REFLECTIONS ON PRACTICE

Using Augmented Reality (AR) and Virtual Reality (VR) to Promote Active And Long-Term Engineering Education

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Recommended Citation:

Christabelle, M. R., & Musib, M. (2021). Using augmented reality (AR) and virtual reality (VR) to promote active and long-term engineering education. *Asian Journal of the Scholarship of Teaching and Learning, 11*(2). 110-120.

ABSTRACT

This study explores the usage of appropriately curated and customised Augmented-Virtual Reality (AVR) infused educational tools to deliver immersive and experiential learning environments to promote active and long-term learning to biomedical engineering (BME) students in a relevant BME module that dealt in the design of medical devices. Such courses are traditionally delivered through lab sessions and are often limited by scheduling, resources, and manpower constraints. Researchers have found that AVR-infused tools may solve those shortcomings and effectively deliver active learning. Both AR and VR were used to explain a fundamental concept pertaining to a medical device and its relevant attributes during a lecture, after which students completed a lecturer-developed feedback questionnaire. Quantitative and qualitative data were collected and analysed. AVR was shown to improve student engagement, learning motivation, learning effectivity, promote long-term and lifelong learning, and thus this study supports the use of AVR in teaching biomedical engineering. In the future, better systems may be developed, especially to further enhance immersiveness, embodied interactions, and intuitiveness.

Keywords: Augmented reality (AR), virtual reality (VR), engineering education, active learning, novel pedagogy, biomedical engineering, long-term learning

INTRODUCTION

Technology has continuously evolved and reshaped education over the years (Bates, 2015). With the ongoing and gradual evolution of relevant technologies to enhance technology-enhanced learning (TEL) strategies in order to promote long-term and active learning, there has been much interest in using augmented reality (AR) and virtual reality (VR) in education and pedagogy, particularly to explain complex concepts, where traditional lectures are not enough. As theorised by Edgar Gale (Masters, 2019), people learn better by teaching others and immediately putting what they learnt into practice. Studies have explored using student-centric active learning in various subjects and disciplines, including medicine (Bucklin et al., 2021; Wilcox et al., 2018), sciences (Ballen et al., 2017), and engineering (Prince, 2004; Christie & de Graaff, 2016). However, its use in biomedical engineering (BME) has been limited, although a few studies have shown its potential to foster technological knowledge (Singh et al., 2018; Singh, 2017) and enhance problem identification as well as solution ideation skills (Siewerdsen et al., 2020).

Current usage of AVR in education

A study by Singh et al. (2020) analysed the use of VR in teaching communication skills between biomedical engineers and other healthcare providers in a clinical setting. They compared VR to traditional videos, and the results show much support towards using VR in BME education. All the students (100%) found VR to be more immersive, and 66% indicated that they preferred the usage of VR in teaching and assessing communication skills.

Furthermore, all the participants (100%) strongly recommended VR in other courses as they found VR to be safer and also allowed them to be better prepared for actual clinical sessions compared to in-person training. For in-person training, students only participated in one single lab session and were unable to rewatch what they have learnt. This is a problem faced by most universities in which resources are lacking with regards to time, location, and manpower for lab and clinical sessions. VR may act as a solution to address such resource constraints, as agreed by the majority of students (60%) in Singh et al. (2020)'s study.

Research on the use of AVR that is specific to BME education is still lacking. As such, this literature search refers to findings from research on using AVR in teaching other engineering, science, and medicine subjects.

For one, the end-product of BME research, such as screening devices and implants, all have to interact with the human body, be it directly or indirectly. As such, an understanding of the human anatomy, as well as its mechanics and physiology is a pivotal part of BME education. Similarly, these subjects also constitute the core curriculum for medicine and nursing students. For these complex subjects, visualisation is a key factor that would affect learning outcomes (Chen, et al., 2020). Previous studies have shown how AVR was used as a visualisation tool in teaching human anatomy and physiology to medicine and nursing students, both with satisfactory student feedback. In Chen et al. (2020)'s study, students who used VR received higher scores in the assessment following the session. For the study with nursing students, 94.7% of the respondents agreed or strongly agreed that VR improved their understanding of the topic (Hardie, et al., 2020).

Another application is in teaching product design, ideation, and problem solving. The industry as a whole demands work-ready graduates and as such, students expect to learn more than just theoretical knowledge. Research suggests that clinical immersion can be an effective learning method which would bridge education and the real world. However, as mentioned earlier, there are limitations in terms of the accessibility and availability of resources for a large cohort (Linsenmeier & Saterbak, 2020). This is where AR/VR-based simulation might be a better alternative. Such systems are already being used in the automotive, electrical, and manufacturing industry to train and conduct skill assessments for employees (Shen & Shirmohammadi, 2008; Nee et al., 2012). The implementation of AR/VR allowed for a more accurate, standardised, safer, and less resource-intensive training method.

