REVIEW ARTICLE

Augmented Reality (AR) and Virtual Reality (VR) Applications During Covid-19 Pandemic Among Preclinical Medical and Dentistry Students: A Mini-Review

Nurul Hayati Mohamad Zainal[1], Rosmaliza Ramli[2], Norsuhana Omar[3], Melati Mahmud[4], Noor Hafizah Abdul Salim[5]

[1] Department of Human Anatomy, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2] Basic and Medical Sciences Unit, School of Dental Sciences, Universiti Sains Malaysia, Health Campus,16150 Kubang Kerian, Kelantan, Malaysia
[3] Department of Physiology, School of Medical Sciences, Universiti Sains Malaysia, Health Campus,16150 Kubang Kerian, Kelantan, Malaysia
[4] Centre for Restorative Dentistry Studies, Faculty of Dentistry UiTM Selangor Branch, UiTM Sungai Buloh Campus, Jalan Hospital, 47000 Sungai Buloh Selangor, Malaysia
[5] Department of Medicine, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ABSTRACT

The efficacy of online learning in delivering theoretical knowledge with appropriate content to students is imperative, especially in the Covid-19 pandemic era. Substantial interactive teaching materials were developed for higher education. However, some were designed immensely general, especially in fulfilling the syllabus of preclinical medical and dentistry students. Augmented reality (AR) is an interactive three-dimension (3D) experience that uses computers to overlay virtual information in the real world whereas virtual reality (VR) is a computer-generated artificial recreation of a real-life experience or situation. Interestingly, both can be complemented and integrated into online and traditional teaching methods. Implementation of these technologies will increase the learning efficacy in understanding the human body's anatomical and physiological changes in the normal or pathological state. As AR and VR technologies are continuously evolving, this review provides the preview and current updates on AR and VR applications in medical and dentistry education which may benefit the educators within these specialities.
Malaysian Journal of Medicine and Health Sciences (2022) 18(14)131-143. doi:10.47836/mjmhs18.s14.15

Keywords: Augmented reality, Virtual reality, Preclinical, Medical students, Dentistry students.

Corresponding Author:
Nurul Hayati Mohamad Zainal, PhD
Email: mz_nurul@upm.edu.my
Tel: +603-97692330

INTRODUCTION

Online learning has become a compulsory new norm for teaching engagement, especially during the pandemic era of coronavirus disease 2019 (Covid-19). This is because of the requirement to adhere to the new policy of social distancing which can reduce the possibility of contracting Covid-19. During the Covid-19 pandemic, all face-to-face (FTF) conventional practical engaging methods are not permitted, which negatively affects the comprehension and assimilation of the subjects. SARS-CoV-2, the virus that causes Covid-19, is transmitted mostly through infected respiratory droplets, with viral infection occurring through direct or indirect contact with nasal, conjunctival, or oral mucosa [1]. The immediate environment of an infected individual can serve as a source of transmission [2]. As social distancing is crucial to minimise the risk of SARS-CoV-2 transmission, online learning that requires no FTF interaction has become the most preferred and recommended method of teaching worldwide during this pandemic. However, online learning-dependency only is not the best practice in teaching preclinical medical and dentistry students. Supplemental learning aids, which include augmented reality (AR) and virtual reality (VR) elements are almost equally important to help them empower the required knowledge.

The preclinical years of the medical and dentistry students are packed with the syllabus of basic science knowledge to prepare students for the latter clinical years [3]. Basic science subjects such as anatomy and physiology require the visual-spatial ability, which is described as the ability to mentally manipulate objects in three-dimensional (3D) figures [4]. The ability to mentally visualize, identify and relate the 3D structures is a critical skill especially in learning the human anatomical structures that are presented in various planes and positions. Medical and dentistry students may benefit from the accessible and cost-effective AR and VR technologies to gain strong foundations in basic clinical knowledge and adequate exposure to prepare themselves for later clinical years.

AR is an interactive 3D experience that uses computers to overlay virtual information in the real world [5]. The AR display a semi-true image, which is a virtual object that is the combination of a real and virtual world which expands or enhances reality with computer-generated elements via the real environment by a mobile phone, tablet or AR glasses. The method of AR technology entails identifying the target object, tracking the detected objects, and superimposing virtual graphics onto the tracked object, which is then presented to them via a display device [6]. To date, AR is classified into three categories, (1) marker-based AR: in which the black box serves as a marker for simpler identification and tracking; (2) markerless AR: in which the natural pattern, which can include pictures, is identified and tracked; and (3) location-based services (LBS) AR: LBS is the GPS positioning function on a mobile device that provides current location information [7].

VR is a computer-generated artificial recreation of a real-life experience or situation. It immerses the user by giving them the sensation of being engaged in a simulated reality, mostly by real-time simulation of visual and audience. Immersion and engagement are the two most important aspects of VR. Immersion denotes the operator's presence in the virtual environment, while interaction denotes the operator's ability to modify [8, 9]. The user is immersed in a simulated environment that is experienced through sensory stimuli (sight, hearing, and motion) that mirror the qualities of the real world. These qualities include high-resolution head-mounted displays, stereo headphones, and motion-tracking systems that are updated constantly [10]. With VR, people can engage efficiently with 3D computerised databases in real-time utilising their natural perception and skills. The key strength of VR, whether in design or training, is that it supports and improves real-time user interaction [8].

AR and VR applications are gaining popularity in medical and dental undergraduate education, as they provide dynamic interactive learning ideas with continuous access and objective evaluation [9]. Both may complement the traditional and online teaching methods for the students to understand the anatomical and physiological changes in the human body system in the normal or pathological state [11]. These methods will allow the students to study the human body system more effectively as compared to the traditional FTF learning method that traditionally utilizes cadavers [12]. Despite cadavers constituting the gold standard for teaching anatomy to medical and dental students, there are significant constraints on their use [10]. AR and VR technologies have specific advantages as compared to conventional cadavers. Using AR and VR technologies, medical lecturers can teach the human body system in a more entertaining approach with less financial, ethical, and supervisory constraints.

