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Using VR (Virtual Reality) Technology to Teach Fall Safety Topics to Students: Simulation Outcomes and Student Learnings

Dr. Mahmud Hasan, University of Houston, Downtown

Strong and diverse teaching, research, industry, and service (department, college, university, and community level) experience in innovative safety environments. Worked in different multinational engineering companies: McDermott International, Inc., Genesis Oil and Gas (Technip USA Inc.), and Shahjibazar Gas Turbine Power Plant. A licensed Certified Safety Professional (CSP) and Professional Engineer (PE) from two states (Texas and Louisiana). Evidence of scholarship as demonstrated by national and/or international publications, and experience with ABET and SACS assessment.

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Abstract

VR (Virtual Reality) which is a new technology, has been used to simulate training that is too expensive and time-consuming to practice in real life. This study aims to find students' learning improvement on Fall related safety by using low-cost VR technology. This will also help practicing how to survive Fall hazard techniques. In the current study, a well-known VR software was used to introduce participants to Fall safety scenarios. Rather than students being passive viewers where the instructor/trainer only demonstrates, the students were given full control to navigate through the virtual environment and to interact with virtual objects using a headset and a handheld controller. Students identified a simple climbing and Fall hazard example before going to more rigorous training in the virtual environment. Results indicated that students were more engaged by the new game-like learning environment and that they reported that they found the experience fun, interesting, and thought-provoking. Their enhanced enthusiasm for what is relatively standard Fall-safety training demonstrates the promise of using game-based virtual environments for vital but otherwise tedious Fall-safety skills training for students.

Keywords: VR (Virtual Reality), Simulation Environment, Humulo Software, Fall safety, Enhanced learning

1. Introduction:

Without a doubt, Fall protection safety rules and equipment are on the minds of employers and workers [1] who work at heights during bridge constructions, high rise buildings, construction sites, manufacturing plants, refineries, house roof installation etc. Statistical data from the BLS (Bureau of Labor Statistics) reveals that Fall remain as one of the most significant causes of worker deaths [2]. Out of 5,250 deaths identified in 2018, 15% involved Falls [3]. Out of these, fourteen percent involved Fall to a lower level. Among the ten occupations with the highest job fatality rate were structural iron and steel workers, roofers, and electrical power-line

installers and repairers [3]. These data indicate that, Fall is still a major safety issue both on the job and outside of worksite.

Students and trainees will be the future worksite safety leaders therefore they need to have in depth knowledge about Fall related safety, hazard identifications, and mitigation. A Fall safety training conducted by VR simulation can save a lot of money to do it in house [4]. It is very important for the students to get training by VR simulation before joining to work force and starting their careers. This work used VR simulation and analysis of Fall safety inspection and prevention which is a common hazard in industries.

With the current safety training programs in the current market, various instructors teach various safety management courses where students are learning theoretical understanding of Fall safety inspection and prevention. The author of this work encountered many students in the classrooms and training programs who previously expressed their opinion to get real life experience to handle Fall related hazards. Practicing class room VR simulations will help students to get proper understanding about real life experience how to prepare against Fall and working at heights safely. To continue the trainers' efforts with enhance students' learning, this work is conducted keeping in mind to work on using VR simulation in classrooms to identify and mitigate Fall hazards in worksites and neighborhoods during working with Fall hazards.

Published literatures [5-8] indicated that VR systems can be effectively used to save and separate trainees from dangerous risks involvement during hazard skills training especially Fall safety. One of the studies conducted by Sulbaran and Baker [9] showed that trainees generally enjoy VR training more than other traditional training methods which includes class room lectures. They also indicated that students remember the knowledge for longer period of time gained from VR training longer than that gained using other methods. As a result, VR hazard-skills training has the potential to reduce risk, increase acceptance, and improve effectiveness among trainees over traditional/prior lecture training method.

2. Objectives:

The present study aimed to determine the impact of Fall safety training via VR environment for trainees, in this case students in a class room setting. The aim in this the current study is to increase learners' motivation, over traditional class room lecture (prior) methods used in the overall study. This was done simultaneously while maintaining or enhancing students' learning

about Fall hazards and Fall-survive techniques. To achieve the goal of this study, the methods used was game-based VR techniques to make Fall safety training a fun. This also ensures students' engagement to learn, while actually helping students remember the steps they need to take to save themselves and others if they ever find themselves in a real Fall situation while working on the sites or in the houses.

