Gauging Effectiveness of 3D VR for Memory Retrieval

Introduction

Virtual Reality (VR) is quickly gaining momentum as a possible tool for safety and skills training in the petrochemical and oil refining industry. As a non-profit, member-centric, representative for plant owners and the contractors who work on plant owner sites, the Health and Safety Council (HASC) has started to invest in VR training tools as a part of their training delivery mix.

Other industries are starting to see reductions in both training cost and training time by using VR as a training tool. Using VR as a training tool for developing both procedural and declarative long-term memories is a natural fit for the petrochemical and oil refining industry as well. Accenture in their report on Immersive Learning for the Future Workforce found that learners using VR for training had 12% higher accuracy and 17% faster time for completion for procedural memory learning.[1] Additionally, Accenture's report found that VR learners had 40% fewer mistakes than those who had not been trained using VR and a 40% reduction in training time.[2]

In July of 2020 HASC started a VR investigation to determine how effective VR could be as a training tool for the contractors and trainees who might come to HASC for safety or skills training especially when integrated with traditional eLearning or Computer Based Training (CBT) tools. This investigation was developed to verify claims regarding the efficacy of VR as a training tool for long-term memory development. Studies have shown that learners who were taught in VR instead of just via traditional video or lecture-based training had an improvement in recall and retention of 28%[3] and that both learner's understanding and remembering were greater using VR compared to traditional learning styles.[4] HASC's investigation reviewed studies and articles to determine if VR would be effective in terms of creating lasting, retrievable memories for HASC's trainees and designed an experiment that included over 1600 individual learners within the petrochemical and oil refining industry.

Industry and VR

In the petrochemical and refinery industry that HASC supports, a great amount of effort is placed on making sure that training is swift, as well as effective. Spending more time on training is not always the most cost-effective way of doing business, so finding a solution that transfers the learning objectives quickly and effectively should be the goal. A study of work in petrochemical plants that included both VR training and non-VR training proved that learners who took training in a VR atmosphere identified valves correctly at a rate 25% greater than their non-VR trained counterparts[5]. Additionally, the same study showed that learners trained using a VR simulation responded to and stopped leaks in the plant in a 42% shorter time frame resulting in smaller spills.[6]

In the case of HASC's experiment, the VR solution that has been developed includes a simulated fire extinguishing exercise. The strength of using VR for this type of training is easy to see as training on the

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[1] Raghavanet al, "Immersive learning for the future workforce." *Accenture Extended Reality (XR)*, 2018, 5.
[2] Ibid, 6.
[3] Allcoat et al, Learning in virtual reality: Effects on performance, emotion and engagement." Department of Psychology, University of Warwick, Coventry, UK, 2018, 6.
[4] Ibid, 7.
[5] Colombo, Nazir, and Manca, "Immersive Virtual Reality for Trainng and Decision Making: Preliminary Results of Experiments Performed with a Plant Simulator." Society of Petroleum Engineers, 2013, 171.
[6] Ibid.

use of a fire extinguisher on a simulated fire can be accomplished in the virtual world, but workers tasked with the use of a fire extinguisher in an emergency are rarely allowed to work with a fire extinguisher and fire in real life. HASC's virtual environment provides workers this opportunity without fear of injuries or the dangers that come with fighting fires in the real world.

HASC used a combination of traditional CBT style learning with three to five-minute, simulated 3D virtual exercises to reinforce the learning objectives provided via a CBT. HASC expects that there will be a greater and more precise recall of these VR exercises, especially in the long-term. Eric Krokos, Catherine Plaisant, and Amitabh Varshney found in their study of 3D virtual environments, "there was no significant difference between the users' ability to immediately recall the words after a 2-min break, but after one week there was a 25% difference in recall in favor of the 3D graphics desktop . . . condition."[7]

Memory

Semantic memory, or the ability to recall words, concepts, or numbers, and episodic memory, or the ability to remember an event, are the two types of memory that safety and skills trainers at HASC try to create for their trainees. A 2019 study headed by Cosimo Tuena that included Italian, French and Swiss researchers established that "episodic memory is a neurocognitive system that allows people to remember the what, where, and when of a personally experienced event."[8] Although semantic memory might be more useful in some situations for field employees in the petrochemical and oil refining industry, particularly in terms of types of equipment, tools, or specifications, episodic memory is perhaps more important for emergencies.