Many interactive online teaching materials that embrace AR and VR elements have been developed for higher education. By implementing visual representations of complicated structures and mechanisms, hands-on experience with visual models has the potential to improve online learning environments [13]. Despite their significant advantages, the use of visual models in undergraduate classrooms is still very minimal, especially in teaching preclinical medical and dentistry students. AR and VR applications serve not only as an online teaching method but are essential supplementary methods in complementing traditional teaching. This review provides the preview and current essential updates on AR and VR technologies used in medical and dental teaching which will benefit educators within these specialities. In this review, we aim to discuss the application, types, outcomes, advantages and disadvantages of using AR and VR in teaching these students.

AR AND VR APPLICATION IN TEACHING PRECLINICAL MEDICAL AND DENTISTRY STUDENTS

AR and VR applications in higher education

Online classrooms, interactive-technologies-to-replace-hands-on-learning, AR and VR are among the alternatives for remote learning for medical and dental students during the Covid-19 pandemic [14]. Before the Covid-19 pandemic, a survey amongst dental and medical students has already shown students' preference for virtual learning over traditional methods [15]. Studies have also demonstrated that AR provided a motivational drive during remote learning [16]. A scoping review of 21 articles indicated that professionals and students from different medical specialities trained via VR demonstrated a higher level of accuracy in their medical practice [17].

Preclinical medical and dentistry in anatomy, physiology and pharmacology

Despite the relatively expensive technology and other difficulties to incorporate AR into university education, several institutions across the globe including Malaysia have attempted to adopt AR and VR in their education system [18]. The medical, dental and health education systems are no exception. These advanced technologies have been applied in both preclinical and clinical teaching to improve students' learning experience and understanding [19-23]. AR and VR technologies are developed to fill in the gaps in the education delivery system where it helps the student to visualise abstract contents more clearly using 3D graphics instead of textual data [24]. These technologies are convenient to students as they can visualise the abstract contents using their mobile devices or the more cutting edge method-immersive visualisation using a head-mounted display device that undergoes continuous improvement for better visualisation and application. [25].

Anatomy is one of the preclinical subjects that involves detailed identification of different structures in the human body. Although the previous method of learning human anatomy using a human cadaver allows students to study anatomical structures with uttermost detail and precision, there are limitations to using this method. Issues related to ethics in using the human body and cadaver availability [26], hazards from chemicals used to fix and preserve cadavers [27, 28], and supervisory [29], pose challenges to teaching anatomy.

During the Covid-19 pandemic, the traditional methods of learning anatomy such as cadaveric dissection and plastination have been replaced by more advanced methods that allow remote learning using cutting-edge technologies—AR and VR [30]. The rise of AR and VR technologies has overcome these problems by providing alternatives where students can individually learn the body structure with no risk of chemical exposure and no or minimal supervisory requirement. In this regard, the use of AR and VR is gaining much interest among students due to their convenience and exciting way of learning [31, 32]. Different AR and VR modules such as the non-immersive 3D construction of skeletal system uploaded onto augmented repository and viewed via mobile devices [31] and the immersive head-mounted display AR with interactive virtual skull application for learning skull anatomy [33] are more preferred by students due to its more exciting and active way of learning and its visuality. However, minimal adverse effects have also been reported in students learning anatomy using these technologies. Headaches, dizziness and blurred vision are the common side effects complaint by students during their lessons [10].

A meta-analysis and systematic review on the impacts of AR and VR on knowledge acquisition of preclinical study on anatomy and physiology identified a non-significant difference in students' test performance between AR and VR and traditional delivery methods. The data indicate that these technologies provide viable alternatives to traditional methods especially when actual specimens are not available [34]. A recent pilot study comparing performance, anxiety level and learning experience in students undergoing AR (Microsoft HoloLens) and traditional projector-based Microsoft PowerPoint was conducted. Students learning via the AR method had a significantly higher preference for the learning experience with a lower level of anxiety during tests as compared to those using the traditional method. Their results demonstrated that AR could improve the psychological aspects of students during the learning process and tests [32]. Similar results have also been demonstrated in a study by Guerrero et al. [31]. Although there are arguments regarding the effectiveness of immersive AR and VR, the use of both non-immersive 2D and 3D methods has been recommended for teaching anatomy [35].

In pharmacology, the use of computer-assisted learning (CAL) has been introduced many years ago to minimise and replace the use of animal tissues and laboratory experiments in understanding pharmacological actions in living organisms [36, 37]. The use of animals for undergraduate students raises concerns as the learning objectives for these student is to focus on the assessment of cognitive and not psychomotor domain. Hence, Some educationists argue that the cognitive domain which focuses on the observational, analytical and interpretative skills can be fulfilled and achieved via CAL [38, 39]. For this reason several countries have phased out animal experiments in undergraduate teaching [40]. More recent advances such as high-fidelity patient simulation (HFPS) adopt both the use of digital and state-of-the-art virtual technologies to bridge pharmacodynamics with its clinical responses in a human model [41]. These alternative methods are validated by national and international bodies worldwide including Europe, the United States, Canada, Japan and Korea, to ensure their acceptance in the scientific community [40]. The application of these alternative methods could overcome the difficulty to link the knowledge of basic science including basic pharmacology learnt at the early phase of the curriculum and its implementation in clinical practice [42] and may improve further the training for clinical prescription for healthcare professionals, especially during this current need for continued social distancing [43].

Despite implementing strict biosafety measures during the handling of microorganisms in microbiology teaching laboratories, inadvertent infection via ingestion, inhalation or skin penetration has been reported [44]. In this regard, an interesting approach to AR has been introduced by a group of researchers from Australia and Singapore to mitigate these biosafety risks [45]. An AR software was developed to mimic the serial dilution and bacterial growth in a conventional laboratory which can be operated and applied to a smartphone/tablet android system. This microbiology teaching tool does not only obviate the need to expose the students to live microorganisms but also offers the advantage of the reduced experiment set-up time without compromising the students' experience in the actual laboratory environment.

