Advancing STEM Education with Virtual and Augmented Reality through Innovative Content Delivery and Immersive Learning Experiences: A Review

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Abstract. Virtual Reality (VR) and Augmented Reality (AR) are transforming education by revolutionizing content delivery and management across various education disciplines. This systematic review paper enlightens the recent surge in VR/AR adoption, driven by advancements in immersive technology, and its impact on multiple educational levels. Nevertheless, VR/AR technology has diverse applied areas, this paper primarily focuses on the utility of VR/AR-based applications in engineering, medical, and natural sciences education. In engineering education, AR facilitates the comprehension of complex concepts, while VR platforms provide immersive learning environments for manufacturing processes. Likewise, VR simulations have emerged in medical education, offering realistic practice scenarios for medical students. AR in natural sciences helps in visualizing abstract concepts and supports interactive learning. Therefore, in this review article, the main goal is to comprehend the recent advancements in the applied areas of VR/AR technology particularly within STEM fields. This review provides essential insights for educators, researchers, and policymakers aiming to leverage the transformative potential of VR/AR technologies.

Keywords: Virtual Reality, Augmented Reality, STEM Education, Immersive Learning

1 Introduction

With recent technological advancements, researchers have been focusing on emerging tools to enhance productivity and the learning experience in STEM education. Recent statistics show that traditional teaching methods are becoming obsolete and in this 21st century, learners are more inclined to use technology [1,2]. Therefore, over the past few years, both Virtual Reality (VR) and Augmented Reality (AR) have become prominent technological innovations for delivering content, leading to improved productivity for learners [3]. Different research studies highlighted the significance of creating a virtual

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environment to gain insights into complex engineering applications, surgical training, and multidisciplinary social interactions. Likewise, AR provides us a foundation to overlay digital information on the real-world environment, allowing (a) engineers to maintain and access the real-time data of the equipment, (b) doctors to visualize the surgical procedure data on the patient's anatomy, and (c) social scientists to depict the geographical locations by visualizing the augmented interpretations [4–6]. Recent Scopus data reveals a predominant focus of VR/AR applications in the medical field (40%), followed by engineering (34%), social sciences (16%), and other educational domains (10%). The results indicate that the scientific community has been actively utilizing these emerging fields, particularly in engineering, medical, and social sciences [7,8]. The following sections explore these fields in detail.

The available scientific studies have provided the foundation to explore the applied areas of VR/AR technology. However, a major research gap exists in providing a comprehensive overview of VR/AR-based applications in educational fields. This specific gap impedes the foundation for researchers in exploring the VR/AR-based immersive learning experience. Therefore, the main goal of this systematic review article is to provide the scientific community with the fundamental backgrounds, utility, and advancements of AR/VR-based applications in STEM education. Most importantly, the selection of the research studies has been done by considering three factors (a) the utility of AR/VR technology in enhancing the immersive learning experience (b)the implication of AR/VR technology in the higher education stream, and (c) the publication year (studies after 2019 are considered)

2 Biomedical Education

The field of biomedical education has witnessed a surge in the use of these immersive technologies, ranging from applications to visualizing anatomical structures of living organisms and microorganisms to simulating complex biomedical machinery like radiotherapy machines. These solutions are being used for classroom teaching, operators and nursing staff training, and remote operation. Traditionally, medical education is centered around textbooks, classroom instruction, and visual aids. However, these methods offer limited detail and lack interactive mechanisms for learners, potentially hindering a deeper understanding of complex medical concepts. The use of immersive technologies like VR/AR has proven to be a remarkable improvement in biomedical education.

