useful in my future career and/or Co-Ops.	10	12	11.13	11	0.74
8	I felt that participating in the VR helped me learn safety concepts.	10	12	11.27	11	0.59
9	The VR experience reinforced/used what was taught during lecture.	10	12	11.20	11	0.68
10	I better understanded safety regulations after the VR experience.	10	12	11.00	11	0.76
11	The situations in the VR experience provided me with realistic situations I would experience.	10	12	11.27	11	0.59
12	I gained a better understanding of safety requirements from the VR scenarios.	10	12	11.20	11	0.68
13	The VR experience created questions about safety to discuss in class.	10	12	11.00	11	0.65

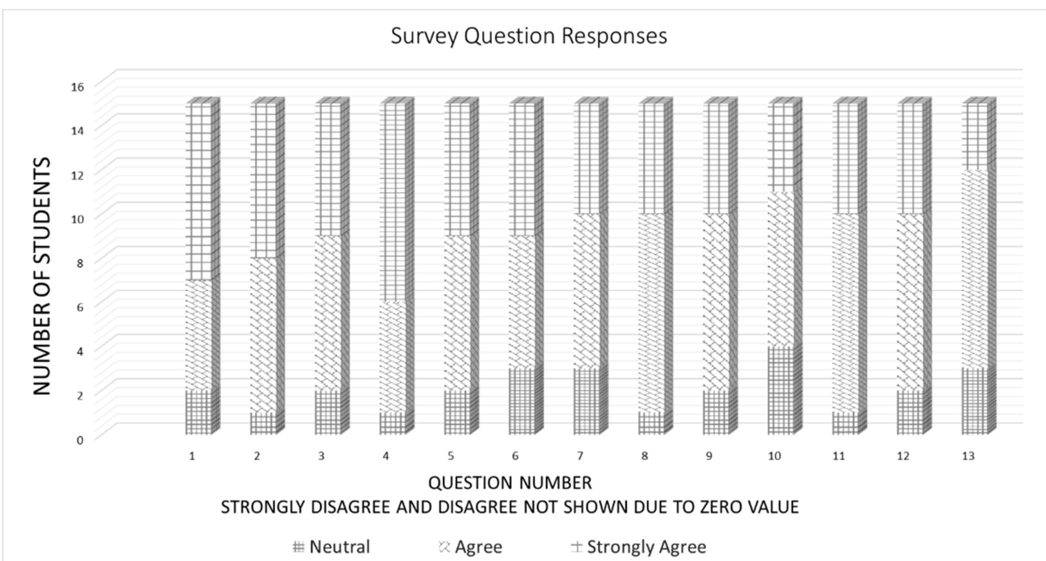

Figure 4: Survey Results

The second quantitative survey focused on participants' reflection upon their experience as well as their opinions on utilizing VR technologies in education and training. These questions had no impact on students' quantitative test results. Instead, they were designed to identify if the participants felt their learning experience was enriched by the presence of VR regardless of whether it had a positive impact on their test score. Several of the questions posed to the participants asked them to reflect upon their experience with the VR safety training and how it directly impacted their understanding of the subject matter. These questions included whether (1) they found the use of VR increased their insight and understanding of key safety concepts, (2) it increased their ability to think critically, and (3) the VR experience increased their understanding of site safety issues.

In addition to questions pertaining to the experience with VR and the possible benefits it poses to education, participants were also asked to reflect on the future of VR and how they expect it will impact them. Participants were asked to indicate if they would like to see more VR in their education, if the experience was able to generate questions and discussions back in the classroom environment, and whether they felt the experience would be valuable to them in their future careers and Co-Ops. The participants were given five different ratings to choose from; Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree with the score of 12, 11, 10, 9, and 8, respectively. Table 2 shows the survey questions, minimum, maximum, mean, mode, and standard deviation. All the participants found the VR training very favorable and felt a positive increase in safety knowledge and critical thinking abilities as a direct result of their VR experience. The minimum and maximum scores for all 13 questions were 10 and 12 which reflects that throughout the entirety of survey, there was not a single instance where a participant indicated "Strongly Disagree" or "Disagree" to any question. The mean of responses to all questions were 11 or higher indicating more responses on "Strongly Agree" and "Agree". The overall very positive attitude towards the experience is evident in the survey records collected by the research team. Figure 4 shows the graphical representation of the second survey results.

There were 3 short response questions at the end of the second survey (Questions 15-17) which allowed for more specific feedback to help future utilization of the VR technology (Table 3). These responses further demonstrated that the students overall had a positive experience and welcomed the VR technology use in the classroom. Question 15 had specific responses for more implementation with greater access to the VR gear. Question 16 resulted in a common trend of courses that are field related, and VR can be utilized to provide field experience. Question 17 results indicated that 78.6% of students suggesting shorter and more frequent VR sessions.

Table 3: Short-Response Questions

Short-Response	
15	What are some improvements that you would want to see with the VR program?
16	Where do you want to see VR used in your education?
17	If there were more VR experiences, what would be the best length of session? Longer, less frequent or Shorter, more frequent

Conclusion:

The analysis of data collected in this study indicated that the VR posed a viable and impactful tool when implemented into the educational environment. The results suggested a clear improvement in the retention and demonstration of knowledge pertaining to construction safety when VR was introduced into the course. Additionally, the atmosphere of the classroom itself experienced a very positive change as well as the introduction of VR peaked the participants interests. Moreover, the VR created a stimulating environment that promoted information absorption and retention. Lastly, participants believed that the VR training was overall beneficial to their educational experience and most believed that the exposure to experiment would have a positive impact on their career.

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