Trainees in this industry are commonly put into situations where they must be able to recall events and situations, especially in emergencies, to ensure against catastrophic damage to equipment, hazardous releases of chemicals and vapors, or dangerous life-threatening personal injury. A study in 2018 of fire emergency response training proved that learners using VR for training reinforcement were able to perform procedures correctly at a rate 50% higher than learners who did not have the VR learning reinforcement.[9]

Both semantic and episodic memories fall under the umbrella of declarative memory which according to Professor Neil Burgess of University College London, "refers to all forms of conscious or explicit memory, including episodic, semantic, and familiarity-based recognition."[10] The key question for HASC is how might elements like 1) spatial cognition, which is the ability to navigate and understand where a subject stands in relation to their environment or 2) embodied cognition, which are memories affected by the elements and movements of the physical body, as well as 3) sensorimotor involvement, how moving and changing elements of the body within an environment, could affect the resilience and solidity of a memory as it is formed. Does being immersed in an environment and having to interact with that environment in a non-passive manner, have a benefit in terms of long-term memory for trainees?

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[7] Krokos, Plaisant, and Varshney, "Virtual Memory Palaces: Immersion Aids Recall." *Virtual Reality*, 2018, 2.

[8] Tuena et al, " Virtual Enactment Effect on Memory in Young and Aged Populations." *Journal of Clinical Medicine*, 2019, 2.

[9] Sankaranarayanan et al. Immersive virtual reality-based training improves response in a simulated operating room fire scenario." *Surgical Endoscopy*, 2018.

[10] Burgess, et al, " The Human Hippocampus and Spatial and Episodic Memory." *Neron*, 2002, 625-641.

Memory and VR

By asking trainees to act, and move in a virtual environment, HASC hopes to activate multiple types of memory cells that will provide deeper, more resilient memories. Head direction cells, place cells, and grid cells have been discovered as a part of memory-making processes. As Eric Krokos states in his article on virtual memory palaces; "along with place cells to help activate memory, grid cells as well play an important part in memory formation, especially with regards to movement direction and speed."[11] HASC expects that 1) the more active a subject is in creating a memory,2) the more place cells, head-direction cells, grid cells, and sensorimotor cells that are used, 3) the more pathways that are activated in creating the memory, the stronger and more resilient the memory will be for the learner.

Multiple trace memory theory is the idea that 1) memories become stronger the more times they are accessed, and 2) the more pathways exist between cells that create the memory, the higher the likelihood that the retrieval of that memory will be successful and the memory be a more exact representation of the actual event. Finding ways to make a stronger, more resilient pathway during memory formation, or forging multiple memory traces via a variety of sensorimotor inputs, is key in creating more long-lasting memories.

HASC's VR Results

HASC rolled out the Fire Watch VR training (course code 19FIREVR) in August of 2020. As of January 2021, over 2,000 learners have used the VR exercises that are a part of the CBT eLearning to reinforce their understanding of the Fire Watch concepts.

To create an experimental and control group to compare VR results against traditional training style results, HASC proctors allowed the learners to "self-select" whether or not they took Fire Watch training with VR exercises (19FIREVR) or the traditional Fire Watch training (19FIRE). The training objectives, the content, knowledge checks, and tests were the exact same between the two courses, the only difference between the lessons was the ability for the learner to take 3D VR exercises integrated into the CBT delivery.

Throughout the experiment, from September 4th to October 12th, 1,237 learners selected the non-VR training, while 440 learners chose the training with VR exercises. This is shown in the Observations row of Table 1.

Table 1 – Immediate Memory Recall Test Scores

t-Test: Two-Sample Assuming Unequal Variances

Test Scores - Immediate Memory Recall	*Non-VR*	*VR*	
Mean	94.08	93.61	
Variance	52.55	46.37	
Observations	1237	440	
Hypothesized Mean Difference	0.00		
df	817.00		
t Stat	1.21		
P(T<=t) one-tail	11.36%		
t Critical one-tail	1.65		
P(T<=t) two-tail	**22.71%**		
t Critical two-tail	1.96		
p-value is greater than 5%	**>5%**	**STATISTICALLY INSIGNIFICANT**	

[11] Krokos, Plaisant, and Varshney, "Virtual Memory Palaces: Immersion Aids Recall." *Virtual Reality*, 2018, 2.

