Using a Virtual Reality Tool for Experimental Learning in Engineering. A Survey of Learner Preferences

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***Abstract*— Engineering laboratories are designed to provide 'real' hands-on experience to the students. However, building laboratories that are suitable to serve a large student population is challenging due to the limited resources. We propose that unsupervised laboratory activities be conducted with virtual reality (VR) tools to support existing laboratories infrastructure or aid lecture delivery with VR experiments. The VR based laboratory permits students to interact virtually with the equipment and connect theoretical concepts with virtual experiments. We have designed a sample of undergrad VR laboratory lessons for students in engineering programs at the University of Glasgow Singapore and the Singapore Institute of Technology (SIT). In this paper, our study aims to obtain student feedback through structured questionnaires to identify what characteristics of the VR technology implementation enhance student engagement in an engineering laboratory provision. We present findings from the questionnaire on the learners' preferences. In particular, our findings identify that although the VR tool's characteristics are engaging, students find the implementation a cumbersome process to access VR lessons. Finally, we provide some recommendations for future implementations.**

Keywords — Virtual Reality, Engineering Education, Kolb's learning cycle.

I. Introduction

Virtual Reality (VR) and Augmented Reality (AR) have been incorporated in laboratory instructions of several fields to enable remote laboratories, such as robotics [1], biomedical engineering [2] and earth science education to enable field experiences [3]. Some of the benefits in teaching and education reported in The National Science Foundation [4] are: supporting spatial awareness and cognition in a three-dimensional world, developing observational skills in real world settings, enabling inquiry and exploration in a field setting, providing every student a first-person experience. Our motivation for incorporating the VR is to enhance the first-person experience of engineering laboratories. It has been pointed out that VR and AR technology can be used to facilitate experimental learning tasks. Moreover, it could enable learning that would be impractical or impossible to undertake in the real world, e.g., molecular bonding [5].

Our main motivation for incorporating VR is to provide the students with more time to familiarize themselves with the engineering laboratories. The VR lesson provides an online copy of the equipment that can be accessed at the students' own time, whereas the physical equipment might only be available for a limited number of timetabled hours. A recent study on the VR market identified that the majority of apps seek to enhance theoretical knowledge rather than procedural-practical skills [6]. This highlights a gap between student needs, research and market-available VR software. More work should provide guidance and best practices on how to implement the VR-based application of theory to real-world problems. Although many existing VR studies emphasize the learning mode of concrete experience, experiential learning is not only about concrete experience.

Our pedagogy approach to incorporating VR in our lessons is based on the Kolb (1984) Learning Cycle [7] in Fig.1. Kolb proposes that experimental learning is based on the understanding that students constantly refine learning that is formed and re-formed through experiences, or learning is a continuous process.

In this study, the VR lessons were designed to make use of two phases of Kolb's learning cycle – Concrete Experience (CE) and Active Experimentation (AE). The virtual experience and experimentation with the VR implementation render these two phases. The learning activities encourage students to learn by doing ("have a go" learners). The VR lesson can reference some Reflective Observation (RO) and Abstract Conceptualisation (AC) from enforcing to the theory or concepts covered in traditional classes.

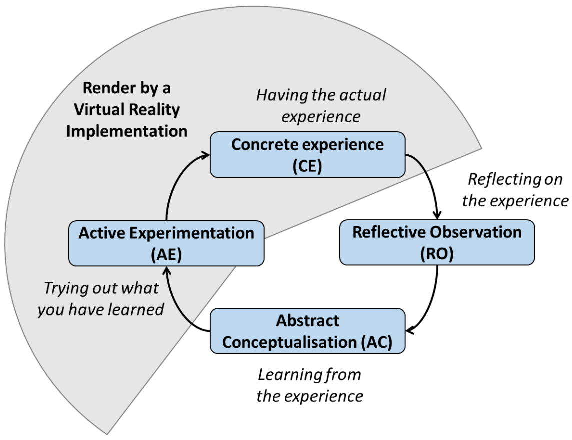

Fig. 1. Virtual Reality implementation in the Kolb's learning cycle.

A research question asked by Fromm et al. [8] was how educational VR applications can be designed to afford the four experiential learning modes (i.e., concrete experience, reflective observation, abstract conceptualization, active experimentation). It was found that participants had difficulties imagining design elements that truly exploit the unique strengths of VR. For example, they suggested to afford abstract conceptualization by implementing pop-up windows with textual explanations [8]. However, another concern raised was that this might not provide any added value. Thus, it is not clear if there might be learning or assessment components that should be designed into the VR lesson that provides added value to the students' learning. As such, one major aim of this paper is to evaluate the students' experience, level of satisfaction with the VR lessons, as well as the learning components that they felt were useful to their learning. In addition, the authors also compare the student experience of using VR-based learning to simple video-based learning.