Preclinical medical and dentistry in early exposure to clinical/practical

As the Covid-19 pandemic caused restrictions on students training in hospitals to prevent undue exposure, VR has also been adopted for preclinical training. A study on the use of VR amongst medical students showed that most of the students agreed that VR served as a realistic platform for initial clinical assessment, diagnosis, and management [20]. Similarly, studies on preclinical prescription practice among European United countries revealed that many software programs have been developed to train medical students to be safer and more efficient in drug prescription, and because of its benefits, the currently limited access to this program should be made more available [19].

AR has also demonstrated similar benefits for dental students. The Covid-19 pandemic has flourished the use of previously less popular and less frequently used software programs such as Microsoft Teams®, Zoom®, Google Classroom®, WebEx®, and Moodle® to be the platforms for the remote e-learning activities as well as the use of AR and VR that allow students to feel and touch the teeth virtually via haptic technology [21]. The need for clinical practice on real teeth and patients indeed could not be overlooked, but AR and VR technologies could provide an alternative way of preclinical and clinical teaching, especially during this Covid-19 pandemic [46]. Mladenovic et al. developed an AR intraoral examination and dental charting [22] and local anaesthesia administration [23]. They supported that this cutting-edge technology is not only essential during the Covid-19 pandemic but should be an integrative tool for future dental education to enhance dental students' confidence in performing these procedures.

TYPES OF AR AND VR APPLICATIONS IN TEACHING PRECLINICAL MEDICAL AND DENTAL STUDENTS

Higher education has been severely impacted by the Covid-19 pandemic. As teaching facilities were closed, medical schools had to transition to online and distance learning. VR and AR have emerged as the technology that can assist in the delivery of remote teaching [47, 48]. The specific types and mechanisms of AR and VR applications in teaching preclinical medical and dental

Table I: The specific types and mechanisms of AR and VR applications in teaching preclinical medical and dental students

Reference article	AR-application type	Target population	Application usage	Mechanisms
(Henssen et al. 2020)	GreyMapp-AR	Medical students and biomedical students	To visualize 3D relations of neuroanatomy structures.	The incorporation of 3D image technology as a virtual dissection table. Students could dissect tissue layers from a virtual human cadaver.
(Maresky et al. 2019)	Oculus Rift VR headset	Medical students	To visualize 3D relations of cardiovascular structures.	The Oculus Rift virtual reality headset enables students to view a virtual cardiac environment. They were able to manipulate the heart in multiple dimensions and toggle between various views of the heart, such as the inside view, vascular view, nervous conduction view, and other dedicated views.
(Birbara, Sammut, and Pather 2020)	VR with AVIE 360-degree stereoscopic immersive interactive visualization system	Medical students	To enable 3D exploration of the human skull	The research utilizes two distinct visualisation modalities: a stereoscopic projection-based system with panoramic visualisation (AVIE), and a desktop system. A 3D exploration of the skull was created with a gaming platform (Unity) that allows for a "fly-through" experience of the various fossa, canals, and foramina.
(Nakai et al. 2022)	Oculus Quest 2, VR headset	Medical students	To enable visualization and exploration of anatomical structures. To improve visualization of the origins and insertions of muscles.	Lectures took place in a VR workspace using a VR headset. VR workspace allowed for more teacher-student interactions.
(Du, Fan, and Yang 2020)	HTC Vive system	Students from the college of medicine and college of engineering	To improve the learning experience through competitive gaming and multiplayer system	Integration of a VR gaming system with a head-mounted display for anatomy education
(Bork et al. 2021)	VesARlius system	Medical students	To enable students to participate in a team-based learning environment	Head-mounted AR system with collaborative and interactive learning capabilities.
(Farag and Hashem 2022)	Haptic Virtual reality	Dental students	To improve psychomotor skills acquisition in preclinical operative dentistry.	Haptic virtual reality simulation combined haptic technology and VR simulation technology for dental students to acquire psychomotor skills for cavity preparation.

CONTINUE

Table I: The specific types and mechanisms of AR and VR applications in teaching preclinical medical and dental students (cont.)

Reference article	AR-application type	Target population	Application usage	Mechanisms
(Torralba 2015)	ARBOOK	Medical, nursing, physiotherapy and podiatry students	To visualize the lower limb 3D structure of the lower limb	The ARBOOK consist of printed bi-dimensional images and text about the anatomy of the lower limb. It also includes anatomical figure cards that can be recognised by a webcam connected to a computer. This allows the virtual AR version of the image to be visualised.
(Darras et al. 2020)	Digital virtual simulation	Medical students	To enable students to learn anatomy and radiology through virtual dissection	3D computed tomography scans are displayed on a near-life size virtual dissection table. Students can manipulate the image and conduct virtual dissections.
(Wang et al. 2020)	Microsoft Hololens	Medical students	To enhance anatomical learning through 3D visualisation	Microsoft Hololens is a head-mounted device enabling students to visualise 3D images.

students are listed in Table I.

AR is a form of computer-generated content that allows people to interact with it in real-world settings. Typically, this is accomplished by overlaying visuals upon what the eye sees using glasses or projectors in the real world. However, it might also involve the sensation of smell, touch, or sound. In a study done in the Netherland, students used the GreyMapp-AR program to examine the displayed brain by focusing the tablet's camera on a printed marker. Students were able to modify the brain image by touching the screen [49]. Another study in Spain employed the ARBOOK, which allows students to see a 3D representation of the lower limb anatomy by flashing the card to a computer camera [50]. These AR applications employed handheld [49] and spatial [50] displays, which were proven effective and engaging, but only allowed for one user. Bork et al., on the other hand, used the VesARlius system which allows for team-based learning environments. The system used an HMD-based AR system and synchronized virtual rooms for all users to enable collaborative learning [51].