3. Descriptions of the Software and Components:

For this work Humulo's VR Fall Protection software was used. This Fall Safety module software training was developed by Humulo Engineering software company. Humulo is the leading company on developing Fall Safety training software in addition to other safety softwares where OSHA (Occupational Safety and Health Administration), NIOSH (National Institute for Occupational Safety and Health) and other safety organizations' rules and standards are discussed. Figure-1 is showing one of the screen shots of that Fall Safety training simulation.

Figure-1: VR Simulation of Fall Safety Training Demo [10]

Students were able to use the software in the class room and were able to practice the Fall simulations using the VR (Virtual Reality) headset/sunglass by their own. The PICO Neo-2 VR Headset with Controller was used to visualize, direct, move etc. purposes inside the virtual world. The Miracast Dongle wifi adapter was used as the software had projection capability from classroom computer using overhead projector to show the students in the classroom how things were inside the VR world for instruction purposes.

4. Descriptions of the Overview of Learning and Training Sequences:

The learning objectives from this software were: identify major Fall hazards, describe types of Fall hazards, protect everyone from these Fall hazards, recognize employer requirements to protect workers from these Fall hazards, recall and inspect required safety equipment, identify climbing height that requires anchoring with wall or areas, practice climbing and anchoring procedures, practice working aloft and re-attaching tools to harness, practice work on elevated platform, and practice climbing down from elevated structures.

The students' overviews of learning were: students were exploring hierarchy of Fall safety which includes 5 levels of Fall safety. Students began by inspecting and donning a harness, as well as attaching the required welding tool to themselves. Students then began climbing the crane ladder, and required using the anchor points to attach themselves as they climb. Once they reach the first crack, they repaired it with the welding tool, re-attached the tool, and then continued their climb. They then climbed to the middle platform (answer a question about what anchor points they should and shouldn't use), anchored themselves, and then repaired a crack on the middle platform. Once complete the students climbed to the top platform to reset the breaker box. Students then climbed back down the crane, making sure to use their anchor points along the way.

The Fall safety software purchased from Humulo Engineering contained four modules: Simulation-1 HumuloVR Training Tutorial, Simulation-2 Explore Hierarchy of Fall Safety, Simulation-3 Fall Safety Quiz, and Simulation-4 Fall Safety Practice.

Simulation-1 HumuloVR Training Tutorial:

In this module participants followed and worked on these items:

- Hit the two downward arrows,
- Climbed the ladder,
- Went to second floor,
- Went near to a table for grabbing welding equipment,
- Completed the welding.

Figure-2 shows a few of Simulation-1 module photos in the virtual world. In this figure, (a) indicates the instructions that need to be followed to do this module, (b) indicates one of the downward arrows that need to be hit, (c) indicates the instructions that need to be followed

before climbing the ladder, (d) indicates climbing the ladder, (e) indicates climbing to second floor, (f) indicates hands' position during climbing to second floor, (g) indicates the instructions that need to go to near to a table for grabbing welding equipment, and (h) indicates completion of the welding.

(a)

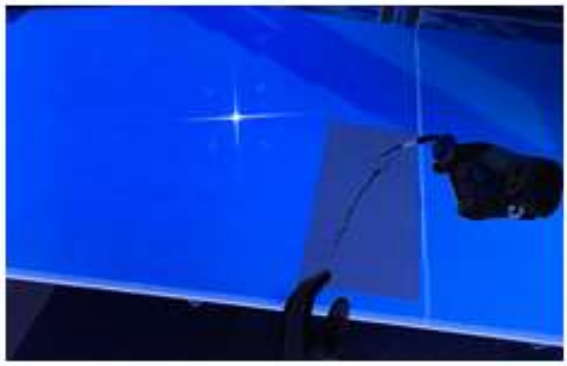
(b)

(c)

(d)

(e)

(f)



(g) (h)

