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Review Article

Revolutionizing Anatomy Education: AI or VR - Which Technology will Dominate?

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Abstract

Anatomy education (AE) is poised for a substantial revolution, propelled by advancements in artificial intelligence (AI) and virtual reality (VR) technologies. These novel tools are set to transform the teaching and learning of anatomy, providing tailored, interactive, and immersive experiences that may improve student engagement, retention, and overall educational outcomes. The combination of AI and VR technologies in anatomy teaching can furnish students with a more thorough comprehension of the human body, facilitating a profound appreciation for the intricacies of anatomy. Furthermore, AI and VR technologies can enhance the cultivation of critical thinking and problem-solving abilities, which are vital for success in the medical field. AI and VR technologies can facilitate the connection between theoretical knowledge and practical application by offering students engaging and immersive learning experiences. Moreover, these technologies facilitate students' exploration of the human body in a highly detailed and realistic way, enabling them to visualize and engage with intricate anatomical processes. We hypothecate that the future of AE hinges on the integration of AI and VR as learning tools.

Keyword: Cadaveric Dissection, AI, Virtual Reality, Learning Anatomy.

INTRODUCTION

Anatomy education (AE) is an essential aspect of healthcare professional training, equipping students with a thorough knowledge of the human body and its many layers. A robust understanding of anatomy is essential for diagnosis, therapy, and patient management. Anatomy education equips students with an in-depth comprehension of the structure of the human body, fostering a profound grasp of regional relationships and a deeper appreciation for the interdependencies of human systems [1]. Anatomy education (AE) plays a pivotal role in cultivating a comprehensive set of clinical competencies, including diagnostic proficiency, therapeutic expertise, and holistic patient care. A sound knowledge of anatomy is needed by healthcare professionals to deliver high-quality patient care, make accurate diagnoses, or develop effective treatment plans. Although adherence to protocols and reliance on pattern recognition, or so-called proficiency-based medical care, may facilitate the execution of medical tasks, a profound grasp of anatomy is indispensable for delivering optimal patient care. In the absence of a robust foundation in anatomy, healthcare professionals may lack the contextual understanding and insight necessary to make informed decisions and adapt to complex clinical scenarios. Medical procedures, unaccompanied by a deep grasp of anatomical principles, are insufficient to provide a foundation for future professional development. Anatomy education provides a solid foundation for career development and patient care [1, 2].

Traditional Methods of Anatomy Education

For centuries, AE has relied heavily on time-honored approaches, including hands-on cadaveric dissection and traditional classroom lectures, to form the cornerstone of medical training. While these methods have been generally effective, they have several limitations. Cadaveric dissection can be time-consuming and is often limited by the availability of body donor cadavers. Didactic lectures, on the other hand, can be

passive and lacking in interactivity [3]. Moreover, traditional methods of anatomy teaching may be limited in their ability to provide students with a comprehensive knowledge of human anatomy. Cadaveric dissection can furnish students with a detailed appreciation of human anatomy; yet, it may be constrained in its capacity to elucidate the interrelationships among various anatomical structures. While didactic lectures excel at imparting a broad, conceptual grasp of human anatomy, they often fall short in replicating the tactile, experiential learning that is essential for developing a deeper, more nuanced understanding of the subject. Despite their efficacy, all teaching methodologies, including lectures, group work, and dissection, possess inherent limitations, thereby necessitating a multifaceted approach to achieve optimal learning outcomes. Nevertheless, a concerning trend has emerged over the past decade, wherein medical curricula have been restructured to allocate diminished time and content to anatomical sciences [4, 5]. The rationale underlying this paradigm shift remains a topic of intense debate, with potential contributing factors including the perceived complexity of the subject matter and the prioritization of specialized knowledge acquisition in advanced training.

The Role of Technology in Anatomy Education

Technology possesses the capacity to revolutionize AE by providing novel alternatives to conventional pedagogical approaches. Artificial Intelligence (AI) and Virtual Reality (VR) are two technologies that have demonstrated considerable potential in AE [6, 7]. Additional developing technologies, such as visual dissection tables, digital anatomy platforms, 3D printing, augmented reality, and haptic technology, are being investigated for their prospective applications in AE [8]. Furthermore, technology can enhance the creation of individualized learning experiences, allowing students to progress at their own pace and concentrate on specific areas of interest [8, 9]. The integration of learning technologies facilitates real-time feedback, allowing students to monitor their progress and target areas for improvement. Additionally, technology-mediated platforms can cultivate collaborative learning environments, enhancing communication and teamwork among students [10, 11].