VR employs computer technology to produce the 3D image of a simulated environment [52]. Screen-based VR, immersive VR environments, and virtual worlds are the three basic types of VR simulators. Screen-based VR offers a user interface that is linked to mechanical or haptic devices and can be viewed on any screen or desktop. Darras et al. devised a virtual dissection curriculum for first-year medical students that was integrated into radiology classes. Students can virtually execute their dissection on a virtual dissection table through software interactions [53]. Similarly, a study in Saudi Arabia used Haptic VR simulation (HVRS) Simodont Dental Repair to integrate psychomotor competence for dental students in preclinical operative dentistry class [54].

On the other hand, immersive VR describes a user who is immersed in a virtual environment and loses awareness of the real world. Head-Mounted Displays (HMDs) enhance the simulated environment's immersive experience. Examples of HMDs seen in both western and eastern studies are Oculus Rift, HTC Vive and Oculus Quest and AVIE 360-degree stereoscopic immersive interactive visualisation system [55-58].

A study in Japan used a VR workspace and a VR headset to deliver anatomy classes (Oculus Quest)[58]. The VR workspace allows interaction between students and teachers. Another study in Canada employed VR to teach cardiac anatomy. Students were able to inspect, manipulate, and magnify the anatomical structures using this technology [55, 58]. The more details there are, the more realistic the image will be. However, educators must consider the quantity of space the data requires for the contents.

An Australian study used the Unity® gaming platform in their simulated 3D exploration of the skull. The students experience navigating through various foramen or canals in the skull by "flying through" them [56]. While VR delivery is engaging, the study concluded that it might cause physical discomfort [56]. On the other hand, a study from Taiwan expanded the application of VR by including a VR gaming system with single (SP) and multiple player (MP) modes. This MP mode's competitive nature causes higher stress levels among the MP participants. Nevertheless, the MP group scored higher on incompetency and interest than the control group [57].

AR and VR are mainly used for teaching, learning, and training technical competencies among preclinical medical and dental students in both Western and Asian countries [10, 54]. Training for emergency response and teaching soft skills are two more aspects of medical education that may incorporate VR [59, 60].

OUTCOME/PERCEPTION OF USING AR AND VR IN TEACHING PRECLINICAL MEDICAL AND DENTAL STUDENTS

VR applications among medical and dental students are of increasing interest. It is a 24/7 concept access with objective evaluation offering interactive learning compatible with the current era. However, the outcome of reported studies of VR and AR in medical and dental teaching is still low in evidence and needs proven scientific recommendations, especially on the clinical protocol [9]. In dentistry, VR is mostly applied in studies on prosthodontics, restorative dentistry and oral and maxillofacial surgery. In contrast, only a few studies are related to dental radiology, paediatric dentistry, orthodontics and periodontology [61]. In these studies, the VR interventions were evaluated in terms of student and teacher knowledge, clinical skills, attitude, and satisfaction.

The use of haptic dentistry simulators has evolved into a possible VR-based teaching tool for pre-clinical dental education [62]. Digital teaching has also been shown to improve and enhance student learning experiences [63]. Multiple manufacturers come with different designs and applications in simulation depending on disciplines in clinical skills. For example, the Moog Simodont Dental Trainer (Nieuw-Vennep the Netherlands) is among the earliest VR applications on the market. Students in different regions who have used Moog simulators can employ what they have learned virtually into practice in the real world. A cross-sectional study among dental students in Western Australia agreed that VR-based simulation should be an adjunct in pre-clinical training [64]. However, most students (88%) disagreed with the statement that Simodont® Moog Simodont Dental Trainer (Nieuw-Vennep the Netherlands) should be used in replacement of traditional simulation in preclinical training for paediatric dentistry.

Dental students acquire a better comprehension of the structure of a tooth by using VR. The viability of using VR to teach root canal anatomy was assessed in a pilot study [65]. Findings suggested that by employing VR, they were able to obtain a better grasp of the anatomy of the tooth as compared to conventional methods. AR and VR technologies are promising tools for difficult operations in maxillofacial surgery, and they can aid in achieving predictable and safe therapeutic outcomes. In Brazil, participants reported a substantially more precise technique and consumed significantly less time during VR application in an inferior alveolar nerve block anaesthesia [66].

The consensus is that VR is the way for future dentistry education, particularly considering the Covid-19 pandemic's constraints on FTF learning. AR should be utilised as a complementary resource or teaching aid in dentistry education, not as a total replacement for traditional techniques.

ADVANTAGES OF USING AR AND VR IN TEACHING PRECLINICAL MEDICAL AND DENTAL STUDENTS

Impact on student performance, student learning experience, and student feedback are all advantages of employing AR and VR in educating preclinical medical and dentistry students.

Impact on Student Performance (Effectiveness)

Medical

AR systems can be used to supplement didactic aids in gross anatomy classes and expedite interactive student-centred learning. Maresky et al. assessed the viability and efficacy of a VR computer-generated model in teaching cardiac anatomy [55]. Prior to learning cardiac anatomy, 42 first-year Canadian undergraduate medical students engaged in an anatomically correct VR heart simulation. The VR group outperformed the control group by 21.4% in conventional content, 26.4% in visual-spatial (VS) content, and and 23.9% higher overall in the assessment parameters (55)[55], which supported that VR provides an anatomically correct and immersive VS environment in which learners can engage in 3D with the anatomy of the heart.

The performance of 30 first-year American medical students that utilised 3D visualization or 2D screens to review head and neck anatomy was compared in a CT-based teaching session [67]. Pre-test vs. post-test comparisons indicated significant in-group improvement in both groups, with the AR group improving from 59% to 95% and the screen group improving from 57% to 80%. Analysis between-group indicated that the AR group performed much better on the post-test [67]. In comparison to a traditional 2D screen-based review, immersive 3D visualisation with embedded stereoscopic depth has the potential to enhance short-term anatomic recall in the head and neck. Moreover, 3D visualizations stimulate the interest of students in the anatomy laboratory.

