PRELIMINARY INVESTIGATION OF A CFD-ASSISTED VIRTUAL REALITY EXPERIENCE IN ENGINEERING EDUCATION

S. Solmaz [1]
Department of Chemical Engineering, KU Leuven
Leuven, Belgium
ORCID: 0000-0001-5431-4038

L. Kester
Department of Education, Utrecht University
Utrecht, The Netherlands
ORCID: 0000-0003-0482-0391

T. Van Gerven
Department of Chemical Engineering, KU Leuven
Leuven, Belgium
ORCID: 0000-0003-2051-5696

Conference Key Areas: *Physics and Engineering Education;Virtual and Remote Labs*
Keywords: *immersive learning, virtual reality, computational fluid dynamics, instructional design, engineering education*

ABSTRACT

Virtual reality has become a significant asset to diversify tools in the support of engineering education and training. The cognitive and behavioral advantages of virtual reality (VR) can help lecturers reduce entry barriers to concepts that students struggle with. Computational fluid dynamics (CFD) simulations are imperative tools intensively utilized in the design and analysis of chemical engineering problems. Although CFD simulation tools can be directly applied in engineering education, they bring several challenges in the implementation and operation for both students and lecturers. In this study, to tackle these challenges, we developed the "Virtual Garage" as a task-centered educational VR application with CFD simulations. The Virtual Garage is composed of a holistic immersive experience to educate students through a real-life engineering problem solved with CFD simulation data using a VR headset. The prototype is tested by graduate students (n=24). Participants assessed usability, user experience, task load and cybersickness via standard questionnaires together with self-reported questions and a semi-structured interview. Preliminary results reflect that the Virtual Garage is well-received by participants. We identify features that can further enhance the usability and user experience.

[1] *Corresponding Author*

S. Solmaz

serkan.solmaz@kuleuven.be

doi:10.5821/conference-9788412322262.1317

1 INTRODUCTION

Computational fluid dynamics (CFD) simulations are heavily applied in engineering design and analysis to solve engineering problems in a time cost effective fashion. Educational use of CFD simulations may be challenging due to expert-centric user experience in conventional simulation environments, which requires complex skills to perform CFD simulations and interpret obtained results to make justifiable decisions. Learning in conventional simulation environments often happens by learning-by-doing on 2D desktop settings. Such environments do not comprise any assistance except help options relevant to the usability of the tool. These conventional simulation environments have been criticized by educational scientists and were found less efficient than that of traditional instructional designs [1].

Utilization of virtual reality in support of immersive learning has been a hot topic in engineering education. Immersive virtual reality learning environments may reduce the entry barrier to complex learning subjects including CFD simulations. These environments can positively trigger cognitive skills with advanced interactions and easy-to-access technical content, as well as behavioral aspects of learning such as attracting and motivating students. This might open gates for user-friendly, high-quality complex learning environments assisted with CFD simulations. Many researchers have investigated the integration and implementation of CFD simulation data in virtual reality, especially for visualization purposes [2]. However, no study has been found in the literature implementing an immersive complex learning method with CFD simulations in a digital environment.

In this paper, we present the VR application “Virtual Garage”, as an immersive complex learning environment, composed of a holistic interactive experience to educate students through real-life engineering problems solved with CFD simulation data using a VR headset. Our fundamental objective is to develop an immersive learning environment and investigate its effect on cognitive and behavioral aspects. First, we should ensure a proper virtual reality experience to accomplish this. Therefore, as a preliminary investigation, we assessed usability, user experience, task load and cybersickness in the Virtual Garage based on available standard tests.

2 METHODOLOGY

2.1 Design of complex learning environment

A task-centered educational experience is adapted to design an immersive complex learning environment with the four-component instructional design (4C/ID) model. Among many interesting instructional design methodologies, the 4C/ID model has become a prominent tool to support complex learning environments in numerous disciplines [3]. The model presents four major components to enable complex learning; learning tasks, supportive information, just-in-time information and part-task practice. The learning environment in the Virtual Garage is fundamentally structured by applying the 4C/ID components together with various instructional design principles highlighted by the design tool. A sequential principle is set for the learning task to increase complexity in the learning environment gradually. Multimedia and signaling principles are mainly implemented in the supportive and just-in-time information, respectively. As a part-task practice, a pre-training module is developed to teach interactions in VR and let users explore the learning environment and routine aspects of usability in VR. The entire VR experience is divided into two subsequent sections, Module1 and Module2, as shown in Fig. 1. Module1 is composed of pre-training and theory sections. Module2 is the assignment with CFD simulations to solve problems introduced in the theory. Both sections take approximately 20 min to complete. Users are strongly advised to take a 5 min break between modules by taking the VR goggles off, thereby alleviating cybersickness.

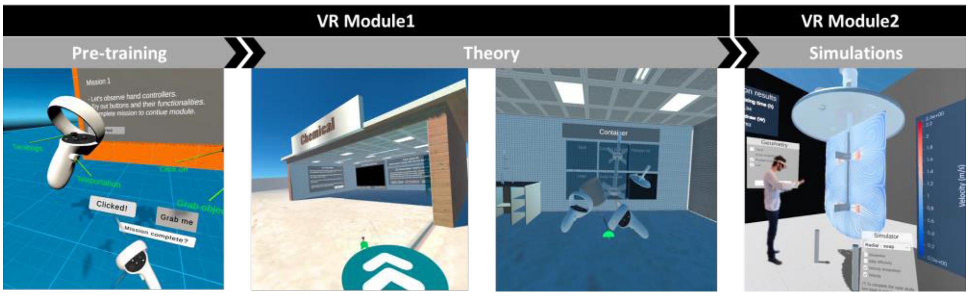

Fig. 1. Scenes in the Virtual Garage; Module1 and Module2

2.2 Software and hardware

To develop the Virtual Garage, we utilized the Unity game engine. CFD simulations were calculated in a workstation with COMSOL v5.6, and integrated into Unity using an extract-based data processing approach [4]. The VR experience was developed for Meta Quest 2 VR goggles.