From the literature, it can also be seen that AVR-based educational tools improve learning motivation and effectiveness (Hodgson, et al., 2019; Hardie, et al., 2020; Chen, et al., 2020). Hodgson, et al. (2019)'s paper discusses two different case studies of VR being used to teach pharmacology and ecology. In the case of the pharmacology class, 89% of students indicated that they fairly agree, agree, or strongly agree that VR enhanced their learning interest. For the ecology class, 71% showed interest in exploring the topic further after the VR session. Similar results were also found in the use of VR to teach nursing students, with 79.8% of participants agreeing or strongly agreeing that the session with VR enhanced their learning motivation (Hardie, et al., 2020). Chen, et al. (2020)'s study with medicine students also found that participants showed high levels of motivation with the session and towards the use of VR in education.

While AVR's potential is well acknowledged in the literature, research towards its use specifically in BME education is still lacking. This reflection aims to discuss students' perception and attitude towards the use of AVR in teaching university-level BME modules, how it affects students learning experiences as well as its future implications on education and lifelong learning.

METHODOLOGY

Integration and implementing AVR into the BME learning platform

The study involved 88 students taking the core BME module BN3101 "Biomedical Engineering Design", which deals in the design and development of medical devices for various medical applications. This module also involved students gaining appropriate fundamental knowledge about relevant human anatomical features.

For one lecture session, an external vendor from the commercial sector was invited to give a short demonstration using their pre-developed content/kits that students could experience and try out. During the session, students could access both AR and VR technologies through a mobile phone app which they could download.

For the VR portion, students were invited to connect their smartphones to a mobile VR headset, where they could choose between various simulations available on the app, such as an artificial hip implant, hip joint, and so on. Students were then able to visualise the whole process and experience the technology used in such diagnostic evaluations. The simulation was also projected onto the screen for everyone to experience and observe the 3D models of parts of the human anatomy and the relevant medical implants (Figure 1). For the AR portion, students could rotate the anatomical model to learn about different parts of the knee, such as how knee implants are placed and connected to the underlying bone, and other parts of the anatomy by touching and navigating through their smartphone screens.

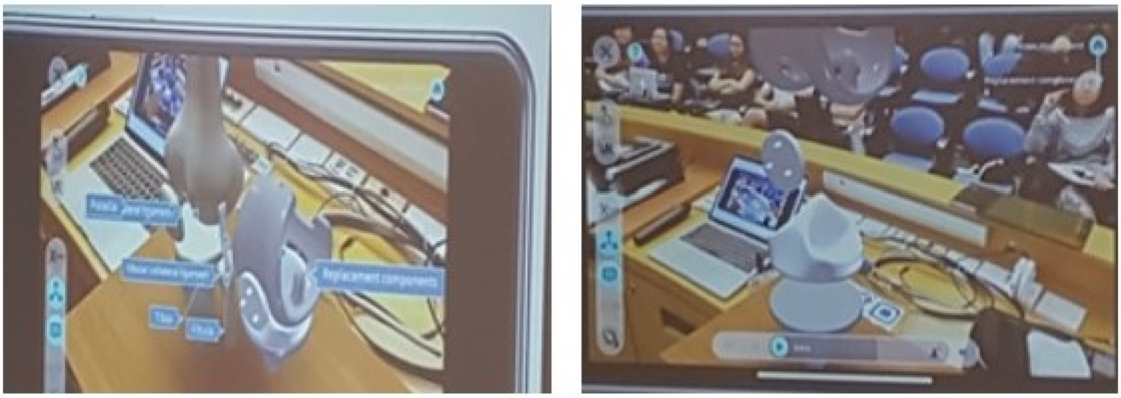

Figure 1. 3D knee model and relevant medical implants associated as experienced by the students in the classroom.

In this application, both AR and VR were used to help students visualise and experience how medical implants are inserted into the body. Students can also observe how medical implants may interact with the human body. The freedom to rotate and navigate through the models allows for a higher level of visualisation, immersion, and interaction.

EVALUATION

Students taking BN3101 were invited to voluntarily and anonymously submit feedback after the session through a questionnaire developed by the lecturer (see Appendix A). In the first part of the questionnaire, students were asked to rate 20 statements on a five-point Likert scale (from 5-"Strongly Agree" to "1-Strongly Disagree"). This was then followed by 12 open-ended questions to collect qualitative feedback and further analyse the rationale behind their quantitative scoring.