Our intent is to show that the virtual environment provides hands-on experience and, consequently, the balance between theory and practice can be achieved in teaching. One way to develop material is to design the VR lesson by considering several short hands-on learning activities to link to the theory. Like traditional laboratory manuals, which are designed to scaffold learning tasks by dividing them into smaller hands-on subtasks. The VR lessons shouldn't be isolated and formal laboratory lessons should follow them. The students are expected to feel more confident conducting the practical tasks after going through VR sessions. In particular, a first virtual experience focused on the equipment itself is essential to get familiarity with the components of the system. The VR lessons are expected to provide more time to experiment with engineering systems. The advantage is that the student can work independently and is not limited by fixed-time session. However, the challenge is that the VR lesson will not be supervised, although the students are provided with instantaneous feedback from the VR lessons and have access to discussion forums and consultations with the lecturer.

The rest of the paper is organized as follows. Section II provides the methodology of the proposed work, Section III details the results followed by Section IV which concludes the paper.

II. Methodology

A. Virtual Reality Tool and Setup

We developed lessons using the EON-XR tool[1] for AR and VR. 2nd Year Mechanical Engineering students from the Dynamics and Mechatronics Design modules and 2nd Year Aerospace Engineering students from the Aerospace Control module were invited to experience the lessons.

EON-XR is a mixed reality app equipped with functionality that enables educators to create lessons without programming experience.

A survey was designed to evaluate students' perception of the VR lessons and identify the tool's characteristics that the student found engaging. In the following subsections, the VR lessons are presented.

B. VR lesson: Learn To Describe Shock Absorbers System Functions

The first lesson is related to the Dynamics module, and the learning activity is designed to instruct students to identify the spring and damper components within a shock absorber system, see Fig. 2, and to link the mechanical component with its mathematical model. The learning outcomes were set as follows: On completion of this lab, the student are be able to:

- Identify the components of the system,
- Describe the function and define the mathematical model of the: Spring, Damper

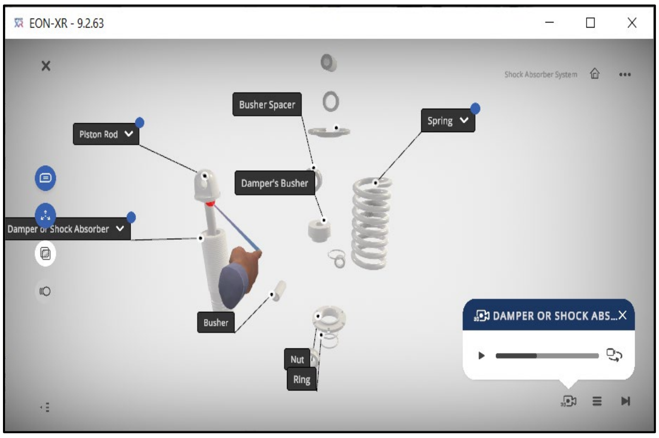

Fig. 2. VR lab lesson of a shock absorber system (https://share.eon-xr.com/lesson/469/229198).

C. VR lesson: Experience the 2DOF helicopter control system

The second lesson is related to the Aerospace Control Lab. The learning activity is designed as a pre-lab activity to instruct students to identify the components of the 2 Degrees of Freedom (2DOF) helicopter control system, see Fig. 3, and its possible system configurations. The learning outcomes were set as follows: On completion of this lab, the students are able to identify the components of the system configurations as follows:

- Describe the pitch and the yaw axes
- Describe the experiment implementation.

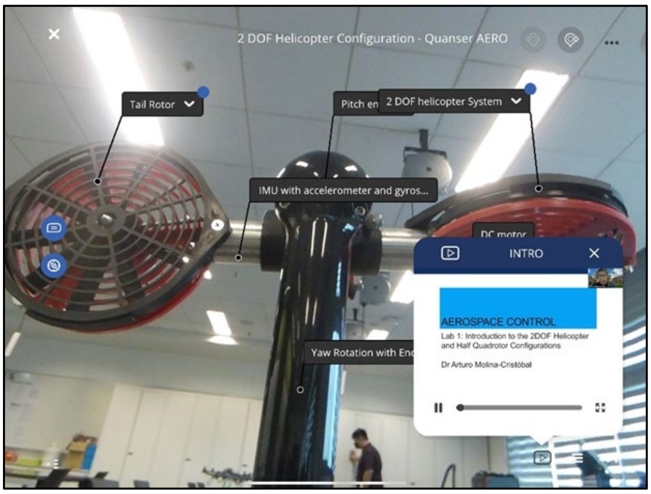

Fig. 3. VR lab lesson of a 2DOF helicopter control system (https://share.eon-xr.com/lesson/469/228966)