Figure-2: A few screenshots on Simulation-1

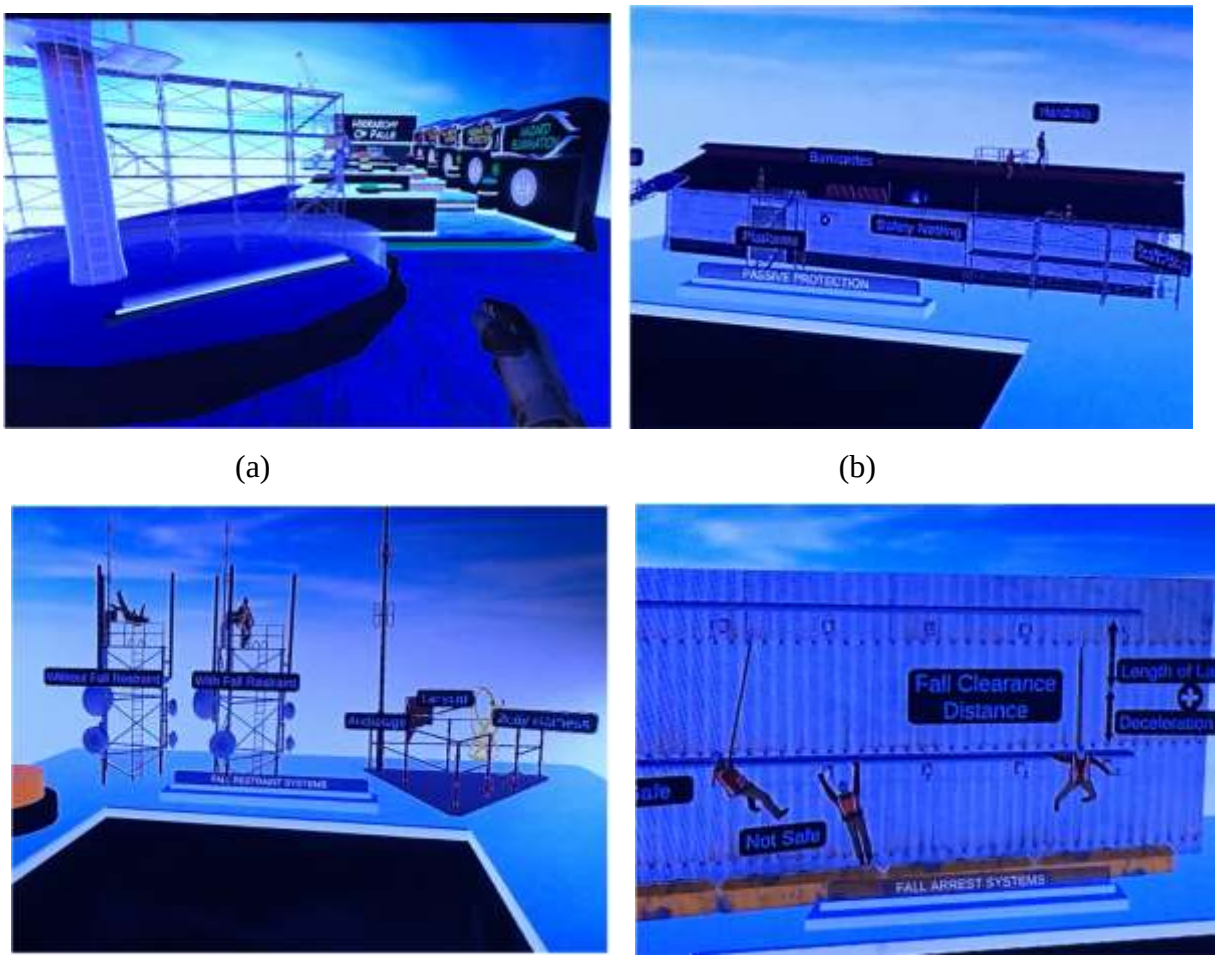
These screen shots are important as they show the inside of VR world and how students access to different stages on their lessons on each module.

Simulation-2 Explore Hierarchy of Fall Safety:

In this module participants followed and worked on these items:

- Read the instructions about this module,
- Went to different hierarchies of Fall safety,
- Went to different tables to grab equipment related to Fall safety,
- For Hazard Elimination went to Table-1,
- For Passive Fall Protection went to Table-2,
- For Fall Restraint Systems went to Table-3,
- For Fall Arrest Systems went to Table-4,
- For Admin Controls went to Table-5,
- These activities led to performances/scores that shown to trainees,
- At the end returned to Main Menu.

Figure-3 shows a few of Simulation-2 module photos in the virtual world. In this figure, (a) indicates the view needs to go to different hierarchies of Fall safety, (b) indicates the view for Passive Fall Protection, (c) indicates the view for Fall Restraint Systems, and (d) indicates the view for Fall Arrest Systems.