Artificial Intelligence in Anatomy Education

AI has already begun to make a significant impact on anatomy education, with applications ranging from adaptive learning systems to automated assessment tools [11, 12]. A principal advantage of AI is its capacity to personalize learning experiences, adjusting content and difficulty levels to meet the specific needs of individual learners. AI-driven anatomy education platforms can offer immediate feedback, assisting students in pinpointing areas requiring improvement [13, 14]. Moreover, AI can facilitate the development of intelligent tutoring systems, enabling students to receive one-on-one instruction and guidance. AI can also provide students with access to vast amounts of anatomical data, enabling them to explore the human body in a highly detailed and realistic manner. Furthermore, AI can facilitate the development of virtual labs, with zero risks to students or the environment [7-15].

Virtual Reality in Anatomy Education

VR technology enables students to explore the human body in a highly immersive and interactive manner, allowing them to visualize and interact with complex anatomical structures. VR can also be utilized to simulate medical situations, giving trainees a secure and controlled setting to exhibit what they have learnt [17]. Moreover, VR can facilitate the development of experiential learning experiences, enabling students to learn by doing rather than just reading or listening. VR can also provide students with access to rare or unusual anatomical specimens, enabling them to explore the human body in a highly detailed and realistic manner [17, 18]. As previously mentioned, virtual reality (VR) enhances collaborative learning by facilitating interactive group work, peer-to-peer knowledge sharing, and collective expertise development, ultimately leading to improved student understanding and retention [18, 19].

Comparison between AI and VR

AI and VR are two distinct technologies that are transforming AE. While AI excels in analyzing and processing vast amounts of anatomical data, VR shines in creating immersive and interactive learning experiences [7, 20]. With regards to AE, AI-powered adaptive learning systems modify lessons to the learner's abilities. In contrast, VR-based interactive simulations can transport students into the human body, allowing them to explore and interact with virtual cadavers. When it comes to anatomy research, AI-driven algorithms can quickly identify patterns and correlations in large datasets of anatomical images. On the other hand, VR-based visualization tools can enable researchers to explore and analyze complex anatomical structures in 3D [22, 22]. We hypothecate that the synergistic integration of AI and VR has transformative potential in anatomical education (AE), revolutionizing the field in unprecedented ways. The combination of AI's analytical capabilities with VR's immersive features, can elevate anatomical sciences to new heights, driving accelerated discovery and innovation.

Challenges and Limitations

Despite the potential benefits of AI and VR in anatomy education, several challenges and limitations must be addressed. These include, but are not limited to, the issue highlighted herewith.

Cost

One of the primary challenges associated with the adoption of AI and VR technologies in anatomy education is cost. AI and VR technologies can be expensive, making them inaccessible to some institutions and students. The cost of purchasing and maintaining AI

and VR equipment, such as head-mounted displays and haptic feedback devices, can be prohibitively expensive for many institutions. Furthermore, the cost of developing and licensing high-quality, anatomically accurate content for AI and VR platforms can be substantial [23]. Moreover, the cost of training faculty and staff to effectively integrate AI and VR technologies into their teaching practices can also be a significant challenge. Institutions may need to invest in professional development programs to equip faculty and staff with the expertise to harness the full potential of AI and VR technologies in the classroom.

Technical Difficulties

Another challenge associated with the adoption of AI and VR technologies in anatomy education is technical difficulties. AI and VR technologies can be prone to technical difficulties, such as glitches and lag, which can disrupt the learning experience and reduce student engagement. Technical difficulties can also make it difficult for faculty and staff to effectively integrate AI and VR technologies into their teaching practices [24]. Furthermore, technical difficulties can also limit the accessibility of AI and VR technologies for students with disabilities. For example, students with visual or hearing impairments may require specialized equipment or software to access AI and VR content, which can be a significant challenge.

Limited Content

A third challenge in the adoption of AI and VR technologies in AE lies in the paucity of high-quality anatomical content that can fully leverage these state-of-the-art resources. There may not be as much high-quality, anatomically accurate content available for AI and VR platforms as there is for traditional teaching methods. Such constraints can limit the effectiveness of these technologies and lead to student disapproval [11-24]. Moreover, the development of high-quality, anatomically accurate content for AI and VR platforms can be a significant challenge. Content developers must be anatomists with a profound understanding of anatomy and the needs of anatomy students, as well as the technical skills and knowledge to develop effective AI and VR content.

Faculty Training

A fourth challenge pertinent to the adoption of these technologies in AE is faculty willingness for re-training. Faculty may require training to effectively integrate AI and VR technologies into their teaching. Such an undertaking can be a significant challenge, as faculty may need to learn new technical skills and pedagogical approaches to effectively use AI and VR technologies in the classroom [7, 25]. Furthermore, faculty training can also be a challenge due to the rapidly evolving nature of AI and VR technologies. Faculty may need to continually update their skills and knowledge to keep pace with the latest developments in AI and VR, which can be a significant challenge.