A recent pilot study involving 16 first-year German medical students utilised the VesARlius system, a unique AR learning experience, that supplements traditional education such as anatomy textbooks with 3D models, and computer-based online platforms [68]. When compared to a pre-test, both the experimental group (collaborative AR) and the control group (conventional anatomy atlases and 3D models) showed significant improved performance in an anatomy knowledge test after intensive group learning sessions. However, there were no significant differences in the test outcomes between the two groups. The students' high experience of mental effort, qualitative and quantitative feedback; and the results of a System Usability Scale questionnaire support the potential of the collaborative AR system [68]. Students' understanding of 3D topographic anatomy improves as compared to comparable AR systems for single-user encounters. These findings suggest that collaborative AR systems promote interactive, student-centred learning in groups and can become a key component of a contemporary, multi-modal anatomy curriculum.

Dentistry

The Virtual Educational System for Dentistry was used to assess the effectiveness of pre-clinical training in ceramic crown preparation in 57 Chinese dental students [69]. Students' perceptions of the virtual educational system were evaluated. After virtual learning, the overall score on the outcome evaluation and the error scores were significantly different from those before virtual learning. Except for the evaluation item "damage of surrounding teeth," significant interactions were observed between time and student group in the mean scores of process and result assessments. Students can improve their clinical abilities by using a Virtual Educational System for Dentistry with the Virtual Learning Network Platform and Real-time Dental Training and Evaluation System in pre-clinical operative training [69].

Zhang et al. investigated the effectiveness of VR in periodontal preclinical training and established an optimal performance mode in the basic periodontal lesson to enhance future preclinical training methods amongst 60 undergraduate Chinese students [70]. There were four groups: (Group J), the traditional jaw model/control group; (Group V), the VR group; (Group V-J), the virtual-jaw group and (Group J-V), the jaw-virtual group. In the first theoretical outcomes, no significant differences were observed. The V-J and J-V groups' scores on the second theoretical exam were significantly higher than their marks on the first theoretical exam. Students in Groups V-J and J-V performed much better on the operation process and the scaling process than students in the other two groups. As a result, combining VR and a jaw model into periodontal preclinical training improves student grades and professional skill acquisition. However, prior to VR, the jaw model must be used to obtain high efficacy [70].

Reymus et al. evaluated the efficiency of embedding VR in teaching root canal anatomy in the endodontic curriculum to 42 third-year German undergraduate dentistry students undergoing preclinical training [65]. A cone-beam computed tomography (CBCT) scan was used to digitise extracted human teeth, which were then converted into Standard Tessellation Language (STL) files. Amongst 2D radiography, CBCT scanning, and VR simulation; students agreed that CBCT and VR facilitate them to distinguish all anatomic features more effectively than radiography. The VR simulation was found to be superior to CBCT scanning and radiography because it allowed for a better grasp of root canal anatomy. The VR simulation in the endodontic curriculum was positively received by the majority of dentistry students. This study concludes that VR outperforms 3D reconstructions and 2D radiographs in teaching root canal anatomy [65].

The performance of the Moog Simodont dental trainer (VR) in the pre-clinical curriculum of the operative dentistry course's direct restoration module was evaluated using manual and digital methods in a Hong Kong study amongst 32 second-year undergraduate students [71]. Afterwards, the students were evaluated in a single-blinded method while completing a Class I preparation. In comparison to the control group, the percentage of students who performed satisfactory preparations and domains in both the manual and digital evaluations was higher in the group exposed to Moog Simodont dental trainer (VR). The use of the Moog Simodont dental trainer (VR) resulted in significantly improved student satisfaction [71].

Student Learning Experience

Medical

VR and AR are just as useful for teaching anatomy as tablets, but they have specific advantages, such as improved learner immersion and engagement assessed in an Australian study [10]. There were three learning modes randomly assigned to 59 undergraduate students: VR, AR or tablet-based (TB), and they completed a session on skull anatomy followed by an anatomical knowledge assessment. The students' perceptions of each learning method, as well as any negative consequences, were recorded. However, mean assessment scores in VR, AR, and TB did not differ significantly [10].

Guetterman et al. used mixed methods in a randomised controlled experiment to assess the differences in the impacts of MPathic-VR, a virtual human (VH)-based simulation, in training health care personnel in empathetic communication. They combined qualitative reflections with a comparison of two quantitative measures: MPathic-VR-calculated scores and objective structured clinical exam (OSCE) scores [72]. Second-year medical students (n=206) from three US medical schools were given simulations to help them enhance their empathetic communications skills. When compared to the control group, learners in the intervention group had considerably higher OSCE results. Data analysis showed that nonverbal behaviours accounted for the majority of the variance between high, middle, and low performers. Medium and high OSCE scorers commonly acknowledged the importance of nonverbal communication. Only those with medium or high scores were encouraged to learn more about communication [72]. Higher performers were the most eager to learn, particularly on nonverbal talents, and VHs have the potential to promote empathic communication in the health care setting.

Dentistry

In Iowa, USA, 70 first-year dentistry students were assessed about their perception of learning dental anatomy utilising natural extracted teeth, 3D printed models, 3D virtual models and AR technologies [73]. Students agreed that natural teeth were evaluated as having the most educational value, 3D printed teeth as the handiest and the AR application as the most engaging modality. Participants who had little to no experience with video games tend to score AR as having a great educational value, whereas students who had little familiarity with 3D modelling, rated the 3D model as having high accessibility. The perceptions were the natural extracted tooth was thought to have the greatest educational value, while the 3D printed model was the most user-friendly and the AR model was the most engaging [73].

Preclinical students' acceptance of learning dental morphologies in VR was investigated by Liebermann et al. in three sections of the teaching environment: (a) digital data generation; (b) tooth morphologies creation via VR dental learning environment; and (c) preclinical students' evaluation via questionnaires [74]. When compared to a traditional textbook, 34.9% of students understood dental morphologies significantly better, 57.1% much better, and 7.9% equivalently well. Interestingly, they were voluntarily to spend up to 500 euros on VR devices out of their expenses. Thus, the haptic and auditory teaching features of the integrated information boards were regarded more positively than the simply visual ones. The VR dental learning environment was well-accepted by all students, and the study concluded that it should be made a permanent element of the dentistry curriculum [74].