2.3 Data collection

Usability, user experience, task load and cybersickness were assessed by participants. Questionnaires were repeated after each module. Participants additionally filled out other questionnaires to provide sociodemographic information, experience, and self-reported questions on content. Additionally, a semi-structured oral interview was carried out at the end of the session to point out positive and negative aspects of the Virtual Garage.

3 RESULTS

Experiments were conducted at the department of chemical engineering at KU Leuven with 24 participants from the graduate school. All participants completed the entire test without any issues. Prior to the study, ethical approval was obtained from the ethics committee at KU Leuven. National and regional safety measures with regard to COVID-19 were strictly applied during the experiments such as proper ventilation of the testing environment, disinfection of equipment and social distancing.

Preliminary results on the usability with the system usability scale (SUS) are shown in Fig. 2. Both Module1 and Module2 were well received by users resulting in mean scores of 74.37 and 73.85, respectively. A SUS score above 68 is considered good [5]. More interestingly, it appeared that participants scored differently between Module1 and Module2. Statistical analysis should be performed to clarify the reasoning behind participants' preferences to identify differences in these patterns, for example, experience with simulation content. For the time being, our data processing is still work-in-progress. Future work will focus on data processing to comprehend more participants' behavior. Fig. 3 shows overall scores measured with the NASA Task Load Index (NASA-TLX) test to assess the workload in the modules. Results showed that participants overall found Module2 more demanding than Module1. Only physical demand was lower in Module2, which can be explained by the simplistic design of the simulation environment in Module2. In Module1, users move inside the VR environment to consume supporting information that could be used while solving the problem in Module2 with simulation data.

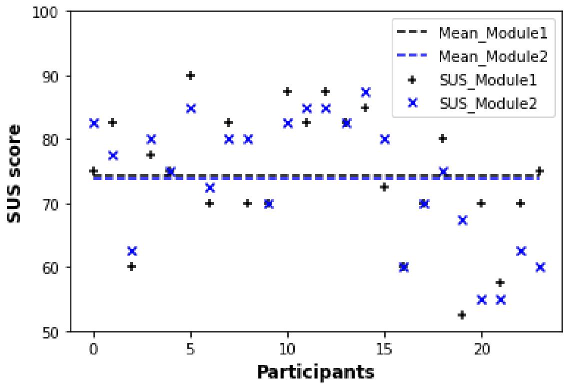

Fig. 2. SUS score

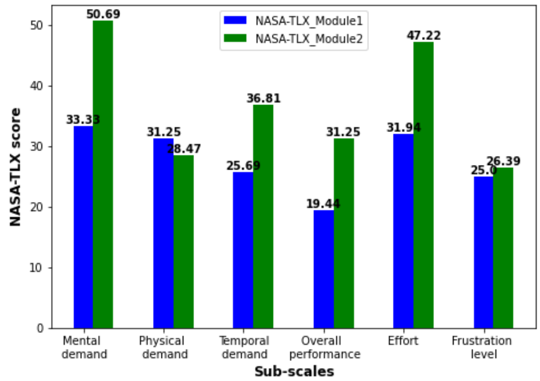

Fig. 3. NASA-TLX score

Meanwhile, Table 1 presents simulator sickness questionnaire (SSQ) scores for different subscales and total simulator sickness. Participants successfully completed the VR experience and didn't verbally report any sicknesses. Participants scored 23.53 for Module1 and 11.53 for Module2. Digital environments with an SSQ score below 40 are assumed to be safe in terms of cybersickness [6].

Table 1. SSQ scores in VR modules

SSQ	Total simulator sickness
Module1	23.53
Module2	11.53

4 SUMMARY AND ACKNOWLEDGMENTS

Our preliminary analysis has shown promising results regarding the development of an immersive complex learning environment with CFD simulations. Data processing is currently underway and more will be reported about the assessment from this set of experiments. Future work will focus on improvements in the prototype and assessments of knowledge gain, task performance and technology acceptance.

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement 812716. This publication reflects only the authors' view exempting the community from any liability. Project website: https://charming-etn.eu/.

REFERENCES

[1] Kirschner, P., Sweller, J. and Clark, R.E., 2006. Why unguided learning does not work: An analysis of the failure of discovery learning, problem-based learning, experiential learning and inquiry-based learning. Educational Psychologist, 41(2), pp.75-86. https://doi.org/10.1207/s15326985ep4102_1

[2] Li, W., Nee, A.Y. and Ong, S.K., 2017. A state-of-the-art review of augmented reality in engineering analysis and simulation. Multimodal Technologies and Interaction, 1(3), p.17. https://doi.org/10.3390/mti1030017

[3] Van Merriënboer, J.J. and Kester, L., 2014. The four-component instructional design model: Multimedia principles in environments for complex learning. Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.007

[4] Solmaz, S. and Van Gerven, T., 2021. Automated integration of extract-based CFD results with AR/VR in engineering education for practitioners. Multimedia Tools and Applications, pp.1-23. https://doi.org/10.1007/s11042-021-10621-9

[5] Lewis, J.R. and Sauro, J., 2018. Item benchmarks for the system usability scale. Journal of Usability Studies, 13(3).

[6] Caserman, P., Garcia-Agundez, A., Gámez Zerban, A. and Göbel, S., 2021. Cybersickness in current-generation virtual reality head-mounted displays: systematic review and outlook. Virtual Reality, 25(4), pp.1153-1170. https://doi.org/10.1007/s10055-021-00513-6