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Harnessing 3D Technology to Transform Anatomy Education

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ABSTRACT

A comprehensive understanding of anatomical structures is essential for medical and healthcare students, as it forms the foundation for clinical evaluations, surgical interventions and diagnostic imaging. The conventional methods employed in anatomy education, which mainly comprise the use of textbooks, lectures and cadaver dissections, could be improved. Such changes could include converting two-dimensional anatomical representations into three-dimensional (3D) structures to help address the ethical and logistical challenges related to cadaver use. Due to technological advancements, 3D technologies, such as virtual reality, augmented reality and mixed reality, can provide students with immersive and interactive learning experiences that improve their understanding of complex anatomical linkages and spatial orientation. Furthermore, 3D models offer a practical and morally acceptable alternative to the use of accurate cadaveric material. Research has shown that 3D models increase student involvement and enthusiasm. Despite the numerous advantages of incorporating 3D technology into anatomy education, several barriers must be addressed. These include faculty training and the significant financial investment needed to acquire equipment and licenses. Additionally, senior faculty members may face challenges in adapting to new technologies. Notwithstanding these obstacles, 3D technologies are valuable due to their long-term advantages, such as improved educational quality and the potential to attract higher numbers of students. By incorporating such technological advances in anatomy instruction, educational institutions can enhance students' preparation for the challenges of modern clinical practice and create dynamic and engaging learning environments.

Keywords: *Clinical reasoning, Cognitive process, Assessment methods, Evaluation, Nursing students*

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INTRODUCTION

Understanding the concepts, structures and relations in anatomy is crucial for medical and healthcare students during their undergraduate training, as it serves as the foundation for clinical examinations, surgeries and imaging (1). Conventional anatomy education, which is mainly dependent on the use of textbooks, lectures and cadaver dissections, poses various difficulties. The main problem is the need for students to comprehend three-dimensional (3D) anatomical structures from two-dimensional (2D) representations and depictions, which can be challenging (2). The intricate nature of embryological development further complicates the task, as it introduces an additional level of complexity in understanding the anatomical transformations that occur over time.

Furthermore, the dependence on cadaveric material presents ethical and logistical concerns (3). Obtaining cadavers may be restricted due to regulations, limited availability and constraints on school funds. When cadavers are available, their dissection may be daunting for students and may only partially reproduce the dynamic characteristics of living anatomy. Although cadaver dissection offers an engaging learning experience, it also presents difficulties, among them the storage of specimens, the potential health hazards associated with formaldehyde exposure during embalming, and the emotional strain it may impose on students (3, 4). Because of their static character, cadaveric specimens do not effectively represent the physiological components of anatomy in a living person.

The recent advent of 3D technologies in anatomy education offers a potential solution to these difficulties. By providing immersive and interactive learning experiences, 3D technologies can enable students to perceive intricate anatomical systems in ways that conventional approaches cannot (5, 6). Through the utilisation of 3D holograms, virtual reality (VR), augmented reality (AR) and mixed reality (MR) technologies, students can access authentic 3D models that they can alter, observe from various perspectives and engage with in real time. The integration of 3D technologies in medical education is becoming more prevalent. For example, surgeons use preoperative 3D images from contrast-enhanced computed tomography and magnetic resonance imaging to make clinical decisions and plan surgeries. Moreover, by utilising modern visualisation techniques, it is now possible to conceptually rebuild volumetric pictures in 3D, which allows for an improved understanding of lesions and vascular structures that could previously only be observed in 2D.

VR provides a fully immersive experience by allowing users to detach from the real world and fully engage with the virtual environment. This technology has undergone assessments for application in training and various therapeutic tasks (7). AR superimposes computer-generated pictures over the physical world to improve users' perceptions and interactions with their surroundings, while MR systems enhance the user experience by smoothly incorporating virtual items into the real world to enable interactions that include both dimensions (8, 9). 3D printed models, digital 3D visualisations, and AR/VR applications provide more accessible, practical and immersive ways of studying human anatomy and can thereby facilitate an understanding of the spatial relationships between different structures (10, 11). Furthermore, the development of 3D hologram technology presents numerous distinct benefits compared to VR and AR. It is significantly lighter and more portable, which allows its application in different environments (12, 13). 3D holograms are also viewable from any perspective, which is valuable for students who are learning intricate medical procedures and surgeries.

The rapid advancements in technology and the increasing use of e-learning require a reassessment of anatomy teaching. By utilising 3D technologies, educational institutions could offer tailored and captivating anatomy instruction, thereby overcoming the constraints of conventional approaches and equipping students for the intricacies of contemporary clinical practice.