Quantitative assessment

The 20 statements in the first part of the questionnaire are classified into five categories: (1) interest and motivation in learning, (2) learning effectivity, (3) long-term and lifelong learning, (4) understanding of AVR, and (5) general feedback about the session. From the responses, student feedback was positive for all five categories, with the overall mean being 4.18 out of 5 (SD 0.5). Figure 2 shows the mean score by category.

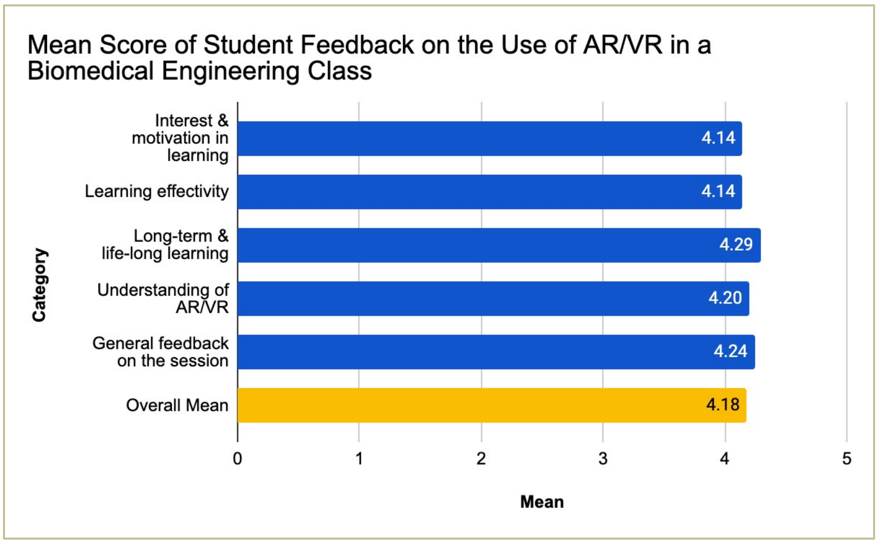

Figure 2. Mean scores of student feedback on the use of AR/VR in the class, by category.

The best response was received for the long-term and lifelong learning category, with an overall mean score of 4.29, which is explained further below.

Long-term and lifelong learning

The long-term and lifelong learning category achieved the best results amongst the five categories, with a mean score of 4.29. First, 92.1% (*n*=81) indicated that AR and VR has great potential in promoting long-term and lifelong learning. Along with that, 93.2% (*n*=82) also indicated that they agree or strongly agree that AR and VR are examples of technology-enhanced education. This statement has the second highest score amongst all statements, with a mean of 4.33 (SD 0.60), thus indicating that students have high expectations on the future use of AR and VR in continuing education and technology (CET) courses beyond university and other tertiary-level modules. The distribution of responses for this category can be seen in Figure 3.