D. VR lesson: Introducing an industrial robot

A lesson on introducing the industrial robot to mechanical engineering students was created as we can see its wide application in manufacturing industries. Typical applications

[1] https://eonreality.com/

such as welding, painting, assembly, disassembly, picking and place kind of activities this kind of robots can do, see Fig. 4. As a result, the students can program this robot for a given application.

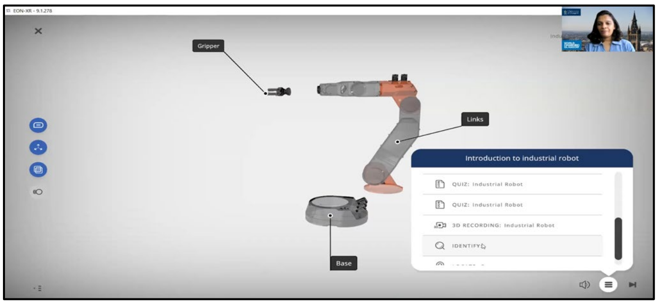

Fig. 4. VR lab lesson of a 2DOF helicopter control system (https://share.eon-xr.com/lesson/469/230456)

Each VR lesson contained the following short learning activities:

- An introduction
- a 3D recording describing the components
- quizzes
- an activity to identify components.

As part of the general functionalities, the students are able to explore the CAD models by navigating around the system or separating them into components.

E. *Questionnaire survey*

The questionnaire survey was conducted using Microsoft Forms and restricted to students from our program. The students were invited to participate in the survey anonymously. All students participants were in the second trimester of their first year. Forty students responded, and the results are reported in the next section.

III. Results

Fig 5 shows the responses to question Q1, "Overall, how satisfied are you with the experience of learning through VR?" The overwhelming majority were very or somewhat satisfied.

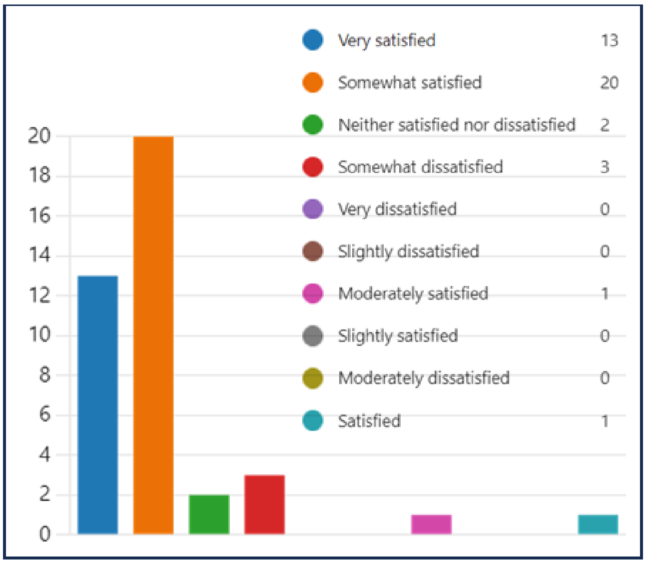

Fig. 5. Response to Q1: Overall, how satisfied are you with the experience of learning through VR?

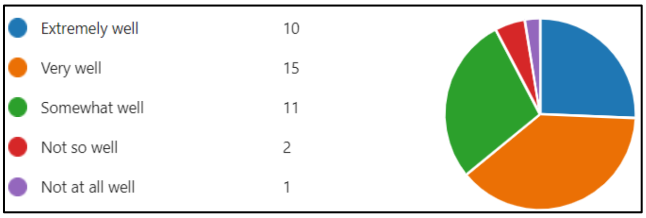

Fig. 6. Response to Q2: How much does the experience meet your expectations from a VR-based session?