BENEFITS OF INTEGRATING 3D TECHNOLOGY INTO ANATOMY EDUCATION

There are many compelling reasons to employ 3D technology learning tools in anatomy education. First, 3D technology offers students immersive and interactive learning experiences, which enable them to discover and visualise complex anatomical systems in ways that surpass traditional textbook and lecture-based learning methods (14). Thus, students can develop a more profound understanding of these systems' spatial arrangements (14). Second, 3D technology can help improve students' engagement in and motivation for anatomy learning. In a previous study (15), students reported increased engagement in learning when they were exposed to 3D anatomy models compared to traditional methods of teaching. Furthermore, researchers in a separate study (16) suggested that students' perceived acceptance of technology can help improve their ability to engage in self-regulated learning by enhancing their intrinsic motivation and increasing their learning engagement. Third, the use of 3D technology can help bridge gaps in anatomy education, particularly in situations where access to cadavers and other materials may be limited or restricted. 3D models offer a safe and ethical alternative to cadaveric materials, and they can be used to supplement or, in some cases, replace traditional teaching methods (17, 18).

In many UK medical schools, the extent of the use of the conventional method of anatomy teaching using cadaveric dissection has been reduced or substituted with more modern approaches, such as prosection, plastic models and multimedia-based learning packages (19, 20). VR has been integrated into neuroanatomy teaching in Latin America, and a study was conducted in the region to assess the efficacy of providing neuroanatomy instruction using VR. The findings indicated that the students who received instruction with VR exhibited a higher level of proficiency in describing images, including neighbouring structures, than those who were not taught using VR (21). In China, the Peking Union Medical College developed virtual learning resources (VLR) for its medical students (17), and a study was undertaken to compare the results of teaching with VR vs. conventional teaching methods. The researchers found that using skull VLR was effective in teaching anatomical structures when used with cadaver skulls and atlases. A model of this nature can assist people in comprehending intricate anatomical components while maintaining a high level of motivation and manageable side effects.

Studies on student satisfaction with 3D technology in anatomy training have shown significant results (17, 22, 23). Students have frequently shown higher levels of involvement and contentment when using 3D technology to understand anatomical features than when traditional methods are used (24–26). Students appreciate the immersive and interactive features of 3D technology because they can boost the students' understanding of the spatial relationships inside the human body and improve their overall learning experience. Furthermore, students have reported that using 3D tools offers increased flexibility and diversity in instructional approaches, which cater to different learning styles and preferences.

CHALLENGES TO USING 3D TECHNOLOGY TOOLS IN ANATOMY EDUCATION

There is consensus among researchers that 3D and virtual technologies represent accessible and cost-effective options for delivering anatomy teaching without compromising the quality of students' learning opportunities (5). Furthermore, studies have demonstrated how such technologies can be designed for personalised use, which could provide an effective adjunct for self-directed learning and supplement traditional classroom methods (5). Although 3D technologies have the potential to revolutionise anatomy teaching, they also present certain challenges for universities in terms of commercialisation and integration into the existing curriculum. One of the major issues is the cost associated with adopting 3D technology tools to teach anatomy (27–29). As the demand for 3D technologies increases, the cost of acquiring the necessary equipment, such as high-resolution displays, head-mounted devices, and other essential hardware, is also increasing. For example, Epson Moverio BT-200 Smart Glasses cost approximately RM16K, HoloLens 2 by Microsoft costs around RM23K, and a 65" high-resolution display may range from RM6K to RM25K, depending on the brand.

In addition, most virtual atlas tools, which may be used on computers, laptops and smart devices, require the purchase of a licence. Institutions can, therefore, face significant financial burdens when obtaining the necessary licences for multiple devices, especially if they aim to provide 3D technology experiences to large numbers of students (30). Generally, different types of product packages are offered to institutions. These may be based on, for example, the number of users or devices, the licence period, and the addition of other features, all of which can further increase the cost. Apart from the direct costs, universities also need to invest in the appropriate IT infrastructure and technical support staff to ensure the smooth operation of these technologies. Moreover, institutions seeking the full immersive experiences offered by VR and AR need to purchase head-mounted devices for each student, which may constitute a significant investment.

Given these financial challenges, universities may prefer to maintain traditional methods of teaching rather than adopt 3D technologies. However, from a long-term perspective, investing in 3D technologies can be beneficial to universities, as they can increase the quality and effectiveness of teaching and attract prospective students who are seeking more innovative and engaging learning experiences (31). Institutions should, therefore, explore alternative financing mechanisms and seek collaboration with other institutions and private firms, for example, through partnerships and resource sharing, to mitigate the cost of acquiring and integrating 3D technologies into their curricula. Governments should also fund research and development efforts aimed at making 3D technologies more affordable and accessible to all institutions within the educational sector. While the cost of 3D technologies presents a significant challenge to universities seeking to integrate these tools into the anatomy curriculum, the potential benefits make them a worthwhile investment.

A further challenge to the use of 3D technology tools is that lecturers from older generations may lack technology. Research has shown that some older lecturers may have limited experience with using technology for teaching, and this may hinder their ability to adopt 3D technologies effectively. A study revealed that this lack of technical competence is a major barrier to the implementation of 3D technology in teaching (32), as older lecturers may struggle to navigate 3D software, troubleshoot technical issues and integrate the technology into their curricula effectively.

Notwithstanding, older lecturers may find the time and effort required to learn and implement 3D technology in teaching challenging. They may already have established teaching approaches and be hesitant to adopt new technologies because these would require

significant effort to learn and integrate into their curricula (33). The integration of 3D technologies may necessitate additional time to prepare and organise materials as well as to rearrange teaching styles and approaches.