Student Feedback

Medical

A Japanese study investigated the benefits of VR in anatomy lectures and whether they may be utilised to enhance medical students' comprehension of anatomy when compared to other online lecture formats amongst 30 medical students [75]. Three distinctive systems (cardiovascular, musculoskeletal and nervous system) in anatomy lectures were covered in a VR workspace (Spatial) using a VR headset (Oculus Quest 2, Menlo Park, CA). Students agreed that accessibility to the course content from anywhere and anytime via a virtual space, and the ability to control anatomical structures were extremely beneficial. Amongst advantages of the VR workspace was the ability to access and magnify anatomical heart structures which enhanced their overall 3D understanding. Because they have access to many 3D models, students were able to share their knowledge and experiences in real-time. The use of skeletal material and muscles in the 3D model increased the visualisation of muscle origins and insertions. Furthermore, the use of visualisation of multiple materials which include real-time images (e.g., ultrasound) and nervous system in 3D models can occur concurrently and VR workspace usage in lectures facilitates more teacher-student interaction [75].

AR Magic Mirror (AR MM) system, a new clinical application of imaging methods provides an interactive learning tool as a supplementary to a regular dissection macroscopic anatomy course. AR MM system was evaluated by 880 first-year medical students in Munich [11]. It includes a real-time tracking device which allows the system to link a deposited section image to a projection of the user's body and as a huge display that resembles a real-world physical mirror. Users can interactively study radiological images on multiple anatomical intersecting planes using gesture input. All remarks that emphasised the system's ability to serve as an extra learning resource for anatomical education were endorsed by the respondents [11]. Active learning, 3D understanding, and a better understanding of the course of structures are among them. An AR MM system can be integrated into anatomy lectures to help educate medical students on clinical requirements and to provide more participatory, student-centred learning.

According to Atli et al., adopting VR as a basic component of pre-clerkship medical students' neurosurgical and neuroanatomy education can improve neurosurgery education. Twelve second-year medical students in Ohio evaluated a year-long neurosurgery elective course that used an interactive VR platform as the primary teaching instrument [76]. Four components of the course include: (1) didactic/lecture-based learning, (2) problem-based learning, (3) hands-on skills lab, and (4) VR-based learning via Surgical Theater's Precision VR visualisation platform. All students agreed that VR helped them comprehend better, VR was an excellent learning tool and the course was a great learning experience. Moreover, 92% agreed that VR assisted in retaining the anatomical/functional information of the brain/spine whereas 69% comprehend neurosurgical skills better [76]. Thus, a complete multi-component neurosurgery elective course that integrated VR as a fundamental teaching tool could ameliorate neurosurgical lessons in medical school.

Dentistry

The learning of clinical and technical skills, as well as the transfer of these abilities to the clinic, are critical components of preclinical dentistry education. The students' perceptions of pre-clinical paediatric dental training received in a VR-based dental simulation environment (Moog Simodont® Dental Trainer) and traditional simulation environments were assessed in an Australian study [64]. Hundred dental students underwent pulpotomies and stainless-steel crowns (SSCs) training in the Simodont® and conventional pre-clinical simulation laboratories. The use of Simodont® aided student learning and student understanding in paediatric dentistry by 51% and 56%, respectively. For both practical exercises, participants felt more at ease with simulation training than with Simodont®. The findings suggest that Simodont® could be utilised as a supplement in pre-clinical paediatric dentistry restorative activities for training dental students [64].

Phantom heads are an effective approach to safely educating preclinical students about dental procedures while also significantly improving their skills. The phantom head is attached to a dental operating unit with a torso in a position arrangement of a seated position, precisely like a patient would in a clinic [77]. The placement of the operator and the patient, as well as doing dental treatments with an assistant and infection control protocols, are all replicated using the phantom heads. Modern computerised phantom head training machines can deliver simultaneous augmented feedback and have VR capabilities. In these units, adjunctive training appears to improve student learning and skill acquisition while decreasing teacher supervision time. However, VR is not reliable as the only source of feedback, and the facilitator's input is still crucial [77].

DISADVANTAGES, LIMITATIONS AND CHALLENGES OF USING AR AND VR IN TEACHING PRECLINICAL MEDICAL AND DENTAL STUDENTS

As with any advancement in technology, using AR and VR as a tool must be employed appropriately to be fully effective. Despite the immense promise of AR and VR and the advantages discussed above, there are some disadvantages, limitations and challenges that result in these technologies' ineffectiveness or misuse. However, if the process or workflow in the study was difficult but had no effect on the results, it is most likely considered a challenge rather than a limitation.

For many years, the main barriers to using VR in education were the cost and computing power required to create realistic environments [78, 79]. Advanced technology is often expensive. In addition, some AR and VR systems were difficult to operate and the equipment the users were required to wear was cumbersome and hampered [80]. Fortunately, developments in mobile device technology have made the use of AR and VR systems possible, as well as reduced the size of VR equipment [81]. Without compromising the quality, mobile devices with inexpensive viewers such as Google Cardboard have made VR extremely affordable. While VR can be a valuable asset in most fields of endeavour, it can also be a significant disadvantage in traditional education, which is built on personal human communication and interpersonal interactions. Unlike traditional education, VR only involves interaction between the user and the software. This can impair the relationships and communication between students and humans. One study carried out by Boling et al. found that most of their study participants viewed online courses as individualizing learning and limiting interaction with others. Students described feeling isolated from their teachers, the system's content, and classmates. Participants in these courses explained how their online interactions were text-based lectures and several reading and writing assignments completed. Many of those tasks limited the ability of the students to develop a higher level of cognitive skills and imaginative thinking [82].

One inevitable disadvantage of relying on AR and VR environments is that it has the probability of technical failure that must be catered for. VR devices, like any other computer, can break or crash, and the likelihood of any malfunction occurring may increase as the VR devices are used by many users [81, 83]. As a result, in the event of technical difficulties, internet outages, or other unanticipated situations that prevent the entire class from utilising VR, backup devices and lesson plans should be available. Furthermore, studies reported that several participants experienced physiological symptoms such as nausea, motion sickness, or minor headaches while using the VR devices [84]. The symptoms can affect as high as 10-20% of users [85].

