Exploring the Virtual Frontier: The Impact of Virtual Reality on Undergraduate Biology Education at the American University in Dubai

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Manuscript received October 30, 2023; revised December 17, 2023; accepted January 22, 2024; published May 14, 2024

***Abstract*—Virtual Reality (VR) technology is revolutionizing education, providing unique opportunities for immersive and interactive learning. This study explores the potential of VR to enhance undergraduate biology education—a pioneering endeavor within the United Arab Emirates (UAE). This research follows a structured three-stage approach which includes: pre-assessments, immersive VR experiences, and post-assessments that evaluate the impact of VR on students' knowledge and skills. This is complemented by a Likert-scale comprehensive learning survey designed to assess the students' level of engagement and satisfaction. Using VR, students navigate a detailed 3D model of the human body and its organs and findings suggest that immersive VR holds substantial promise as an educational tool in UAE undergraduate biology education. Pre-assessments and post-assessments demonstrated a statistically significant improvement in biology assessment scores, indicating enhanced comprehension of complex concepts after a single VR session. Furthermore, the learning survey results suggest high levels of student engagement and satisfaction in the VR environment. The introduction of VR technology into undergraduate biology education is innovative, shedding light on its untapped potential. This study provides insights into the broader applicability of immersive VR in science education and its potential to transform learning experiences, benefiting both students and educators.**

***Keywords*—virtual reality, immersive learning, education, undergraduate biology, student engagement, educational technology**

I. Introduction

The educational landscape has been transformed by technological advancements [1]. Traditional teaching methods have gradually integrated technology that enhances learning experiences. One notable innovation is the integration of Virtual Reality (VR) into educational settings.

In the context of education, VR can be described as a virtual environment generated by a computer and/or mobile device that provides a strong sense of presence and sensory immersion to users [2]. Virtual worlds are generated using modern software and are typically experienced through high-resolution head-mounted displays, motion tracking and stereo sound [3]. The integration of VR systems into education provides the opportunity to create immersive and interactive environments that extend beyond the possibilities of traditional teaching methods and offers the potential to reshape the ways in which students engage with complex concepts.

VR has been historically under-utilized in education due to its high cost and limited availability [4]. However, the rapid advancement of technology and reduced costs have made it possible to incorporate this innovative instructional technology into classrooms [2, 5]. In higher education, VR has been most widely utilized in medical courses for teaching anatomy and specific technical skills (e.g., surgical skills) [6, 7], as well as engineering courses to enhance practical and procedural knowledge (i.e., knowing how to perform specific tasks) [8].

In the context of biology education, students can use VR to traverse the inner workings of cells and organs, explore a wide range of disease states, and witness physiological processes that extend beyond the boundaries of traditional classroom settings. By offering a tangible link between theoretical principles and practical applications, VR has the potential to enhance both conceptual and practical understanding of how the human body functions.

The benefits of VR in medical and biological education go beyond performance and exam scores. A recent meta-analysis of 15 randomized controlled studies on the performance of VR anatomy education found that VR improved student interest in anatomy [9]. Similarly, in a study of virtual science learning in 105 university students, immersive VR significantly outperformed desktop VR in student motivation and sense of presence [10]. Other studies have shown that VR can significantly enhance engagement with teaching materials, which in turn is positively linked to performance [11]. Given that student engagement plays a significant role in academic achievement [12] and persistence of learning [13], teaching approaches that improve engagement are important to investigate in order to improve educational outcomes.

In this study, we investigated the impact of adding VR into the undergraduate biology curriculum at the American University in Dubai (AUD). The primary goal was to analyze the impact of a VR biology lab experience on knowledge acquisition, engagement, and satisfaction among undergraduate biology students. This is a pioneering trial of fully immersive VR in the undergraduate biology curriculum within the United Arab Emirates [14]. By comparing the

doi: 10.18178/ijiet.2024.14.5.2092

learning outcomes of students before and after exposure to a VR lab experience, this research aims to provide empirical insights into the educational benefits of VR and explores the possible impact of VR on student engagement and overall learning experiences.