Student Accessibility

Another challenge to adopting AI and VR technologies in anatomy education is ensuring student accessibility, as some students may lack access to these technologies outside the classroom, potentially limiting their engagement and learning opportunities. This can be a significant challenge, as students may need to access AI and VR content outside of the classroom to complete assignments or prepare for exams [8, 26]. Moreover, student accessibility can also be a challenge due to the digital divide. Some students may not have access to the necessary hardware or software to access AI and VR content, which can limit their ability to engage with these tools. Institutions may need to provide students with access to AI and VR technologies outside of the classroom, such as through computer labs or virtual reality centers. This is particularly true in developing countries and especially sub-Saharan Africa [27].

Figure 1: Cadaveric dissection provides a tactile experience, while virtual dissection offers enhanced accessibility and interactive visualization. A blended approach, combining both methods, creates a comprehensive learning experience, enhancing student understanding and retention of anatomical knowledge. This hybrid model prepares students for success in anatomical and clinical practice

Figure 2: A Depiction of AR and VR in Teaching Human Anatomy
Source: https://www.ixrlabs.com/blog/how-effective-is-virtual-reality-in-teaching-human-anatomy/

Sub-Saharan African Countries and Other Developing Nations

It is pertinent to mention developing nations, as our planet Earth is often described as a global community, which is indeed the present reality. The COVID-19 pandemic and world wars serve as examples; they didn't originate in poor nations, yet their impact was felt globally. Similarly, practical or full-fledged AI technology, as well as VR, come with costs. How would developing nations cope with these technologies, given their unique challenges?

The adoption of AI and VR in anatomy education in sub-Saharan Africa faces significant challenges, including limited access to technology, inadequate infrastructure, resource scarcity, brain drain, and restricted access to electricity, all of which collectively pose substantial hurdles. Many institutions lack even the most basic technologies, such as computers and internet connectivity, while outdated technology and scarce funding hinder the development and implementation of AI and VR content. The brain drain in the region has, arguably, led to a shortage of skilled professionals who could develop and implement AI and VR content, Additionally, the lack of infrastructure, such as reliable electricity and internet connectivity, makes it difficult to maintain and support AI and VR technologies. However, despite these challenges, the outlook is bright for sub-Saharan Africa. Just as GSM technology has become ubiquitous in the region, AI and VR technologies can also become commonplace as education tools. With the increasing access to affordable digital devices, many Africans are gaining access to the internet and digital technologies. This growing digital landscape creates an environment conducive to the adoption of AI and VR technologies in AE. Interestingly, the "African Union's Digital Transformation Strategy" is driving digital-growth across Africa Also, the United Nations' Sustainable Agenda promotes the development and application of digital technologies, including AI and VR. With continued investment and support, AI and VR technologies can become integral tools for anatomy education in sub-Saharan Africa, enhancing the learning experience and improving healthcare outcomes.

Future Directions

Despite these challenges, the future of AI and VR in anatomy education looks promising. As these technologies continue to evolve and improve, we can expect to see even more innovative applications in the field. Some potential future directions suggested in literature [7, 28 - 29] include:

Personalized Learning:

AI-driven adaptive learning systems facilitate personalized education by generating bespoke learning plans tailored to individual students' cognitive profiles, learning styles, and aptitudes. Through continuous assessment and curriculum 'remolding', these systems enable targeted knowledge acquisition, reinforce existing strengths, and optimize learning trajectories. This tailored approach fosters enhanced academic performance, boosts student engagement, and streamlines instructional time, ultimately yielding a more efficacious and efficient educational experience.

Immersive Learning Environments:

Virtual Reality (VR) technology facilitates the development of highly immersive and realistic simulated learning environments that accurately replicate complex clinical scenarios. These virtual settings enable students to develop and refine their skills in a safe, controlled, and experiential manner, free from the constraints of traditional learning environments. By simulating a broad spectrum of scenarios, including routine procedures and high-acuity emergency situations, VR technology provides students with unparalleled opportunities for skill acquisition and refinement, while prioritizing patient safety. Through strategic integration of VR, educators can craft impactful, experiential learning experiences that enhance knowledge retention, boost confidence, and foster competency.

Collaborative Learning:

The integration of AI and VR technologies enables immersive collaborative learning experiences, allowing students to engage in interactive virtual projects that promote teamwork, communication, and in-depth understanding of complex anatomical concepts. Virtual platforms facilitate dynamic learning activities through features such as virtual breakout rooms, collaborative workspaces, and real-time feedback tools, fostering a sense of community and collective purpose. This collaborative virtual environment cultivates essential skills in teamwork, problem-solving, and critical thinking, preparing students for effective interdisciplinary collaboration.