Students and teachers are required to consider time allocation when learning how to utilise their AR and VR devices. Images and text can become fuzzy if head-mounted displays are not properly calibrated [85]. Moreover, the increased cognitive load on learning how to manoeuvre and analyse the virtual world necessitates teachers to allocate time in their schedule to educate students on how to utilize their devices [81]. Aside from using the tools, teachers and administrators must also obtain or construct virtual worlds or simulations for their students. Because most teachers lack the time or technical abilities to create their VR apps, subsidiary parties will almost certainly be necessary to create and manage these programmes and their contents [83]. Additionally, teachers must be able to readily modify, customise, or update the programmes they are using to meet the needs of their lesson [86].

In addition, there must be explicit course objectives to be achieved with which VR can be embedded [83, 87]. In some circumstances, VR may not be the optimal tool for reaching given learning objectives [88], so it is critical to review the course curriculum and determine whether VR is appropriate or whether other teaching approaches are preferable.

Finally, incorporating AR and VR into medical and dental education can be challenging, and some students may be apprehensive about using the new technology [89]. The causes could be linked to the need to rethink the lesson planning from a teacher-centred, delivery-based perspective to a student-centred perspective. It may also take longer to teach a topic using VR as compared with traditional methods [81]. Teachers may be discouraged from utilising AR and VR tools in their classrooms if they are difficult to use [83]. However, inevitably teachers need to update themselves with the current advancement in teaching methods to make them on par with the latest technology and the students' needs. This will ensure that the teachers are confident in using these technologies in their classroom while exploring the exciting possibilities that AR and VR may present.

CONCLUSION

The AR and VR environment is consistently evolving. Although it offers a range of interesting and exciting alternative ways of teaching and learning, it may not be the sole method of content delivery. The disadvantages of using AR and VR only to teach medical and dental students, as presented and discussed above, render this technology unsuitable as a stand-alone teaching method. Indeed, the modernisation of medical and dentistry education using AR and VR may offer great accomplishments. The inability to deliver the visual-spatial images during conventional online teaching and the unfavourable use of cadavers during the traditional F2F method are two examples of limitations of the current teaching methods that can prevail with AR and VR technologies. Therefore, the use of AR and VR should be used as a supplemental resource or teaching aid but not as a complete replacement for online and traditional learning methods in preclinical medical and dental education.

REFERENCES

1. Cevik M, Kuppalli K, Kindrachuk J, Peiris M. Virology, transmission, and pathogenesis of SARS-CoV-2. BMJ. 2020;371:m3862. doi: 10.1136/bmj.m3862.
2. Hui KPY, Cheung M-C, Perera RAPM, Ng K-C, Bui CHT, Ho JCW, et al. Tropism, replication competence, and innate immune responses of the coronavirus SARS-CoV-2 in human respiratory tract and conjunctiva: an analysis in ex-vivo and in-vitro cultures. The Lancet Respiratory Medicine. 2020;8(7):687-95. doi: 10.1016/s2213-2600(20)30193-4.
3. Hogh A, Muller-Hilke B. Learning strategies and their correlation with academic success in biology and physiology examinations during the preclinical years of medical school. PLoS One. 2021;16(1):e0245851. doi: 10.1371/journal.pone.0245851.
4. Azer SA, Azer S. 3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature. Health Professions Education. 2016;2(2):80-98. doi: https://doi.org/10.1016/j.hpe.2016.05.002.
5. Kucuk S, Kapakin S, Goktas Y. Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load. Anat Sci Educ. 2016;9(5):411-21. doi: 10.1002/ase.1603.
6. Hsieh MC, Lee JJ. Preliminary Study of VR and AR Applications in Medical and Healthcare Education. Journal of Nursing and Health Studies. 2018;03(01). doi: 10.21767/2574-2825.100030.
7. Cheng J, Chen K, Chen W. Comparison of marker-based AR and marker-less AR: a case study on indoor decoration system. Lean and Computing in Construction Congress (LC3): Proceedings of the Joint Conference on Computing in Construction (JC3)2017. p. 483-90.
8. McCloy R, Stone R. Virtual reality in surgery. BMJ. 2001;323(7318):912-5. doi: 10.1136/bmj.323.7318.912.
9. J oda T, Gallucci GO, Wismeijer D, Zitzmann NU. Augmented and virtual reality in dental medicine: A systematic review. Comput Biol Med. 2019;108:93-100. doi: 10.1016/j.compbiomed.2019.03.012.
10. Moro C, Stromberga Z, Raikos A, Stirling A. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ. 2017;10(6):549-59. doi: 10.1002/ase.1696.
11. Kugelmann D, Stratmann L, Nuhlen N, Bork F, Hoffmann S, Samarbarksh G, et al. An Augmented Reality magic mirror as additive teaching device for gross anatomy. Ann Anat. 2018;215:71-7. doi: 10.1016/j.aanat.2017.09.011.
12. Layona R, Yulianto B, Tunardi Y. Web based Augmented Reality for Human Body Anatomy Learning. Procedia Computer Science. 2018;135:457-64. doi: https://doi.org/10.1016/j.procs.2018.08.197.
13. Gonzalez AA, Lizana PA, Pino S, Miller BG, Merino C. Augmented reality-based learning for the comprehension of cardiac physiology in undergraduate biomedical students. Advances in Physiology Education. 2020;44(3):314-22. doi: 10.1152/advan.00137.2019.
14. Remtulla R. The Present and Future Applications of Technology in Adapting Medical Education Amidst the COVID-19 Pandemic. JMIR Med Educ. 2020;6(2):e20190. doi: 10.2196/20190.
15. Daud A, Bagria A, Shah K, Puryer J. Should Undergraduate Lectures be Compulsory? The Views of Dental and Medical Students from a UK University. Dent J (Basel). 2017;5(2). doi: 10.3390/dj5020015.
16. Campos-Mesa M-C, Castaceda-Vázquez C, DelCastillo-Andrés Y, González-Campos G. Augmented Reality and the Flipped Classroom—A Comparative Analysis of University Student Motivation in Semi-Presence-Based Education Due to COVID-19: A Pilot Study. Sustainability. 2022;14(4). doi: 10.3390/su14042319.
17. Samadbeik M, Yaaghobi D, Bastani P, Abhari S, Rezaee R, Garavand A. The Applications of Virtual Reality Technology in Medical Groups Teaching. Journal of advances in medical education & professionalism. 2018;6(3):123-9.
18. Papanastasiou G, Drigas A, Skianis C, Lytras M, Papanastasiou E. Virtual and augmented reality effects on K-12, higher and tertiary education students' twenty-first century skills. Virtual Reality. 2018;23(4):425-36. doi: 10.1007/s10055-018-0363-2.
19. Bakkum MJ, Tichelaar J, Papaioannidou P, Likic R, Sanz Alvarez EJ, Christiaens T, et al. Harmonizing and improving European education in prescribing: An overview of digital educational resources used in clinical pharmacology and therapeutics. Br J Clin Pharmacol. 2021;87(3):1001-11. doi: 10.1111/bcp.14453.
20. De Ponti R, Marazzato J, Maresca AM, Rovera F, Carcano G, Ferrario MM. Pre-graduation medical