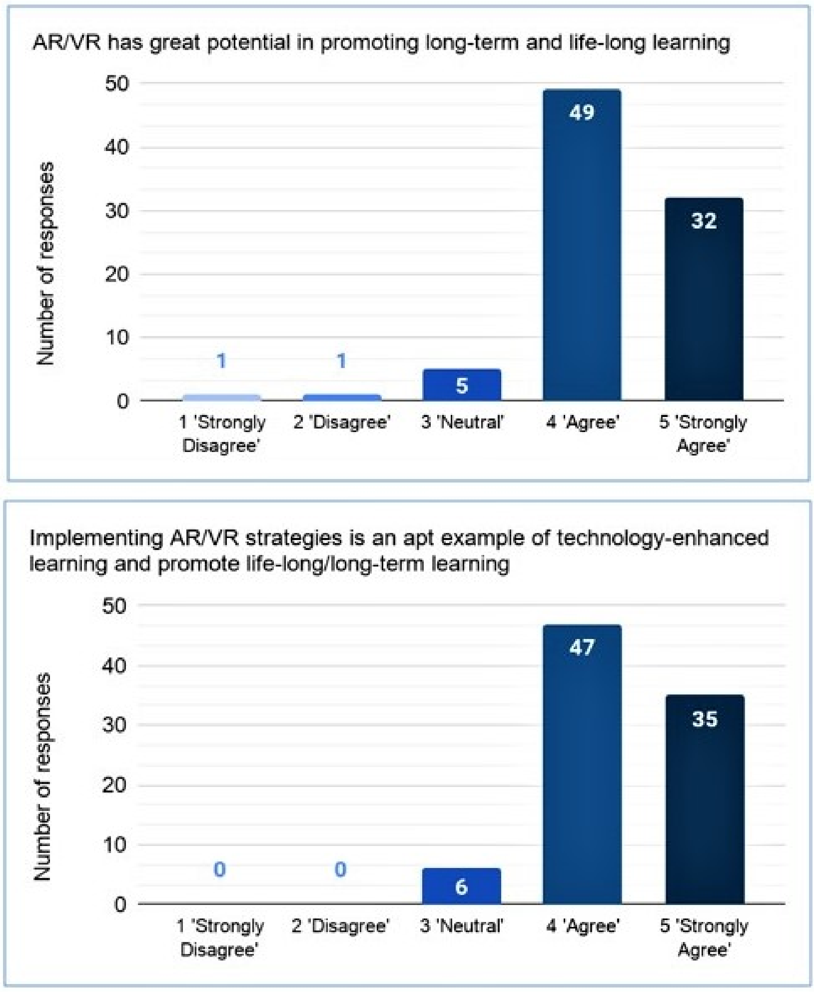

Figure 3. Students' responses to statements on the role of AR and VR in promoting lifelong/long-term learning.

Following analysis of the quantitative student feedback, a table was created to comprehend students' opinion on the various questions as it appeared in the feedback form (see Appendix B).

Qualitative data analysis

The questionnaire also included 12 open-ended questions on the use of AR and VR in education. Students were asked to identify their likes, dislikes, and key takeaways from the session as well as their expectations of the future use of AR and VR. Common themes which emerged from the feedback include excitement about the use of new technology, AR and VR as a visualisation tool, system limitations, and future expectations of their implementation in higher education and lifelong learning.

Excitement about the new technology

Numerous students mentioned that the session was “fun”, “exciting”, and “engaging” compared to traditional teaching methods. Respondents also mentioned that using AR and VR “motivates them to learn about the topic”. These comments are in line with the quantitative results on learning interest and motivation, suggesting that AR and VR can reinvigorate university-level education. The following are qualitative comments from the students:

> “AR and VR-based learning was fun, exciting and engaging.”

> “It (AR and VR) is interesting. More interactive that the usual lecture way of learning.”

> “It will make learning more fun and help to increase my understanding.”

When asked about what they liked about the session, a few students also highlighted the advantage of having both AR and VR through a mobile app.

> “I liked that it was done through a smartphone, it was just like using another app. It can be done anywhere, which means students can constantly learn even outside of tutorial sessions.”

These comments are in line with the quantitative results on learning interest and motivation which suggest that AR and VR can reinvigorate university-level education.

AR and VR as a visualisation tool

With regards to using AR and VR for BME education, numerous students mentioned that both AR and VR help them visualise and understand better, and promote collaborative learning. Following are a few of their comments:

> “It (AR and VR) is rather revolutionary and creative, be a plus in the biomedical engineering seeing as most of the devices produced/designs are implanted and to see devices within the human body, is not common/convenient without this (AR and VR).”

> “It helps students like us who not have much experience in the medical field to visualize the mechanics & structure of the human organs better.”

> “AR and VR are good for team-based learning or to understand device design from various perspectives”.

From the feedback, students seem to agree that AR and VR has a huge potential for teaching various BME-related subjects, especially those which involve anatomy, physiology, and product design.

Implementation in long-term and lifelong learning

These comments are in line with the quantitative results and show that students have high expectations in AR and VR's role in promoting and delivering long-term and lifelong learning

> "AR/VR's convenience can encourage more people to learn in the comfort of their homes. AR/VR can work as a supplementary material for school and will always be relevant as their applications are widespread."

> "Anything can be made into AR/VR mode which makes it limitless. Students will be able to visualize the situation better in school or at work that promotes better understanding."

DISCUSSION

This Reflection aims to discuss students' perceptions and attitudes towards using AR and VR in teaching university-level BME modules. First, with regards to learning interest and motivation, the results from this study show overall positive feedback, with a mean of 4.14, which is consistent with the literature which indicate that participants agree or strongly agree that AVR-based learning improved their learning motivation compared to traditional methods (Hodgson, et al., 2019; Hardie, et al., 2020; Chen, et al., 2020).

While the long-term effects were not measured in this study, it is apparent that there are short-term benefits from the use of AVR-based educational tools. One reason for such improvement in motivation is the excitement students feel with using a novel technology that is outside of their usual learning experience. This is a common finding in the existing literature on using AVR in education (Singh et al., 2020; Chen et al., 2020; Hardie et al., 2020; Shen & Shirmohammadi, 2008; Hodgeson et al., 2019), where using AVR-based tools allow students to take a break from the stagnant routine of traditional lectures and tutorials.