A few main resources used in traditional anatomy study include cadavers, 3D and plastic models and textbooks. [9] has presented various studies that prove that immersive technologies can lead to improved knowledge retention compared to traditional learning methods. An AR tool (AEducAR 2.0) developed by the University of Bologna [10] was tested on 130 students to learn three anatomical topics; orbit zone, facia bones, and mimic muscles. Students declared to find AR a helpful tool for studying (94%) and for their future medical career (95%). Fig. 1a shows facial bones visualized using this AR tool. A study by Nan Jiang et.al. [11] created an interactive AR tool to display the model of the canine skull. Using this tool, a student can select a skull structure that gets highlighted and the student can also see the text related to that part. Moreover, students could observe the dorsal view, ventral view, side view, and nuchal view of the skull model by dragging and rotating the model. One instance of the app is shown in Fig. 1b. Another study by Jesus Uribe et.al. [12] used AR holograms as an educational intervention for anatomy learning and results show that mobilebased AR was as effective as Peer Teaching Program (PTP) in acquiring shortterm learning. Fig. 1c shows the Cardiac Hologram Model transacted to visualize heart chambers.

There is also a possibility that the digital content is displayed on physical objects like manikins or cadavers. ARISE developed by [13] is one such example and one instance of the solution is shown in Fig. 1d. Companies like GigXR [14] employ Extended Reality (XR) to create immersive healthcare education experiences. Their HoloHuman platform offers interactive 3D anatomy models (Fig. 1e), while HoloPatient simulates various medical conditions (Fig. 1f) for nursing students.

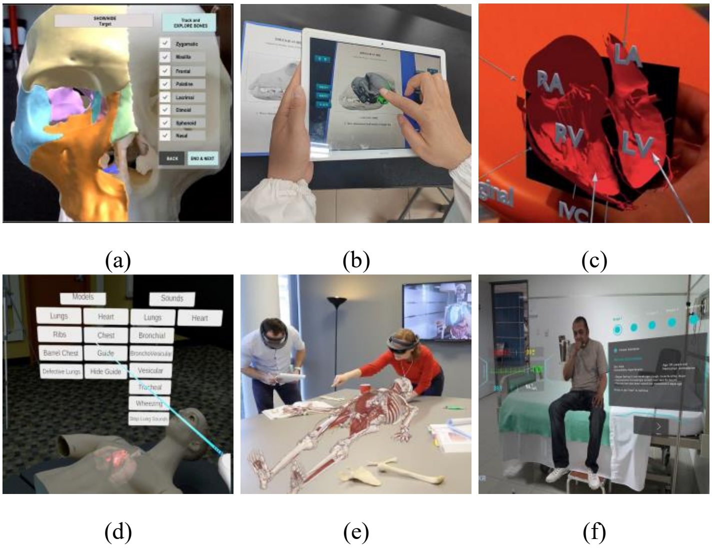

Fig.1. (a) Facial bones visualized using AEducAR 2.0 [10]; **(b)** Interactive Canine Skull Model [11]; (c) Cardiac Hologram Model [12]; **(d)** UI of ARISE [13]; **(e-f)** HoloHuman and HoloPatient by GigXR [14]

VR and AR have emerged as useful tools to train professionals in Cardiopulmonary Resuscitation (CPR) for cardiac arrest. [15] presents a Virtual Reality application to support learning and practicing basic techniques of CPR using force sensors to measure user interaction. Fig.2a shows the VR simulation with the value of the force sensor while Fig.2b shows a person performing CPR on a manikin with a VR headset.

(a) (b)

Fig.2. (a) VR Simulation;**(b)** Test Session [15]

Understanding and operating complex biomedical equipment is another critical pillar of biomedical education. Machines like MRI scanners, CT scans, and LINACs play a vital role in modern medicine, and proficiency in their use is essential for various healthcare professionals. [16] offers VR training for MRI operators, simulating the control room and MRI scan process, including patient interaction and result display. Accurate set-up and patient positioning are crucial for successful radiotherapy treatment. VR and AR technologies are emerging as powerful tools, not only for training and evaluating the accuracy of these procedures but also for potentially guiding them in real-time [17,18].

Beyond training applications, VR and AR are also being explored for visualizing complex biomedical data. For instance, systems like [19] allow researchers to extract even deeper insights from biomedical computational fluid dynamics (CFD) simulations using VR and AR.