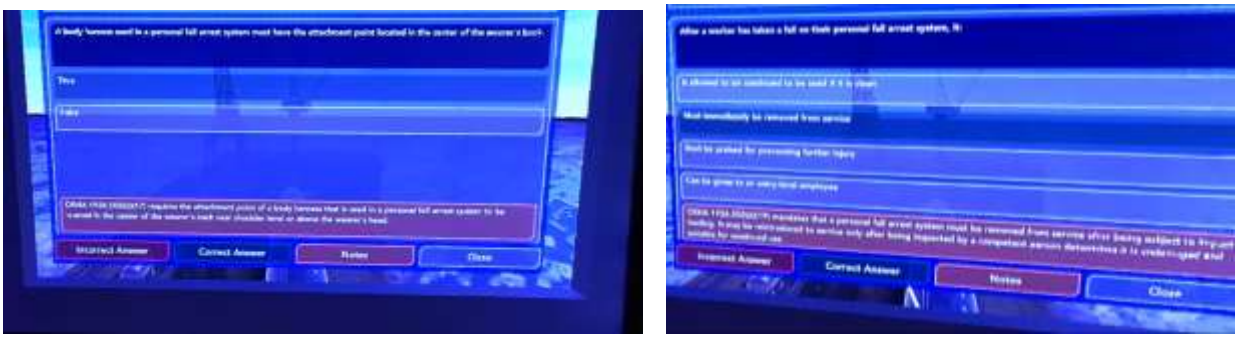
(a) (b)

(c) (d)

Figure-3: A few screenshots on Simulation-2

Simulation-3 Fall Safety Quiz:

In this module participants faced several of questions and few choices for answers related to Fall safety. The participants were required to select the best possible answers. Figure-4 shows a few of Simulation-3 module photos in the virtual world. In this figure, (a) indicates one of the quiz questions with multiple of choices, and (b) indicates another of the quiz questions with multiple of choices.



(a) (b)

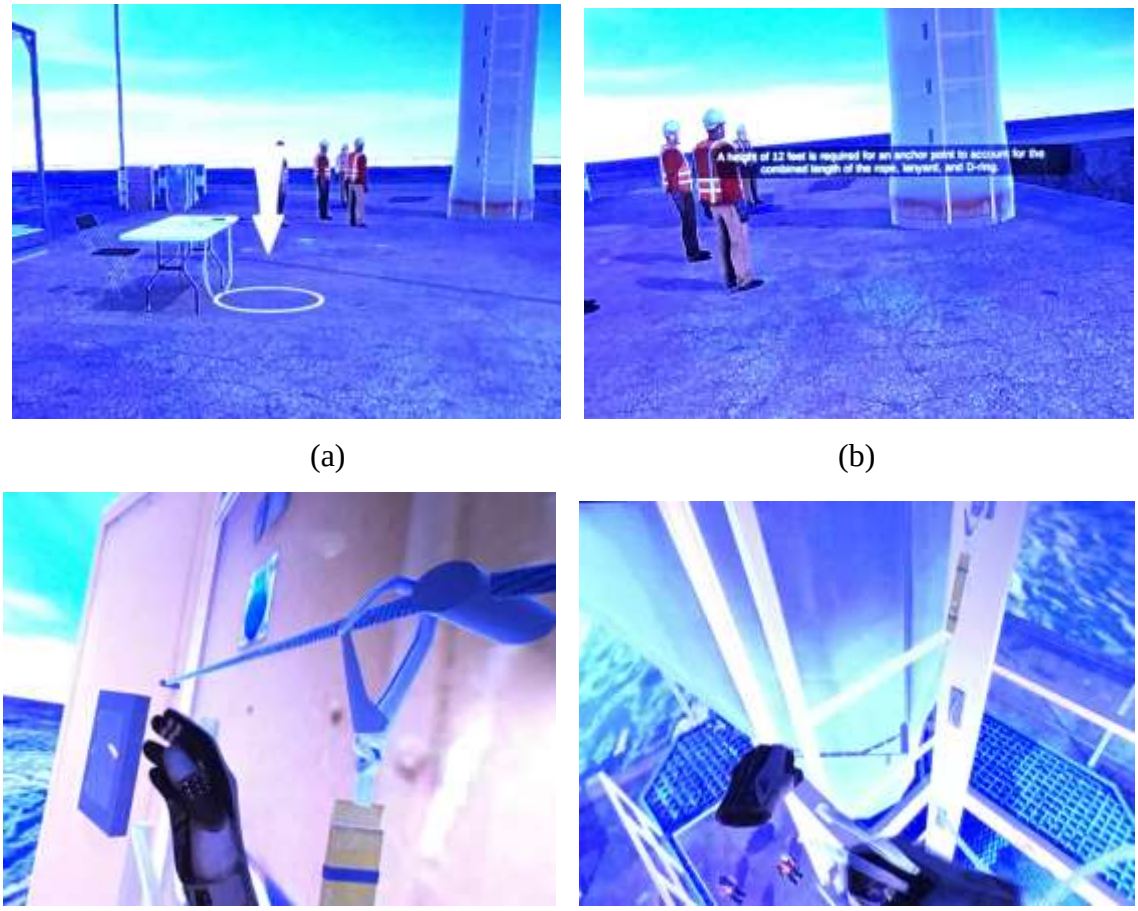
Figure-4: A few screenshots on Simulation-3