Many lecturers may also face resistance from students who may prefer traditional teaching methods or find the technology unnecessary. Some students may feel intimidated by the technology or have difficulty using it, which may lead to frustration and resistance to the new approach (34, 35). Frustration involves processes that require an individual's cognitive resources to be redirected to activities that are extraneous to learning, which may inhibit students' learning processes and academic performance (34).

To address these challenges, lecturers can provide training sessions and workshops on the use of 3D technology, ensure ongoing technical support, and adopt a blended learning approach. Providing proper training and support may help older lecturers overcome the technological competence barrier and reduce the challenges associated with the integration of 3D technology that they may experience. Additionally, blending the technology into existing teaching methods can help reduce the time required to learn and teach the technology and improve its overall effectiveness (36).

ADVANCES IN AND THE FUTURE OF 3D TECHNOLOGY IN ANATOMY EDUCATION

The field of holographic technology has undergone a remarkable transformation with the advent of devices like the Microsoft HoloLens (Microsoft, United States) and the Magic Leap One (Magic Leap, Inc., United States). These state-of-the-art platforms are revolutionising the educational landscape, particularly in anatomy training. Pearson's HoloHuman (Pearson and 3D4Medical, United States), an application that empowers students and educators to delve into each layer of the human body comprehensively and interactively, marks a significant shift in how anatomy is understood and taught. Similarly, significant strides have been made with AR in education through the introduction of unique programmes like Anatomy 4D and Complete Anatomy (30, 37, 38). These programmes have leveraged AR interfaces to revolutionise the study of human anatomy and provide students and instructors with immersive journeys through the body's intricate systems. AR allows for the exploration of complex anatomical features using smartphones to unveil hidden organs and systems by peeling back layers or zooming in on specific components for a closer look (37).

The emergence of VR technology has also had a significant influence on medical education, with devices like the Oculus Rift (Oculus VR, United States) and HTC VIVE (HTC Corporation, Taiwan) being increasingly employed at educational institutions (39–41). These headsets have a variety of interactive capabilities. Software applications such as Anatomyou VR and Complete Anatomy have been created to provide students with exact anatomical models that may be studied from different viewpoints (30, 42).

Anatomy Studio is an innovative 3D technology and collaborative MR tool that allows virtual dissection using augmented 3D reconstruction. The process involves the use of a tablet to sketch and visualise anatomical structures by drawing contours on 2D images of genuine cross-sections (cryosections) using MR-based visualisation techniques. The tablet's interactive surface allows for a realistic drawing experience, while the 3D visualisation enhances users' understanding of the rebuilt information to a greater degree than conventional desktop methods. Users can utilise mid-air motions to engage with Anatomy Studio, thus allowing them to browse through the slices in the MR visualisation. Further,

Anatomy Studio facilitates real-time collaboration between multiple professionals so they can observe and communicate the adjustments each makes to the shapes. Consequently, this tool can assist students and surgeons in acquiring proficiency in surgical techniques.

Medical schools could focus their resources on providing appropriate educational instruments and promoting self-directed learning. This may be the area of education where technologically advanced teaching tools offer the most benefit compared to classrooms where standardised learning occurs. Although access to cadavers is not always possible, the existing anatomy curriculum is satisfactory and fit for purpose in many ways (17, 18). Nevertheless, readily available technological advancements, such as web-based applications, have transformed education, with a growing trend towards distance learning. Technology will likely shape the future of anatomy instruction in medical institutions. Therefore, it is essential for these institutions to determine the optimal way to incorporate technology into their instructional strategies for undergraduate medical students.

The knowledge gained during their medical education influences doctors' performance. Students and clinicians agree that anatomy knowledge is essential for effective clinical practice. It is thus concerning that anatomy is receiving less time in current new medical curricula than previously. To address this issue, it is crucial that resources tailored to student preferences are made available. It has been reported that students nowadays routinely utilise electronic resources to supplement their anatomy education (5). Medical schools that implement and formally support innovative anatomy learning methods will certainly empower students in their anatomy studies considerably more than those schools that do not.

CONCLUSION

Incorporating 3D technology in anatomy education offers an innovative solution to the limitations of conventional teaching approaches. VR, AR, MR and 3D modelling are technologies that offer immersive and interactive learning experiences. These technologies improve the ability of students to see and comprehend complicated anatomical structures. They also provide secure and morally acceptable substitutes for cadaver dissection, strengthen students' involvement and motivation, and improve their educational achievements.

While adopting 3D technology may pose financial and technological challenges, its strategic benefits, such as improved educational quality and the ability to attract technologically proficient students, far outweigh the costs. Institutions should proactively explore alternative funding methods, provide comprehensive training, and foster a culture in which these resources are progressively integrated into the curriculum to reap the long-term rewards.

The ongoing developments in 3D technology will further influence anatomy teaching by enhancing its levels of interactivity and efficacy. Medical schools can enrich students' education by adopting these technological advances to provide students with the necessary information and abilities for modern clinical practice and thereby secure a more promising future for healthcare education.

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