Virtual dissection table

This technology simulates real human dissection on a dissection-table size, digital interface. The Anatomage® virtual dissection table is a revolutionary digital teaching tool that has an impact on the way students learn anatomy. It allows users to reconstruct CT scans and sectional images, providing an unparalleled level of detail of the human body. Students can explore the virtual anatomy, examine features across multiple planes, manipulate cross-sections, and accurately locate structures, making connections between anatomical regions. This immersive experience enables students to visually dissect virtual cadavers with stunning near reality. It enables unparalleled detail with magnification capabilities, a valuable resource for anatomy education.

Notwithstanding its numerous benefits, the Anatomage table's adoption is hindered by a significant limitation: its substantial cost and associated licensing requirements render it inaccessible to many anatomy departments in resource-constrained settings, particularly in developing countries. In addition, in developing countries, cadavers are much easier to acquire [30, 31]. Secondly, it lacks the real feelings of actual dissection [32, 33]. Notably, our experience suggests that students who have completed cadaveric dissection benefit most from the virtual table, leveraging it as a tool for review and in-depth learning. Considering the enormous cost of Anatomage® tables compared to AI and VR technologies, the latter offer a more promising and cost-effective solution for anatomy education in developing countries, particularly in sub-Saharan Africa. Nevertheless, for those institutions and students who have access to this remarkable technology, the Anatomage® virtual dissection table is an unparalleled tool for exploring the wonders of human anatomy.

Augmented Reality (AR)

While often conflated, Virtual Reality (VR) and Augmented Reality (AR) are distinct technologies. While both technologies manipulate the user's perception of reality, they differ fundamentally in their approach. VR envelops users in a fully immersive, computer-generated realm, entirely supplanting the physical world with a simulated environment that revolutionizes the way we interact, experience, and perceive reality. This is typically achieved through the use of a headset or other device that provides a 360-degree view of the virtual world. In contrast, AR seamlessly merges the physical and digital realms, overlaying relevant information, virtual objects, and sensory experiences onto the real world, thereby enhancing and redefining the way we interact with our surroundings. AR is a complementary technology with its unique applications and use cases. While VR seeks to replace reality, AR aims to augment and enhance it [34]. This distinction highlights the unique strengths and capabilities of each technology and underscores the importance of understanding their differences in order to harness their full potential [21-35].

However, when considering the learning of anatomy, particularly from a developing nation's perspective, VR and AI seem to offer sufficient benefits, at least for the time being. The immersive and interactive nature of VR, combined with the analytical capabilities of AI, provides a powerful tool for anatomy education. This technology enables students to explore the human body in unprecedented detail, facilitating a deeper understanding of complex anatomical structures. Furthermore, the cost-effectiveness and accessibility of VR and AI make them an attractive solution for resource-constrained environments. As such, the integration of VR and AI in anatomy education has the potential to revolutionize the way students learn and understand the human body.

CONCLUSION

The future of AE is poised for a transformative leap, driven by the synergy convergence of AI and VR technologies. As these two innovations continue to evolve in tandem, their combined potential will unlock unprecedented opportunities for immersive, personalized, and effective learning experiences. Neither AI nor VR can single-handedly revolutionize anatomy education; rather, their collaborative integration holds the key to unlocking a brighter future. Harnessing the strengths of both AI and VR will create a holistic learning environment that not only enhances knowledge retention and understanding but also fosters the development of professional cognitive skills. The success of this endeavor depends on educators, researchers, and technologists working together to overcome the challenges and limitations associated with the adoption of AI and VR in anatomy education. Together, we can empower the next generation of healthcare professionals to excel in their fields and improve patient outcomes.

Nevertheless, for prospective surgeons, the “cadaver lab" serves as a crucible of education. The weight of duty is tangible when novice hands meticulously traverse and explore the anatomy of the

human body. As fingers apply pressure on tissue, students discern the subtleties of each layer's reaction, learning to differentiate delicate regions from those that exhibit resistance. Assumptions are contested as tendons are erroneously identified as nerves, exposing the intricacy of human anatomy. In this pulsed environment, the distinctions between education and experience converge. Students, at the onset of their medical training, are irrevocably transformed by the tactile experience of the cadaver lab. As they explore the complexities of the human body, they grow to recognize the seriousness of their future career and the significant responsibility associated with handling a scalpel.

Ultimately, the optimal integration of anatomy technologies lies in their judicious application as adjuncts to, rather than replacements for, traditional cadaveric dissection, thereby empowering future healthcare professionals to attain excellence in their fields and improve patient outcomes.

Conflict of Interest: None

Authors Contributions
CAO: Conception, research, re-validation, and write-up.
MTO: Validation, research, and write-up.

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