3 Engineering and Natural Science

We have reviewed recent use of VR/AR technology in engineering and natural science education as well. In a study focusing on N-type MOSFET (NMOS) elements [20], researchers used an AR application to augment the lecture contents to enhance the learner’s understanding of analog and digital circuits. The key finding established that abstract ideas become more tangible hence improving learners’ comprehension. In [21] a detailed review of the use of VR technology in engineering education found the need for a strong theoretical foundation to improve the effectiveness of such technologies in education. As educators are increasingly integrating these technologies into their lesson plans, a formal theoretical framework for incorporating long-researched and established educational theories must be developed. Moreover, the study presented the findings that use of multimedia instructional design process helps to mitigate cognitive load and enhance the learning outcomes in virtual environments. Therefore, a well-thought-out approach to incorporating VR/AR technology into modern-day education needs to be developed.

In another study [22] related to natural science, the researchers developed an AR system to visualize concepts of topography and hydrology in AR environment. It helped to demonstrate the type of terrain that would be covered in a field trip of a group of students. Moreover, a VR application was also developed and presented in this study that used georeferenced drone images and photogrammetry software to create a 3D model of the outcrop. This allowed students to visualize the outcrop situated at a remote location in a virtual environment.

In [23] several reasons as to why students are opting out of science education in Europe are analyzed. The foremost reason is the amount of cognitive effort required to grasp the difficult concepts necessary for understanding the included topics. VR/AR technology can easily fill in the gap here by reducing the cognitive load on the learner's mind and presenting abstract and complex science concepts in a more straightforward and less complex way.

4 Conclusion

In this systematic review article, the influence of emerging technological innovations, VR/AR on the educational disciplines has been explored and critically assessed for the immersive learning experience. The existing statistics highlighted that within STEM education, VR/AR applications have been prominently utilized in medical, engineering, and social sciences disciplines. However, medical education is found to be the prominent one in the enormous utilization of these technologies for effective yet interactive learning experiences. Additionally, both engineers as well as social scientists have also been actively involved in utilizing VR/AR technology for efficient understanding of complex concepts. Based on the insights provided, this article lays a foundation for the scientific community to understand, explore, and implement VR/AR applications within STEM education. Furthermore, the applied areas of VR/AR technology, specifically in STEM education, still need to be explored, and based on the limited existing findings, it is further recommended to critically assess real-world applied scenarios of AR/VR Technology.

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References

1. Babajide Tolulope Familoni and Nneamaka Chisom Onyebuchi. Augmented and virtual reality in us education: a review: analyzing the impact, effectiveness, and future prospects of ar/vr tools in enhancing learning experiences. *International Journal of Applied Research in Social Sciences*, 6(4):642–663, 2024.
2. Matteo Zallio, Taihe Huang, Yutaka Osaki, Shiqi Hong, Xiaomin Chang, Wei Liu, and Takumi Ohashi. The ethics of immersion: A scoping review of vr and ar technologies. 2024.