Simulation-4 Fall Safety Practice:

In this module participants followed and worked on these items:

- Read the instructions in related to this module,
- Walked near to the table,
- Grabbed PPE (Personal Protective Equipment) requirements for Fall safety,
- Inspected Fall harness,
- Worn the Fall harness,
- Inspected hooks,
- Put the hooks,
- Grabbed and put the welding gun,
- Went to near to the tower,
- Climbed the ladder,
- Did a welding on the tower,
- Climbed to the first platform,
- Did another welding,
- Climbed another ladder for second platform,
- Walked left side for Breaker box,
- Opened the Breaker box door,
- Flipped the breaker inside of it,
- Descended back to the ground,
- Hit the downward arrow to complete the module.

Figure-4 shows a few of Simulation-5 module photos in the virtual world. In this figure, (a) indicates the downward arrow where Fall harness is inspected and worn, (b) indicates the view near to the tower which needs to be climbed by the ladder, (c) indicates walking left side for Breaker box that needs to be opened and flipped, and (d) indicates descending back to the ground.



(a) (b)

(c) (d)

Figure-5: Few screenshots on Simulation-4

5. Methodology for Learning Assessment:

Students shared their experiences with others in the class rooms during and after using the VR software. In addition to students hearing class lectures, the instructor was able to demonstrate the simulations using the Miracast Dongle adapter while projecting from class room projector. After that headsets and controllers are given to individual students to practice the VR simulations by themselves by entering to virtual world. They were also engaged with different situations of

Fall hazards during VR simulations which helped them to understand the class materials related to awareness of Fall and working at heights. This was an interactive class overall.

This training was designed to give students hands on experience on Fall safety on a virtual environment which can save money to bring them on the worksites to get real life experience. Also, students needed to aware of equipment needed to address this Fall safety. Different Fall safety scenarios are created in the virtual world and students participated those events.

In total 23 students participated in this work by enrolling to course title Offshore Fall & Safety Inspection course which was offered in Spring-2022 semester. The Fall Safety module software training developed by Humulo Engineering software company is used for this training. Figure-6 is showing that students were getting Fall Safety training using VR headsets (attached with heads) and controllers (hold by hands). Each headset and controller cost $699, whereas each Fall safety module license cost $30.

(a)

(b)

Figure-6: Students are getting Fall Safety training using VR headsets and controllers

Students were assessed before using this Fall safety training software as well as after taking this software. The same students were given both a VR test and a non-VR test in a few weeks interval. There was time for the students to learn the material between the treatments. Students were tested on the same 10 different questions on Fall safety in a MCQ (Multiple Choice Question) format. Difference of their after and before scores are also tabulated to measure their performance outcomes.

Number of students engaged in class room use of this VR software related to Fall safety while working at heights were tracked. Keeping track of attendees during VR simulation were recorded. How to increase more students' involvement were surveyed to seek their opinion what they wanted to learn.

6. Results and Discussions:

Table-1 is showing students' outcomes before (Pre-Assessment) and after (Post-Assessment) using this software and training. Negative (-) sign is placed for the outcome where score was reduced/decreased after using this training. Positive (+) sign is placed for the outcome where students' scores were increased after using this training. A few students did not participate in this outcome and their scores are reported as 'NA' (means Not Available). The questions for this assessment training are listed in the Appendix.