II. Methodology

A. Participants

To comprehensively assess the influence of Virtual Reality (VR) on educational outcomes, a cohort of 20 undergraduate students were selected from the Bachelor of Science (B.S.) in Biology Program at AUD. These students, representing a cross-section of the program, initiated an investigative exploration into the field of immersive education.

Importantly, these students entered the study with a substantive academic background in the biological sciences. They had successfully completed a comprehensive general biology course, which served as the foundation for their participation. This course provided them with a comprehensive understanding of human anatomical structures, the intricacies of organ systems, and the nuanced interplay of their functions. Their prior educational experiences were rooted in traditional classroom and laboratory settings. The selection of students for this study was based on purposive sampling, with the criterion that all participants were undergraduate biology students who had completed the aforementioned general biology course.

The decision to partake in this research study was entirely voluntary, with each student expressing their willingness to engage in this innovative pedagogical experiment. Their consent reflected their shared interest in evaluating the potential of VR technology to enhance their educational journey. These students were active participants in our study, initiating a collective inquiry to investigate the influence of VR on their educational achievements.

B. Procedures

The study was conducted in three stages: a pre-assessment, VR experience, and post-assessment in addition to a Likert-scale learning experience survey. The pre- and post-assessment questionnaire (Appendix A), meticulously designed by the authors, consists of 12 descriptive questions. These questions, were intentionally formulated to be descriptive rather than direct in order to assess the impact of Virtual Reality (VR) on students' knowledge. The questions cover various biology concepts, including cardiovascular function, digestive processes, and neurological functions. The format allowed for a nuanced evaluation of any evolution in students' understanding before and after the VR session.

Similarly, the learning experience survey (Appendix B) incorporates Likert scale questions (1–10) designed by the authors to quantitatively measure engagement, satisfaction, and the perceived educational value of the VR experience. The inclusion of open-ended questions in this survey also allowed for qualitative insights into students' preferences, challenges, and suggestions for improvement. Detailed items for the questionnaires are available in Appendices A and B, providing a comprehensive overview of the tools used in the study.

The pre-assessment was designed to evaluate the biology knowledge and skills of students at baseline, prior to the VR experience.

Following the pre-assessment, students completed a one-hour educational VR session where they explored the organs and concepts covered in the pre-assessment questionnaire (Fig. 1). Students used the HTC VIVE Pro immersive VR headset to complete their labs [15]. The head-mounted device is tracked by multiple bases mounted on the wall to locate all users inside the VR lab. The headset uses two infrared sensors and two handheld controllers to track the motion of users wearing the headset [16]. The headset included a front-facing camera, detachable speakers and adjustments for lens and interpupillary distance [17]. The headset displayed a real-time simulation of the human body through the platform Sharecare YOU [18]. This platform allows users to freely navigate and explore an anatomically accurate, 3D model of the human body, its organs, and their natural function [18].

Fig. 1. Students wearing the HTC VIVE Pro immersive VR headset and completing the VR biology lab.

Following the VR experience, students completed the post-assessment and learning experience survey. The post-assessment replicated the pre-assessment questions to maintain consistency in the evaluation process. The intent was to assess the influence of the Virtual Reality (VR) session on participants' knowledge and skills after the VR experience. Importantly, between assessments, students did not have access to external resources. Additionally, the VR session did not provide explicit answers to the questions but rather facilitated an immersive exploration of the same content covered in the traditional general biology course and lab that participants had completed prior to the study. This methodological approach was designed to isolate the impact of VR, allowing participants to apply their pre-existing knowledge in a novel and engaging context. The learning experience survey, which assessed participant engagement and satisfaction with the VR experience by comparing traditional classroom instruction and textbook-based learning to the immersive VR experience, was completed by the participants at the end.