training including virtual reality during COVID-19 pandemic: a report on students' perception. BMC Med Educ. 2020;20(1):332. doi: 10.1186/s12909-020-02245-8.
21. Haroon Z, Azad AA, Sharif M, Aslam A, Arshad K, Rafiq S. COVID-19 Era: Challenges and Solutions in Dental Education. Journal of the College of Physicians and Surgeons--Pakistan : JCPSP. 2020;30(10):129-31. doi: 10.29271/jcpsp.2020.supp2.129.
22. Mladenovic R, Matvijenko V, Subaric L, Mladenovic K. Augmented reality as e-learning tool for intraoral examination and dental charting during COVID-19 era. J Dent Educ. 2021. doi: 10.1002/jdd.12780.
23. Mladenovic R, AlQahtani S, Mladenovic K, Bukumiric Z, Zafar S. Effectiveness of technology-enhanced teaching methods of undergraduate dental skills for local anaesthesia administration during COVID-19 era: students' perception. BMC Oral Health. 2022;22(1):40. doi: 10.1186/s12903-022-02077-6.
24. Duarte ML, Santos LR, Guimaraes Junior JB, Peccin MS. Learning anatomy by virtual reality and augmented reality. A scope review. Morphologie. 2020;104(347):254-66. doi: 10.1016/j.morpho.2020.08.004.
25. Zhan T, Yin K, Xiong J, He Z, Wu ST. Augmented Reality and Virtual Reality Displays: Perspectives and Challenges. iScience. 2020;23(8):101397. doi: 10.1016/j.isci.2020.101397.
26. Winkelmann A. Consent and consensus-ethical perspectives on obtaining bodies for anatomical dissection. Clin Anat. 2016;29(1):70-7. doi: 10.1002/ca.22651.
27. Raja DS, Sultana B. Potential Health Hazards for Students Exposed to Formaldehyde in the Gross Anatomy Laboratory. Journal of Environmental Health. 2012;74(6):36-41.
28. Elshaer NSM, Mahmoud MAE. Toxic effects of formalin-treated cadaver on medical students, staff members, and workers in the Alexandria Faculty of Medicine. Alexandria Journal of Medicine. 2019;53(4):337-43. doi: 10.1016/j.ajme.2016.11.006.
29. Zargaran A, Turki MA, Bhaskar J, Spiers HVM, Zargaran D. The Role of Technology in Anatomy Teaching: Striking the Right Balance. Adv Med Educ Pract. 2020;11:259-66. doi: 10.2147/AMEP.S240150.
30. Iwanaga J, Loukas M, Dumont AS, Tubbs RS. A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. Clin Anat. 2021;34(1):108-14. doi: 10.1002/ca.23655.
31. Guerrero JS, Mera JS, Lypez WG, Reinoso RS, D6vila CT. Use of Augmented Reality AR in University Environments. 2018 International Conference on eDemocracy & eGovernment (ICEDEG)2018. p. 291-7.
32. Chen C, Zhang L, Luczak T, Smith E, Burch RF. Using Microsoft HoloLens to improve memory recall in anatomy and physiology: A pilot study to examine the efficacy of using augmented reality in education. Journal of Educational Technology Development and Exchange. 2019;12(1). doi: 10.18785/jetde.1201.02.
33. Duncan-Vaidya EA, Stevenson EL. The Effectiveness of an Augmented Reality Head-Mounted Display in Learning Skull Anatomy at a Community College. Anat Sci Educ. 2021;14(2):221-31. doi: 10.1002/ase.1998.
34. Moro C, Birt J, Stromberga Z, Phelps C, Clark J, Glasziou P, et al. Virtual and Augmented Reality Enhancements to Medical and Science Student Physiology and Anatomy Test Performance: A Systematic Review and Meta-Analysis. Anat Sci Educ. 2021;14(3):368-76. doi: 10.1002/ase.2049.
35. Chytas D, Salmas M, Skandalakis GP, Troupis TG. Augmented and virtual reality in anatomy education: Can they be effective if they do not provide immersive experience? Anat Sci Educ. 2022;15(2):431-3. doi: 10.1002/ase.2119.
36. John LJ. A review of computer assisted learning in medical undergraduates. J Pharmacol Pharmacother. 2013;4(2):86-90. doi: 10.4103/0976-500X.110870.
37. P S, Oommen S, C A, J A. Effectiveness of computer-assisted learning as a teaching method in experimental pharmacology. National Journal of Physiology, Pharmacy and Pharmacology. 2018;8(9). doi: 10.5455/njppp.2018.8.0723926072018.
38. Dewhurst D. Is it possible to meet the learning objectives of undergraduate pharmacology classes with non-animal models? 2008.
39. Hughes IE. