Simulation-Based Safety Training for Plant Maintenance in Virtual Reality

Author(s): Kwegyir-Afful, Ebo; Kantola, Jussi

Title: Simulation-Based Safety Training for Plant Maintenance in Virtual Reality

Year: 2021

Version: Accepted manuscript

Please cite the original version:

Kwegyir-Afful, E. & Kantola, J. (2021). Simulation-Based Safety Training for Plant Maintenance in Virtual Reality. In: Cassenti, D. N., Scataglini, S., Rajulu, S. L. & Wright, J. L. (eds.) *Advances in Simulation and Digital Human Modeling: Proceedings of the AHFE 2020 Virtual Conferences on Human Factors and Simulation, and Digital Human Modeling and Applied Optimization, July 16-20, 2020, USA*, 167-173. AHFE 2020. Advances in Intelligent Systems and Computing, vol 1206. Cham: Springer. https://doi.org/10.1007/978-3-030-51064-0_22

Simulation-based Safety Training for Plant Maintenance in Virtual Reality

Ebo Kwegyir-Afful [1,*] and Jussi Kantola[1]

[1] University of Vaasa, Wolffintie 34, 65200, Vaasa, Finland.
Ebo Kwegyir-Afful@uwasa.fi

This paper presents a 3-D simulation model for safety training in an interactive and fully immersive virtual environment (IVE). The training comprises application of serious games (SGs) designed for filter replacements on a gas-powered plant (GPP) engine model by participants based on plant maintenance health and safety environment (HSE) regulations. Although maintenance work on GPP constitutes significantly in the share of hazards in the industry, there is however, scanty research related to simulation-based training for safety. Research nonetheless indicates the success of this technology in other industrial fields. For this reason, this study explored the possibility for training in safe work practices during maintenance in a gamified virtual environment. The Unreal real-time 3D game engine software was employed for creating virtual objects in the simulation. In total, 38 participants individually undertook the training in the virtual realm and provided feedback on a 5-point Likert scale. Questions pursuant to the assessment included the efficacy of acquired safety knowledge and skills, proximity of the simulation-based training to reality, and the interests and preference of SGs-IVE towards safety training. Results demonstrates participant's perception of the prospects and learning outcome of SGs-IVE towards safety training: A factor that promotes greater cognitive learning for mindful safety practices.

Keywords: Serious games · 3-D simulation · Immersive Virtual Environments · Safety training · Safety countermeasures

1 Introduction

The operation and maintenance of power plants are inherently dangerous. Research also indicates that 88% of accidents are due to dangerous practices on the part of individual workers [1]. Some of these dangerous practices occurs during maintenance work. For this reason, realistic and vibrant safety trainings are not only relevant but necessary in ensuring the prevention of accidents and unwanted occurrences [2]. An interactive and immersive virtual environment (IVE) has the potential in simulating imaginary or real situations for training in a safe computerized environment [3].

In recent times, there has been increase in applications of immersive virtual environment based serious games (SGs-IVE) for industrial training. These training sections provide realistic, safe and interesting tasks for learning that are not obtainable otherwise [4&5]. This is due to the gamified and engaging benefit of the combined technology that promotes greater cognitive learning [3&6]. According to pedagogical research, learning in such an environment presents authentic means of knowledge acquisition [4]. Another reason is that the current generation experiences digital environments in computing technologies and devices and are more conversant in their uses. Thus, learning becomes natural when implemented as games [3&7].

High-risk organizations such as mining, construction and nuclear power plants employ simulation-based safety-training models successfully for risk awareness and safety training [5,6&7]. Despite these outcomes, there is little utilization for industrial safety training in some other risky occupational practices [8&9]. Due to the peculiarity of hazards associated to the operations of gas-powered plant (GPP), successes of the effectiveness of SGs-IVE for safety training in some industries does not necessarily guarantee its effectiveness in GPPs. For this reason, the current study constructed a 3-D virtual model of a GPP to experiment the suitability of the technology for safety training. Specifically, the framework integrates SGs-IVE to provide a pedagogical and behavioral experience. The training lasted from August 2018 to October 2019 for safety training in air filter replacements.

This paper therefore seeks answers to the following research questions.
RQ_1: How close to reality can a 3-D GPP simulation be for safety training?
Since simulation-based training sections varies due to the employed software, technology and design, it is necessary to verify whether our training model is realistic and suitable for the purpose.
RQ_2: How effective will learning in SGs-IVE gas-powered plant be?
Answers to this question will determine the success or otherwise of the experiment.
RQ_3: How suitable is the SGs-IVE equipment for safety training in terms of equipment user-friendliness? In order to determine the benefit and preference of the training section, there is the need to experiment whether the equipment and technology employed performed favorably during the training as well as participants' preference for SGs-IVE.

The paper is structured follows to address these questions: The next section describes the background, methodology and empirical framework of the research. Subsequently, explanation of the experiment procedure follows. Thereafter, the results and discussions elaborate the findings. Finally, the study concludes in retrospect with implications of the findings, limitations and suggestions for further research.

2 Background and Framework

Advances in computer technology has improved productivity and profitability for several industrial applications [7&9]. Such technologies can be channeled to boost productivity and prevent unwanted occurrences and accidents during maintenance work [1](9). SGs, virtual reality (VR) and 3D process simulations are among state-of-the-art technologies employed in industry for this purpose [10].

Figure 1 represents the experiment model and procedure that begins with a review of publications related to applications of SGs-IVE for safety training. Our previously described three RQs were expanded to 6 questionnaires for participants. The researchers explained the experiment procedure to all participants and after agreeing, signed the informed consent form. In consistent with health and safety environment (HSE) regulations, participants were informed beforehand to identify, and control hazards and risks present at the workplace. Participants were then immersed individually in the 3-D simulation with the aid of a head mounted display (HMD) and hand held controllers as seen in Figure 3.

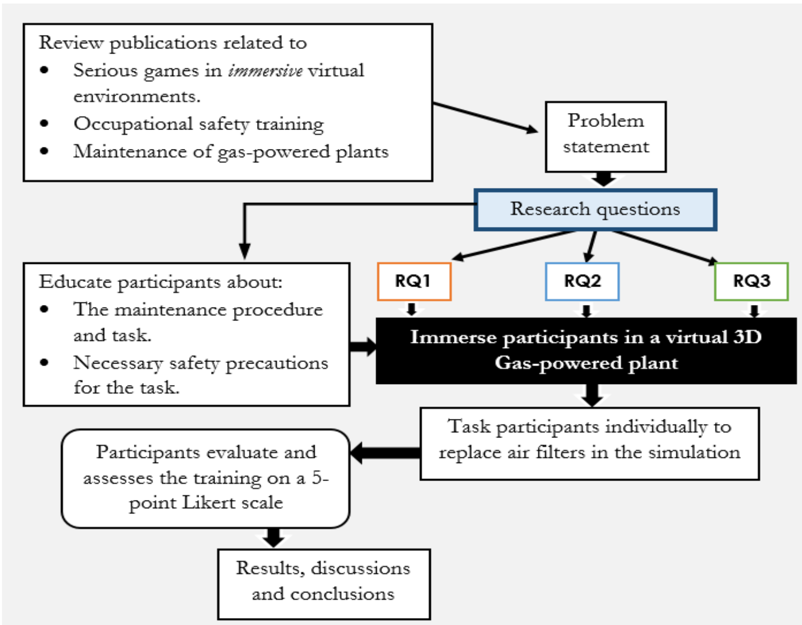

Fig. 1. The experiment conceptual model

Criteria for the choice of participants was a basic level of safety training and industrial work experience. Most students and workers contacted already had this safety card as well as industrial exposure as summer workers and were thus suitable for the experiment. Another criterion was that each participant needed to be conversant with the English language in order to understand the survey instructions and to answer the questionnaire correctly. After performing the task for the training in the virtual realm, participants then answered the 6 questions framed on a 5-point Likert scale from strongly disagree to strongly agree. The combined results of these assessments are synthesized in response to the 3 research questions in Figures 5, 6 and 7.

2.1 Experiment procedure

The entire training for each participant lasted about an hour. The exercises were performed with the aid of on-screen instructions as in Figure 2. Figure 3 shows a participant under training. Details of the task included removing the filter cover, installing new filters and replacing the filter cover after the exercise.

Fig. 2. Task completion

Fig. 3. A participant under training

3 Results

Figure 4 presents the combined response of participants to the six questions in the questionnaire numbered A to F.