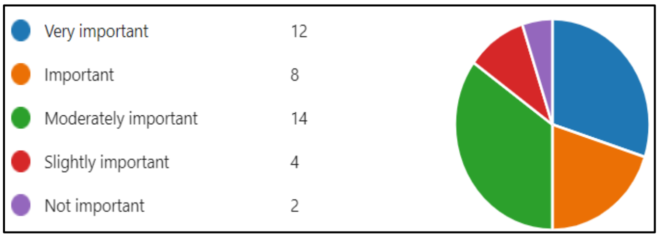

Fig. 7. Response to Q3: How much importance do you feel for VR-based learning in your courses?

Fig. 6 shows that 26% and 38% of the students found that experience met their expectations extremely well and very well, respectively. Fig. 7 shows that 30% and 20% of students found that the VR-based learning very important and important in their courses, respectively. In Fig. 8, 38% of the students found the value of VR-based learning above average.

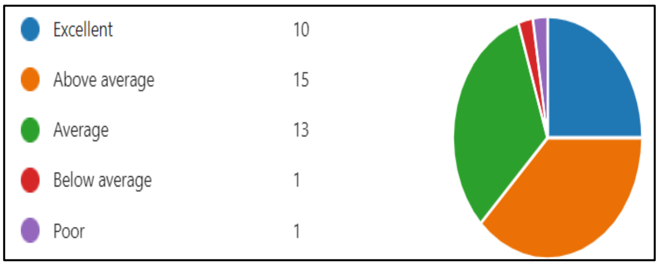

Fig. 8. Response to Q4: How would you rate the value for time spent participating in the VR session?

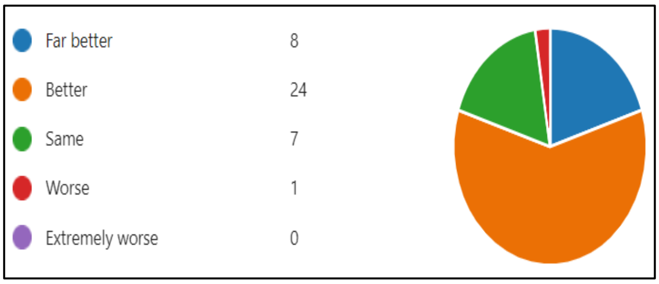

Fig. 9. Response to Q5: How would you rate your learning from the VR compared to the simple video-based learning?

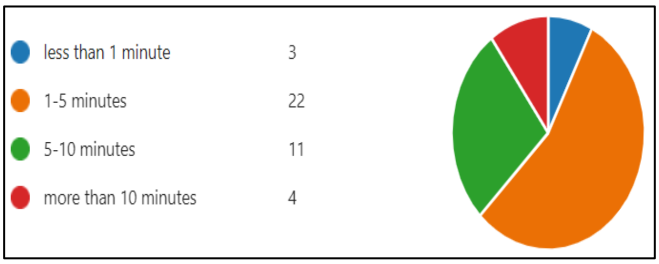

Fig. 10. Response to Q6: How long did it take you to set up the VR session?

Fig 9 shows that 60% of the students found VR better than simple video-based learning, and Fig. 10 shows that students took about 5 minutes to complete the VR session.

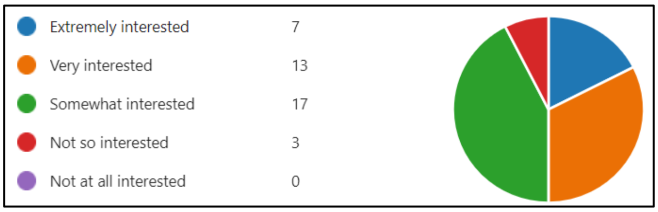

Fig. 11. Response to Q7: How much interested are you to participate in further VR-based learning?

Fig. 12. Response to Q8: How likely are you to recommend to a friend to participate in VR-based learning session?

Fig 11 and 12 shows that the students were interested in participating in further VR-based learning and majority of them were somewhat likely to recommend to a friend to participate in a VR-based learning session.

In Fig. Questions 13 and 14, it can be appreciated that the students preferred the following components: Instructional video, identifying features, Voiceover with 3D playback, and locating parts. Quizzes and PDF material were the least desired elements in the tool. It must be noted that PDF provides 2D visual and clearly students liked the 3D components more than 2D elements.