3. Myeong-Ho Choi, Woongseob Han, Kyosik Min, Dabin Min, Gyuchan Han, KwangSoo Shin, Minseong Kim, and Jae-Hyeung Park. Recent applications of optical elements in augmented and virtual reality displays: A review. *ACS Applied Optical Materials*, 2024.
4. Jiachen Jiang, Guoyang Zhou, Brendan M Duffy, and Vincent G Duffy. Ar and vr–a review on recent progress and applications. In *International Conference on Human-Computer Interaction*, pages 46–63. Springer, 2023.
5. Belen Bermejo, Carlos Juiz, David Cortes, Jeroen Oskam, Teemu Moilanen, Jouko Loijas, Praneschen Govender, Jennifer Hussey, Alexander Lennart Schmidt, Ralf Burbach, et al. Ar/vr teaching-learning experiences in higher education institutions (hei): A systematic literature review. In *Informatics*, volume 10, page 45. MDPI, 2023.
6. Abdullah M Al-Ansi, Mohammed Jaboob, Askar Garad, and Ahmed Al-Ansi. Analyzing augmented reality (ar) and virtual reality (vr) recent development in education. *Social Sciences & Humanities Open*, 8(1):100532, 2023.
7. Mario A Rojas-Sánchez, Pedro R Palos-Sánchez, and José A Folgado-Fernández. Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies*, 28(1):155–192, 2023.
8. Tim Joda, GO Gallucci, Daniel Wismeijer, and Nicola U Zitzmann. Augmented and virtual reality in dental medicine: A systematic review. *Computers in biology and medicine*, 108:93–100, 2019.
9. ML Duarte, LR Santos, JB Guimarães Júnior, and MS Peccin. Learning anatomy by virtual reality and augmented reality. a scope review. *Morphologie*, 104(347):254–266, 2020.
10. Irene Neri, Laura Cercenelli, Massimo Marcuccio, Simone Lodi, Foteini-Dionysia Koufi, Antonietta Fazio, Maria Vittoria Marvi, Emanuela Marcelli, Anna Maria Billi, Alessandra Ruggeri, et al. Dissecting human anatomy learning process through anatomical education with augmented reality: Aeducar 2.0, an updated interdisciplinary study. *Anatomical Sciences Education*, 2024.
11. Nan Jiang, Zhongling Jiang, Yufeng Huang, Mingju Sun, Xuejing Sun, Yanjun Huan, and Fangzheng Li. Application of augmented reality models of canine skull in veterinary anatomical education. *Anatomical Sciences Education*, 17(3):546– 557, 2024.
12. Jesus Uribe, Derek Harmon, Benjamin Laguna, and Jesse Courtier. Augmentedreality enhanced anatomy learning (a-real): Assessing the utility of 3d holographic models for anatomy education. *Annals of 3D Printed Medicine*, 9:100090, 2023.
13. Sadan Suneesh Menon. Arise-augmented reality in surgery and education. 2021.
14. GigXR. Homepage. https://www.gigxr.com/. Last accessed on July 12, 2024.
15. Francisco Javier Garcia Fierros, Jesus Jaime Moreno Escobar, Gabriel Sepulveda Cervantes, Oswaldo Morales Matamoros, and Ricardo Tejeida Padilla. Virtual cpr: Virtual reality mobile application for training in cardiopulmonary resuscitation techniques. *Sensors*, 21(7):2504, 2021.
16. Sławomir Konrad Tadeja, Thomas Bohné, Kacper Godula, Artur Cybulski, and Magdalena Maria Woźniak. Immersive presentations of real-world medical equipment through interactive vr environment populated with the high-fidelity 3d model of mobile mri unit. *Computers & Graphics*, 120:103919, 2024.
17. J Talbot, J Meyer, R Watts, and R Grasset. A method for patient set-up guidance in radiotherapy using augmented reality. *Australasian physical & engineering sciences in medicine*, 32:203–211, 2009.
18. Kazuo Tarutani, Haruyuki Takaki, Masataka Igeta, Masayuki Fujiwara, Ayako Okamura, Futo Horio, Yuki Toudou, Satoshi Nakajima, Kazufumi Kagawa, Masao Tanooka, et al. Development and accuracy evaluation of augmented reality-based patient positioning system in radiotherapy: a phantom study. *in vivo*, 35(4):2081– 2087, 2021.

19. John Venn, Christopher E Larkee, Guilherme JM Garcia, Vitaliy L Rayz, and John F LaDisa Jr. A workflow for viewing biomedical computational fluid dynamics results and corresponding data within virtual and augmented reality environments. *Frontiers in Medical Technology*, 5:1096289, 2023.
20. Yener Yüzüak and Halil Yiğit. Augmented reality application in engineering education: N-type mosfet. *International Journal of Electrical Engineering & Education*, 60(3):245–257, 2023.
21. Adurangba V Oje, Nathaniel J Hunsu, and Dominik May. Virtual reality assisted engineering education: A multimedia learning perspective. *Computers & Education: X Reality*, 3:100033, 2023.
22. Austun Ables. Augmented and virtual reality: Discovering their uses in natural science classrooms and beyond. In *Proceedings of the 2017 ACM SIGUCCS Annual Conference*, pages 61–65, 2017.
23. Håkon Swensen. Potential of augmented reality in sciences education. a literature review. 2016.