C. Statistical Analysis

To assess the effect of VR on biology knowledge, we employed the following scoring system to gain deeper insights into knowledge while mitigating biases. Scores from 0 to 5 were assigned to pre- and post- assessment responses based on the level of correctness, ensuring a nuanced evaluation. To address bias concerns, two raters assessed responses blindly, enhancing reliability and validity. The ratings were consistent across both raters. Total performance was compared using the sum of mean scores pre-assessment and post-assessment. Each question held equal weight, and the score was computed based on the average of correct responses. The pre-assessment was specifically designed to gauge the initial level of knowledge through open-ended inquiries, providing a comprehensive understanding. This approach allowed for the calculation of learning gain by comparing outcomes to baseline levels. With an emphasis on open-ended questions, our methodology aimed to capture nuanced insights. To assess differences before and after VR interventions, we applied nonparametric tests, consistent with the methodologies outlined in previous studies [19, 20], to analyze and compare responses within the participant group. Since data were not normally distributed, Spearman rank correlation coefficients were estimated to identify the magnitude and direction of the association between pre- and post-assessment scores.

To determine if there were statistically significant differences between individuals' average assessment scores prior to and following the VR experience, a paired Wilcoxon test was used. Statistical analysis was conducted in R Version 4.2.2 and figures were generated using the ggplot2 package.

III. Results

Overall, students had significantly higher post-assessment scores compared with their pre-assessment scores ($p = 0.0001$, Fig. 2). The sum of mean scores at the post-assessment was 75.9, a 42.7% increase from a sum of mean scores of 53.2 at the pre-assessment. The effect of VR was positively correlated with the higher post-assessment scores (r = 0.91).

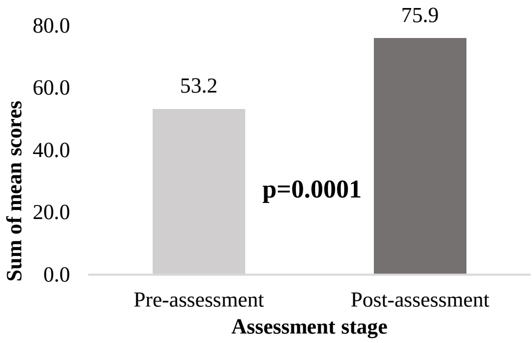

Fig. 2. Individual mean scores before and after exposure to the VR experience.

The learning experience survey indicated overall satisfaction with the VR experience (Fig. 3). Of the 20 students, 70% rated their overall satisfaction with the VR as excellent and 30% rated their overall satisfaction as very good. No students rated their overall satisfaction as average, poor or very poor.

There was a consensus among all participants that the VR experience was informative, engaging, and overall, more beneficial than traditional classroom-based teaching methods (Fig. 3). 95% students strongly agreed or agreed that the VR experience increased their interest in pursuing further studies in biology, while 90% strongly agreed or agreed that the VR experience was more engaging than traditional, lecture-based methods. Compared with traditional teaching methods, students felt that the VR experience was more informative, and valuable, and contributed more to understanding abstract biology concepts (85%, 80% and 75% strongly agreed or agreed, respectively).

Survey question	
1	Increased my interest in pursuing further studies in biology
2	Was more engaging than traditional lecture-based teaching methods
3	Was well-organized
4	Provided more informative learning experiences than textbook-based learning
5	Was a more valuable addition to my biology education than traditional teaching
6	Was easy to navigate
7	Helped me understand biology concepts better than traditional instruction
8	Helped me develop my critical thinking skills
9	Helped me develop my problem-solving skills
10	Was more challenging than traditional lab experiments

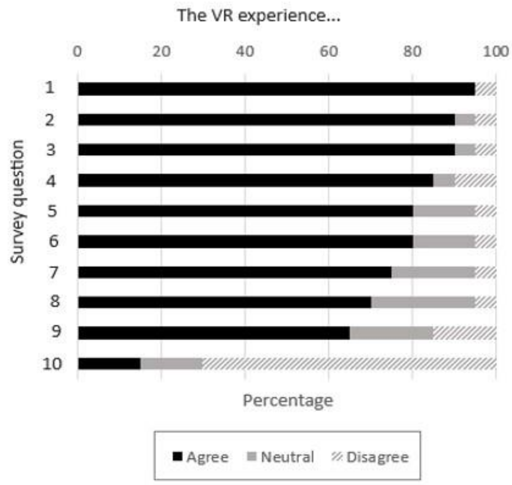

Fig. 3. Overall satisfaction in the learning experience survey. Agree reflects the combination of choices strongly agree and agree, and disagree reflects the combination of choices strongly disagree and disagree in response to each question.