Table-1: Students' performance using this software

Student no.	Pre-Assessment (10)	Post-Assessment (10)	Difference (=Post-Pre Assessment scores)
1	7	9	+2
2	8	9	+1
3	9	9	0
4	6	9	+3
5	9	9	0
6	5	8	+3
7	7	9	+2
8	8	9	+1
9	9	9	0
10	9	NA	NA
11	10	9	-1
12	9	9	0
13	9	7	-2
14	9	NA	NA
15	9	9	0
16	7	9	+2
17	8	9	+1
18	8	9	+1
19	9	9	0
20	8	7	-1
21	9	10	+1
22	7	NA	NA
23	7	NA	NA

Table-1 and Figure-7 show that out of 23 students, results indicated a large number (10 number of students) of students had improvement on learning Fall safety after using this software. It represents 43.48% of the students atteneded this class and training. This is a big percentge and indicated the importance of this training.

Out of the 23 students, 6 number of students' learning on Fall safety did not change (same score). It represents 26.09% of the students atteneded this class and training. Also, 4 number of students did not participitated the post assessment questions, therefore their learning improvements were not able to judge. It represents 17.39% of the students atteneded this class and training.

Whereas, a small number (3 number) of students' learning did not help on learning this software. It represents 13.04% of the students atteneded this class and training. The reason of their lower score might be related to not familiar with this kind of technology during the training as well as other issues. At least one student reported her vertigo while using this software and suggested not to use it while standing or moving too fast in the virtual world. A slow movement reducted her tiggering of vertigo. Students who got lowever scores were given extra time outside classrooms to use this software and training to get better understanding about Fall safety.

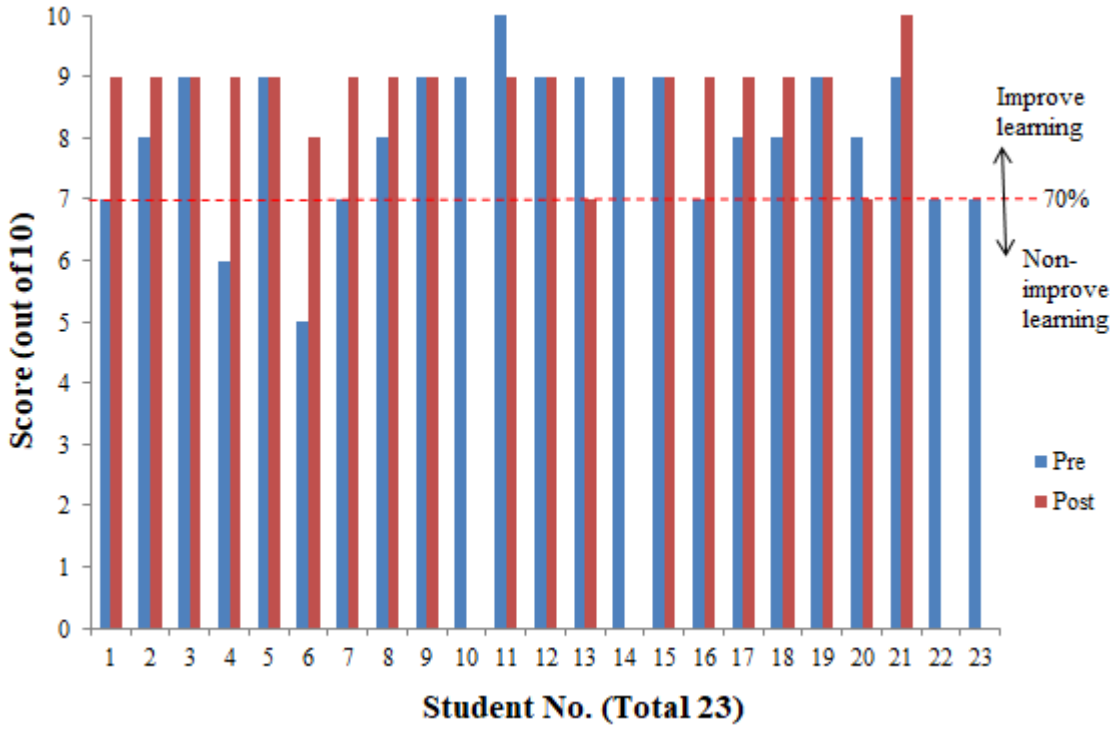


Figure-7: Graphical representation of students' outcomes

Learning improvements were indicated by scores that were equal to or above 7 out of 10, whereas improvement needed scores were indicated for scores that were below 7 out of 10 which

represents below 70% scores. Table-1 and Figure-7 indicated that two students made below 70% score before doing this training, however their knowledge improved 30% after doing this training. This is a success for this training doing it via virtually.