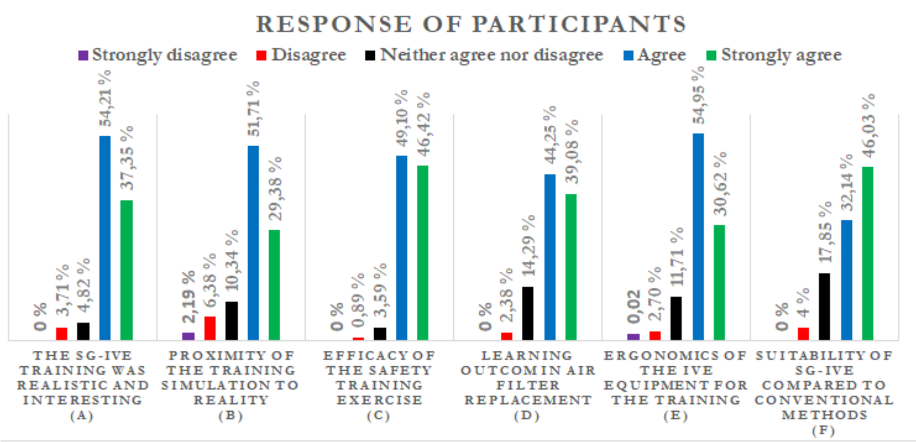

Fig. 4. Coordinated response of participants to the questionnaire

3.1 Mapping answers to research questions

Coordinated results of all participants were synchronized to answer the initial research questions. The first research question **RQ1** regarding the proximity of the safety training in the simulation to reality, responses **A** and **B** in figure 4 were mapped to RQ1 and Figure 5 presents the result.

A. The SGs-IVE training was realistic and interesting.

B. The simulation of the power plant engine / environment was close to a real plant.

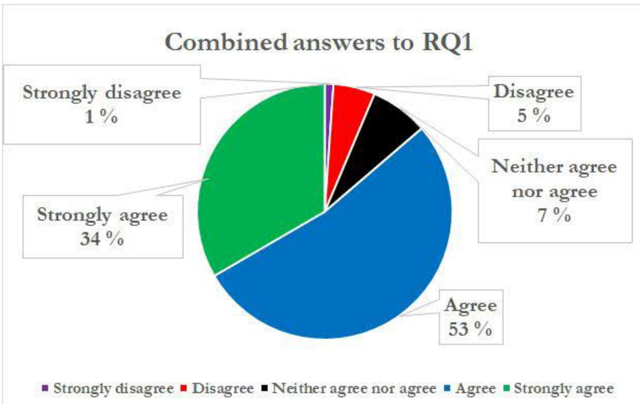

Fig. 5. Combined answers to the first research question (RQ1)

The second research question RQ2 regarding the effectiveness of learning, questionnaires **C** and **D** in Figure 4 covered RQ2. Figure 6 presents the specific result.

C. The SGs-IVE technology offered me an effective way of learning to work safely.

D. The training has granted me knowledge of safety procedures in GPP maintenance.

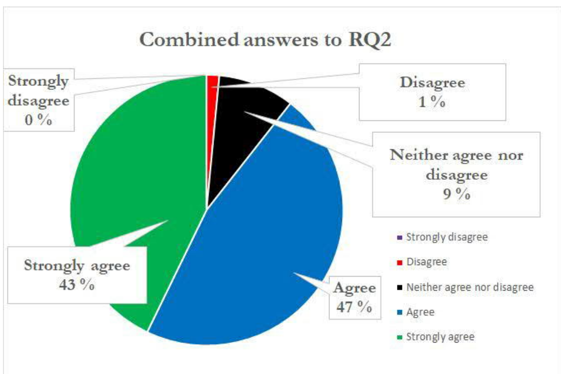

Fig. 6. Combined answers to the second research question (RQ2)

In answer to the third research question RQ3 pertaining to the user-friendliness and suitability of equipment for safety training, response to questionnaires **E** and **F** in Figure 4 were mapped to RQ3 and Figure 7 presents the result.
E. The training equipment and technology were suitable for the training.
F. SG-IVEs are more suitable for training compared to conventional methods.

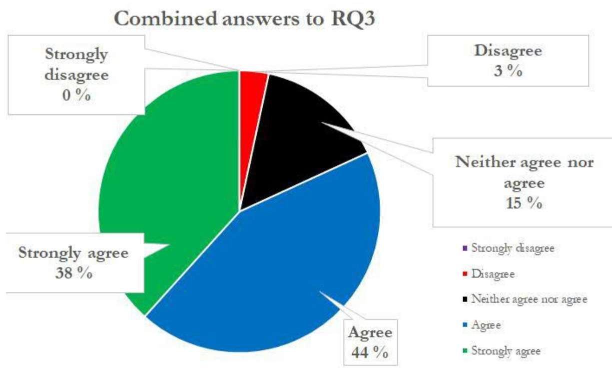

Fig. 7. Combined answers to the third research question (RQ3)