The test scores immediately following the VR and non-VR CBT training were not statistically significant (94.08% vs 93.61%). As a part of this experiment, HASC re-engaged the learners using a chatbot quiz a week after their training to determine if long-term memories were created and how accurate those memories of their training were. This re-engagement was performed via a five-question, text-based, chatbot test delivered directly to the learner's phone seven days after the learner's initial training. 154 non-VR learners followed up completely on the chatbot follow-up, and 53 VR learners followed up completely on the chatbot test as shown in the Observations row of Table 2 below.

Table 2 – Long-Term Memory Recall Test Scores

t-Test: Two-Sample Assuming Unequal Variances

Test Scores - Long-Term Memory Recall	***Non-VR***	***VR***
Mean	69.97	77.83
Variance	575.00	520.68
Observations	154	53
Hypothesized Mean Difference	0.00	
df	94.00	
t Stat	-2.14	
P(T<=t) one-tail	**1.77%**	
t Critical one-tail	1.66	
P(T<=t) two-tail	3.53%	
t Critical two-tail	1.99	
p-value less than 5%	**< 5%**	**STATISTICALLY SIGNIFICANT**

Learners who took non-VR training scored lower on average while learners who took the CBT that incorporated VR exercises scored higher on the five-question chatbot test that was delivered to the learner's phone seven days following the CBT. As the data in Table 2 show, the results of the chatbot test show a statistically significant difference between learners who took the VR exercises and learners who did not (69.97% vs 77.83%).

Additionally, as Chart 1 and 2 show, the scores of VR learners had a higher floor than those learners who did not take the VR training. This could indicate that the opportunity for VR exercises creates a deeper memory in the immediate aftermath of the training, but further research would be necessary to confirm this.

Chart 1 – Box Chart of Non-VR Immediate Memory

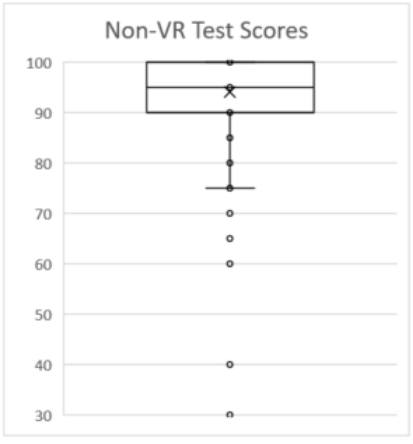
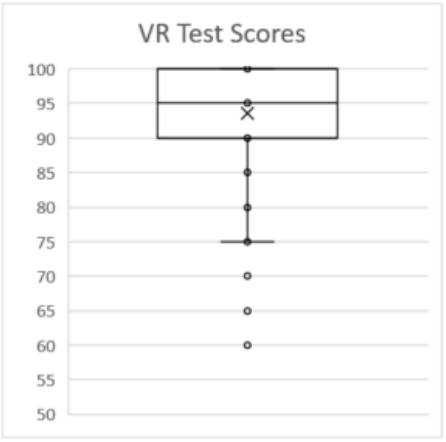


Table 2 – Box Chart of VR Immediate Memory



Conclusion

Currently, HASC's VR training is being used as a reinforcement mechanism as a part of a traditional CBT training deliverable. This is the first of its kind in the nation and the petrochemical and oil refining industry. There is little data from articles reviewed and from the HASC experiment with VR that proves that 3D VR provides significantly greater short-term memory retention than flat 2D training courses that cover the same or similar information. The data from HASC's experiment comparing long-term memory development as measured through the chatbot show that memory retrieval by learners who performed VR exercises with their CBT had greater recall.

As HASC provides training that is designed to be used in the field by employees in field environments, using 3D VR to help ensure long-term memory retrieval makes good financial and training sense. HASC is continuing to collect data on the capabilities of VR in training and is developing a second VR training scenario as well. Further research is necessary to determine the true effectiveness of VR, particularly within the petrochemical and refining industry and HASC looks forward to future analysis along these lines.