In terms of skills development, students felt the VR experience helped in the development of critical thinking skills and problem-solving skills (70% and 65% strongly agreed or agreed, respectively).

In terms of functionality, students felt the VR experience was well organized and easy to navigate (90% and 85% strongly agreed or agreed, respectively). One question had agreeance rated as less than 65%: only 15% of students strongly agreed or agreed that the VR experience was more challenging than traditional lab-based experiments.

Four open-ended questions were included at the end of the learning experience survey to gain further insight into students' experiences with the virtual experience. In response to what they liked best about the experience, several students commented on the benefit of being able to clearly visualize the concepts being taught; the level of detail and realness of the experience; and the hands-on, interactive nature of the lab. One student commented, "It aids in visualizing concepts that are traditionally taught through 2D diagrams. This 3D immersive experience and interaction with the human body parts allow a more memorable and effective understanding than the traditional 2D diagrams found in text books."

When asked if the VR learning experience was better, worse or similar to traditional hands-on biology labs, 40% of students commented that they felt VR was better, noting that VR was much more immersive than traditional lab activities and allowed the student as stated by one participant "to see everything I've learned". 45% students agreed that VR was beneficial but felt it should be applied alongside traditional methods. One student noted, "I think that exhibiting both VR and hands-on learning are necessary to help students learn about the human body."

Students were also asked what they liked least about the VR experience and what they felt could be improved. While the majority of students did not have specific suggestions or complaints, a few students noted some physical or visual discomfort, including motion sickness, dizziness, mild headache and eye strain. One student felt that the headset was not comfortable for people wearing glasses and controls were difficult to use. Suggestions included expanding the application of VR to other areas in biology, such as dissections and virtual surgery, adding detailed notes on the processes being observed (alongside the existing labels) and considering gamifying the immersive virtual experience.

IV. Discussion

The results of this pilot study not only highlight the promise of Virtual Reality (VR) as a powerful educational tool but also underscores the added value of immersive education when compared to traditional classroom and laboratory teaching methods in the context of undergraduate biology education in the United Arab Emirates. The significant increase in biology assessment scores from the pre-assessment to the post-assessment signifies a tangible improvement in students' grasp of biological concepts following a single session with an immersive VR biology laboratory. This indicates that VR has the potential to facilitate a deeper understanding of complex biological concepts. Even though, these students had previous exposure to conventional teaching practices, their participation in the immersive VR biology laboratory session allowed them to surpass the boundaries of traditional learning. By engaging with dynamic, three-dimensional visualizations and interactive simulations, students were able to explore biological concepts in a more intuitive and experiential manner. This experience deepened their understanding of intricate biological subjects and provided a novel approach that complements traditional teaching approaches. The combination of traditional methods with immersive VR technology opens new avenues for enriching the educational experience and enhancing students' comprehension of complex topics in biology.

Furthermore, the outcomes obtained from the learning experience survey provide valuable insights into the students' perception of this innovative learning approach. The fact that all students rated their overall satisfaction as either "excellent" or "very good" underscores the high level of contentment and enthusiasm they experienced during the VR-based learning experience. Moreover, the students expressed that the VR encounter was not only informative but also profoundly engaging. They found the VR approach to be a more beneficial educational method compared to traditional classroom-based teaching techniques.