Another reason is AR and VR's ability to enhance the visualisation of complex anatomical models, making it easier for students to understand the topic in question and remain engaged throughout the lecture session. Not all BME majors have a strong biology background as this is not an admission requirement, and biology is not discussed to a high extent in compulsory core modules. Often times, students are left confused as it is hard to visualise how a medical device would be implanted and consequently interact with the human body. This is also found to be true for medical students and nursing students, where findings suggest that visualisation is a decisive factor that may affect how well students learn complex and abstract subjects (Chen, et al., 2020; Hardie, et al., 2020).

Second, it was found that students had high expectations that AVR-based educational tools will be part of education in the future, including long-term and lifelong learning modules. However, there is a need to consider both sides of this finding. From our study and also in previous studies mentioned, it is clear that AVR-based tools are well received and should be implemented in education. Above its potential in improving tertiary-level education, students agree that AR and VR promote and deliver long-term and lifelong learning modules. Such modules are characterised as being typically taken by older adults on a part-time basis, and that gaining new knowledge and skills are much more important than receiving a good assessment score. AR and VR's ability to be taken outside of a physical classroom and used at any time is thus beneficial and will play an important role in delivering course materials, all while ensuring that the learning process remains engaging. The novelty of AVR-based tools may also attract more people to join the course as it would allow them to not only learn but also experience a new technology.

However, it is worth noting that students' comments are mainly predictive as most of AVR's advantages remain a potential and are not yet achievable in the tools currently available in the market. The application of AR and VR in this study is mainly as a visualisation tool. It lacks immersiveness and interactivity through embodied motions that are often expected from AR and VR systems. Studies suggest that a higher level of immersion and interaction with the VR system brings forth better responses and learning outcomes (Linsenmeier & Saterbak, 2020; McCloy, 2001; Johnson-Glenberg, 2018)). This suggests that simple AR and VR like what was used in this study may be lacking. Reaching an adequate level of immersion and interaction that would improve learning outcomes would require high-capacity systems and hardware.

Considering the exorbitant costs required to build an AVR facility that can be used by a large cohort, their implementation might not be feasible currently. That said, market trend experts predict an increase in the availability and uptake of AR/VR in the next few years. This is on account of increasing investments and the decreasing prices of AR/VR hardware as developers reach economies of scale (Mordor Intelligence, 2021). Along with that, the incoming 5G technology, which would allow a more stable connection, is expected to improve AR/VR experiences and thus their uptake (Grand View Research, 2021). Following this trend, the use of AR/VR in education should soon be more feasible.

LIMITATIONS

In this study, AR and VR was only used in one single lecture and thus the feedback received was purely based on how the students perceive the change in their learning experience. The current study does not show the long-term effects of the use of AVR-based systems in BME modules and how it may impact learning outcomes. Further studies should be done to quantify the short- and long term effects of AVR-based educational tools as compared to traditional teaching and learning methods, through pre- and post-intervention assessments on top of a feedback questionnaire.

CONCLUSION

While the potential of AVR in enhancing student learning outcomes has been widely acknowledged and recognised, its usage and application remains somewhat limited. The reason may be attributed in part to the complexity and price of developing appropriate and relevant platforms. In this study, we delved into the adaptation of AVR as a pedagogical strategy to excite and interest BME students and its potential to be more widely used as a tool to promote teaching efficacy and long-term learning. Thus, this Reflection aims to fill the gap in the literature with regards to the potential use of AR and VR in BME education. Students' perceptions towards the effects of AR and VR on learning motivation, effectivity, as well as long-term and lifelong learning was analysed and a general positive response was received. In line with the literature, this Reflection aims to show that AR and VR-based learning can enhance the three aforementioned categories as well as student engagement, excitement, critical thinking, and integration into the professional environment. Students also seem to be expecting that AR and VR will soon be integrated as a common part of education. That said, the feedback found that the current implementations of AR and VR on mainly visualisation interfaces may be further improved upon with immersiveness, interactivity through embodied motions as two main characteristics to consider in creating future iterations of AR and VR programmes. Overall, AR and VR holds a lot of potential in reshaping and reinvigorating tertiary-level education, as well as promoting and delivering long-term and lifelong learning. Its exact implementation will however depend on future technical advancements and developments of both hardware and software that would decrease its costs and further improve its ease of use.

APPENDIX A. FEEDBACK QUESTIONNAIRE

APPENDIX B. QUANTITATIVE STUDENT FEEDBACK FOR EACH QUESTION GROUPED BY CATEGORY

ABOUT THE CORRESPONDING AUTHOR

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