4 Discussions of results

Results of Figure 4 demonstrates that most participants answered in agreement to the six questions asked. This indicates a general positive outcome to the experiment. Besides, Figure 5 shows 53% in *agreement* and 34% *strongly in agreement* to the proximity of the plant simulation to reality, which answers RQ1 and consistent with literature on the subject [9&11]. Only 5% *disagreed* and 7% *neither agreeing nor disagreeing* to the closeness of the simulation to a real plant. Figure 6 has 43% *strongly in agreement* and 47% *agreeing* to the effectiveness of learning through the SGs-IVE technology. Only 1% *disagreed* and none *strongly disagreed*. This indicates that learning through SGs-IVE in the 3-D GPP is truly effective. Regarding the suitability of the technology in terms of user-friendliness and preference for this training, results in Figure 7 shows that 38% of participants *strongly agreed* and 44% *agreed* to this question. Only 15% *sat on the fence* and 1% disagreed.

5 Conclusion

This paper pragmatically utilizes serious games in an immersive 3-D gas-powered plant engine simulation. The purpose was to analyze the prospects of the technology for improving learning during safety training. Participant's combined results demonstrates that indeed the application of 3-D simulation-based technology has enormous potential in optimizing safety training. Besides the technology being suitable for training in a gas-powered plant model, results also indicated preference for simulation-based safety training to conventional methods. Likewise, it was realized that learning during the training was authentic and interesting. This is consistent to results of the successes of SGs-IVE employed in some high-risk industries such as mining, construction and aviation [6&11]. That the entire exercise was worth the time spent for the training.

Despite these promising results, the research is however limited to filter replacements on GPP engines and cannot be generalized to other maintenance tasks on GPPs engines or to filter replacement on other heavy-duty engines.

Future research targets expanding the study to cover more safety countermeasures in other 3-D plants and factory simulations.

References

1. U. Kjellen and E. Albrechtsen, Prevention of Accidents and Unwanted Occurrences: Theory, Methods, and Tools in Safety Management, T. &. F. Group, Ed., CRC Press, 2017.
2. Q.-q. Wang and X.-d. Yan , "Risk Analysis and Control Measure of Gas Power Generation Enterprise," International Journal of Science and Qualitative Analysis, vol. 3, no. 2, pp. 15-22, 2017.
3. B. Dubbels, "Gamification, serious games, ludic simulation, and other contentious categories." International Journal of Gaming and Computer-Mediated Simulations (IJGCMS), pp. 1-19, 2013.
4. H. M. Lau, J. M. Smit, T. M. Fleming and H. Riper, "Serious games for mental health: are they accessible, feasible, and effective? A systematic review and meta-analysis.," Frontiers in psychiatry, vol. 7, p. 209, 2017.
5. D. Bechtold, D. L. Hoffman, A. Brodersen and K.-H. Tung, "Assurance of Learning and Knowledge Retention: Do AOL Practices Measure Long-Term Knowledge Retention or Short-term Memory Recall?," Journal of Higher Education Theory and Practice, vol. 18, no. 6, 2018.
6. E. Kwegyir-Afful , M. Lindholm , S. Tilabi, S. Tajudeen and J. Kantola , "Optimizing Occupational Safety Through 3-D Simulation and Immersive Virtual Reality. In: Cassenti D. (eds).," in Advances in Human Factors and Simulation pp 97-107. Advances in Intelligent Systems and Computing, Cham.
7. A. A. Yuen, S. H. Choi and X. B. Yang, "A full-immersive CAVE-based VR simulation system of forklift truck operations for safety training," Computer-Aided Design and Applications, vol. 7, no. 2, pp. 235-245, 2010.
8. E. Kwegyir-Afful, E. Kwegyir-Afful, R. Addo Tenkorang and J. Kantola, "Effects of Occupational Health and Safety Assessment Series (OHSAS) Standard: A study on Core Competencies Building and Organizational Learning.," in Advances in Human Factors, Business Management and Leadership AHFE2017, vol. 594, Cham, Switzerland, Springer International Publishing AG 2018, 2017, pp. 395-4057.
9. S. Choi, K. Jung and S. D. Noh, "Virtual reality applications in manufacturing industries: Past research, present findings, and future directions," Concurrent Engineering, vol. 23, no. 1, pp. 40-63, 2015.
10. J. Bailenson, "Virtual Reality Training Solutions," Virtual Reality Development - Projects - Custom Cardboard Headset, Australia, 2019.
11. L. Berg and J. M. Vance, "Industry use of virtual reality in product design and manufacturing: a survey." Virtual reality, vol. 21, no. 1, pp. 1-17, 2017.