These results parallel some recent studies that incorporate VR into biology and medical teaching. A 2020 study randomized 45 university students to three methods of learning human heart anatomy: paper (text and images); 3D interactive human heart model presented on a computer display; and an immersive VR human heart model [3]. The immersive VR group showed the largest improvement in test scores, both within and across groups. Additionally, a 2016 study randomly assigned two groups of second-year medical students to either conventional light or virtual microscopy practical sessions [21]. Students in the virtual microscopy group outperformed those in the traditional microscopy group in both practical and written exams.

Beyond assessment scores, a recent meta-analysis of 15 randomized controlled studies on the performance of VR anatomy education showed that most students have a greater interest in learning via VR methods compared with conventional or 2D teaching methods [9]. Several studies echo these findings, suggesting that undergraduate students across a range of disciplines generally have positive perceptions about the integration of VR into education [8, 22, 23], which can in turn positively impact student knowledge and performance [24, 25]. These findings parallel our own observation that students generally have a positive perception of the VR experience and that engagement is positively affected when compared with traditional teaching methods.

Generally, educational approaches that involve more senses produce longer-lasting and higher-quality working memories [26]. Multisensory processing involves the interaction of concurrent signals from various sensory receptors [26]. By targeting multiple senses simultaneously, VR has the potential to increase the quality of learning and memory, with consequent benefits to test scores as well as practical skills.

Within biology and medical education, the immersive nature of VR allows students to explore intricate structures of organs while visualizing and interacting with complex biological processes. This is otherwise challenging to convey through traditional classes and labs. By manipulating objects, observing real-time biological phenomena, and conducting virtual experiments, students gain a deeper understanding of complex concepts and a stronger connection with the subject matter. Additionally, VR environments and exercises may be easier to tailor to different students to accommodate their diverse learning styles and skill levels. These benefits, alongside our early, positive findings, highlight the potential for VR integration into biology curricula.

Despite the valuable insights provided by this study into the potential benefits of virtual reality in the classroom, it is essential to acknowledge certain limitations. The findings, derived from a small sample size and specific demographics, may not be readily generalizable to a broader population. The constrained duration of exposure to VR technology, absence of randomized control groups, and the exclusive focus on undergraduate education within a singular institutional environment restrict the study's ability to draw universal conclusions. It is important to emphasize that this study represents a foundational exploration, and future research endeavors should aim to address these limitations through large-scale studies.

V. Conclusion

The conclusions derived from this study may extend beyond its immediate context, carrying substantial implications for the field of education. By venturing into the integration of VR within undergraduate biology education in the UAE, this study assumes the role of a pioneer in the field of educational innovation. Remarkably, several of our findings not only corroborate some existing research but also highlight the profound potential of VR to elevate the learning experiences and engagement levels of undergraduate biology students. To fully harness the several benefits that VR can bring to the classroom, it is imperative that future investigations build upon this foundational work. Larger-scale studies, randomized applications, and extended exposure to VR technology are essential components of this ongoing journey, aimed at pinpointing the most effective strategies for seamlessly integrating this transformative tool into undergraduate education. Potential challenges in implementing VR technology include resource constraints, technological accessibility, and the need for specialized training for educators. Overcoming these challenges necessitates collaborative efforts among educational institutions, policymakers, and technology providers. Subtle yet transformative recommendations for educators encompass the incorporation of VR into practical laboratory sessions, the cultivation of collaborative projects harnessing the immersive potential of VR technology, and the provision of tailored professional development opportunities. These nuanced steps not only address challenges but also signify a gradual shift towards a more technologically empowered educational landscape. Moreover, this research also provides valuable insights into the broader applicability of immersive VR technology as a catalyst for transformation in science education beyond the field of Biology. The implications of these findings resonate not only with students and educators in the UAE but also with a global audience in diverse educational settings, all of whom share a common goal: to explore innovative and effective approaches that enhance the overall quality of the learning experience. The practical impact of the current study will also guide educators and policymakers to integrate Virtual Reality (VR) technology into their teaching practices.

In essence, this study paves a path towards a more engaging, interactive, and effective educational landscape where technology serves as an empowering force in shaping the future of learning, not only for biology students in the UAE but for learners worldwide. As we continue to innovate and explore the uncharted territories of educational technology, we find ourselves at the threshold of a new era in education—a future where the boundaries of traditional learning are transcended, and the potential for transformative educational experiences is limitless.

APPENDIX

A. Pre and Post-Assessment Questionnaire

Questions

1) Explain how blood flows between the chambers of the heart and through the valves on both the left and right sides?
2) Can you explain how the heart valves function to regulate blood flow?
3) Explain the process of plaque formation in coronary arteries, leading to coronary heart disease.
4) Describe the muscle movement in the stomach and how it aids in the process of digestion.
5) Provide a description of the internal lining of the stomach.
6) In normal circumstances, the colon moves stool at an appropriate rate to allow for water reabsorption from waste. In the case of diarrhea, how does the rate of stool movement and water absorption get affected?
7) Describe the shape of alveoli within the lungs and explain how its structure complements its function.
8) Compare the appearance and airflow function between healthy lungs and those of a smoker.
9) Write down the pathway of urine formation and excretion using the following keywords: artery, renal pelvis, calyces, urinary bladder, renal cortex, renal medulla.
10) What are the cone-shaped structures found in the renal medulla called?
11) Explain how nerve impulses propagate along neurons.
12) In the context of Multiple Sclerosis (MS), where the immune system destroys the myelin sheath, differentiate between the speed and efficiency of nerve impulses in a normal neuron versus an affected neuron by MS.

B. Learning Experience Survey

Likert Scale Questions (strongly disagree, disagree, neutral, agree, strongly agree)

1) The virtual reality experience was more engaging compared to traditional lecture-based teaching methods.
2) The immersive experience provided more informative learning experiences compared to textbook-based learning.
3) The virtual reality experience helped me understand biology concepts better compared to traditional classroom instruction.
4) The virtual reality experience was more challenging compared to traditional lab experiments.
5) The immersive learning experience was a more valuable addition to my biology education compared to traditional teaching methods.
6) The virtual reality experience increased my interest in pursuing further studies in biology.
7) The virtual reality experience helped me develop my critical thinking skills.
8) The virtual reality experience helped me develop my problem-solving skills.
9) The virtual reality experience was well-organized.
10) The virtual reality experience was easy to navigate.

How would you rate your overall satisfaction with the virtual reality experience?

C. Open-Ended Questions

1) What did you like most about the virtual reality experience?
2) What did you like least about the virtual reality experience?
3) Do you find the learning experience of virtual reality (VR) to be better, worse, or similar to traditional hands-on learning in biology labs? Please provide a brief explanation for your choice.

4) Do you have any suggestions for improving the virtual reality experience?

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

Informed consent was provided from all participants prior to the start of this study. M.T.Z. conceptualized the study, designed the methodology, supervised project administration, and authored the original draft. M.T.Z. also conducted the final review and editing, and handled correspondence. N.M. assisted in drafting assessment questions and participated in the investigation. M.A., G.A., A.D., H.K., and M.K. equally contributed to the investigation and participated in the review process. G.K. contributed significantly to the review process, provided supervision for the technology used, and offered general guidance.

Funding

This research was conducted at AUD with support from the Center for Research, Innovation, and Design (CRID). No external funds or grants were utilized for this study. CRID provided access to the necessary Virtual Reality (VR) tools and resources required to carry out the research, facilitating the investigation into the potential of immersive VR in undergraduate biology education.

Acknowledgements

We acknowledge that ethical approval for this study, along with its procedures, has been successfully obtained through the Ethics Committee at AUD. We also appreciate AUD for providing an environment conducive to innovation and research. Thanks are due to the participants for their valuable time and contributions. Furthermore, we recognize the support provided by the Center for Research, Innovation, and Design (CRID) at AUD, which facilitated the conduction of this study. The collaborative efforts of these entities have significantly enriched this research.

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