Statistical analysis was performed to observe overall class performance. Mean data for the pre- and post-assessment for the students' scores are 8.09 and 8.79 respectively. This indicates a very good knowledge improvement among students. Sample standard deviation for the pre- and post-assessment for the students' scores are 1.2 and 0.71 respectively. Which indicates a little variation or dispersion of scores among students before the training, however a little uniform of scores on students' knowledge after doing the training.

Overall, this training was a great success. By any means, VR teachnology is the new way of teaching and giving Fall safety training to class room students as well as trainees in companies. From students and trainees side this training is very convenient as they can do the training any time they want while not stopping their regular works. From instructors and employers side this training is convenient as they do not need to be avaiable during the training which will help them to do their other important works. This training will save money and avoid risks, injury, even death from Fall hazards during getting the training.

7. Conclusion:

Overall, this work indicates many students' learning improved on Fall safety after getting this training. Students' comments in the class and course evaluation indicated that they liked this software very much and their suggestions to their employers were to implement this kind of VR training in Fall as well as various safety topics to save money. At the end, although VR technology has a lot of potentials, it is still in a growing stage. The equipment (headsets and controllers) is still expensive to purchase and that is limiting on wide scale of VR use, even though the software license is considerably cheaper. Reducing the cost will have large applications of this important safety software for training purposes.

8. Acknowledgements:

The author greatly acknowledges the financial support from 2021-2022 Halliburton project through the CSET (Computer Science & Engineering Technology) department for funding this work.

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Appendix (Fall Safety Training Questions)

University of Houston-Downtown (UHD)

Department of Computer Science and Engineering Technology (CSET),

ENGR 3346 –Offshore Fire and Safety Inspection,

Fall Safety Simulation software use,

Choose the right answer from the below questions. Score_____ (10)

(1) OSHA regulations require some type of fall protection above how many feet in residential construction?

(a) 4 feet

(b) 6 feet

(c) 8 feet

(d) 100 feet

Answer: B

(2) When inspecting fall protection equipment look for:

(a) Cuts, frays, holes, or deterioration of webbing or rope

(b) Deformation of buckles, dee-rings, and snaphooks

(c) Rust/corrosion, deformation, or damage to anchors

(d) All of the listed items

Answer: D

(3) Fall protection system do not include the following:

(a) Personal fall arrest system

(b) Working on flat roof only

(c) Guiderail systems

(d) Safety nets

Answer: B

(4) Following OSHA 29 CFR 1926.502(d), choose the components of a Personal Fall Arrest System from the list below:

(a) Body harness, hardhat, ANSI approved work boots

(b) Lifeline, Anchor, Hardhat

(c) Body harness, Lifeline, Anchor

(d) Body harness, Anchor, ANSI approved work boots

Answer: C

(5) A safety anchor must have the capability of supporting at least ____ pounds per employee attached:

(a) 500

(b) 1500

(c) 3000

(d) 5000

Answer: D

(6) A body harness used in a personal fall arrest system must have the attachment point located in the center of the wearer's a back.

(a) True

(b) False

Answer: A

(7) Roof anchors, dee-rings, and snaphooks with rust on them are not required to be removed from service.

(a) True

(b) False

Answer: B

(8) Ropes or lanyards used as part of a fall protection system must be made from synthetic fibers.

(a) True

(b) False

Answer: A

(9) Dee-rings and snaphooks used in a personal fall arrest system must:

(a) Have a minimum tensile strength of 5000 pounds

(b) Be proof-tested to minimum tensile load of 3600 pounds

(c) Be sized to be compatible to that which it is connected.

(d) All of the listed items

Answer: A

(10).After a worker has taken a fall on their personal fall arrest system, it:

(a) Is allowed to be continued to be used if it is clean

(b) Must immediately be removed from service

(c) Shall be praised for preventing further injury

(d) Can be given to an entry-level employee

Answer: B