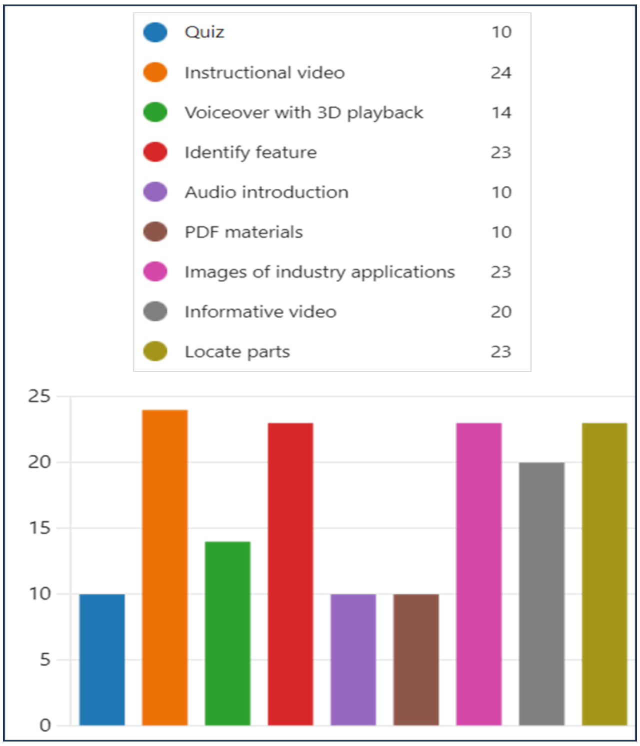

Fig. 13. Response to Q9: What components of the VR lesson would you like more of?

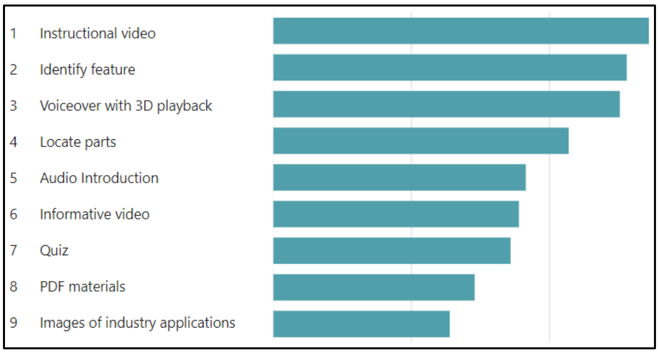

Fig. 14. Response to Q10: How would you rank the importance of the components of the VR lesson?

In the following question, Q11, students were asked about the challenges they found when using the tool. 32 of 40 students reported challenges such as "cumbersome process to access VR lesson", "Didn't really know how to proceed at first", "it took quite a while to load".

In questions Q12 and Q13, the students were asked to report what they liked the best and disliked respectively in the session. The responses included that the session "was innovative", "interactive and futuristic", "Able to identify parts of the system without physically seeing the system, "able to observe instead of theory based", and "being able to interact with components". About 5% of the students found the VR session unnecessary, and one preferred the use of presentation slides to learn.

Finally, in question Q14, the students were asked what improvements they wanted to see in VR-based experience. It was noted that the students would like more interactive elements, more descriptive parts, and additional points of view of the product. Others were related to speed and video performance.

IV. Discussion and Conclusion

A. Discussion

From the questionnaire, it is clear that most students found the VR lessons engaging, and they were satisfied with the experience. It is also important to note that the students took about 5 minutes to complete a VR lesson. Students highly appreciate the interactive parts of the VR experience and innovation. We integrated traditional videos and PDF material, but the students commented that this material was unnecessary.

The students also reported some performance issues with devices; about 50% initially found the process difficult to follow. The instructors assumed that the tool was intuitive and self-explanatory. However, from the comments, it is clear that instructors should explain how to use the app and conduct the VR lesson in full detail, which will be considered in the future.

Although quizzes are not highly ranked, we noted that the students attempted the quizzes and connected the VR lab experiments with theory, which suggests they exercise the cognitive processes of Reflective Observation and Abstract Conceptualization of Kolb's learning cycle. The students enjoyed the interactivity with the system; they identified parts of the system, which indicates that the students went through the two phases of active virtual Experimentation and virtual Concrete Experience and completed Kolb's learning cycle.

B. Conclusions

The survey of learner preferences for the VR tool shows that it enables experimental learning. Students can complete Kolb's learning cycle by rendering a virtual version of the Active Experimentation and Concrete Experience. The respondents have rated their satisfaction levels with the VR experience and ranked the importance of the different components in the VR lessons. It is noted that Reflective Observation and Abstract Conceptualization are demonstrated through the quizzes, although they are not highly ranked by the students, in terms of importance. Thus, more work could be done to study the format and content of the quizzes. Future work also includes further analysis of the cognitive processes, i.e., evaluate how the learning outcomes are achieved through the learning and assessment components. Another avenue is to focus on enabling more interactivity in the VR tool.

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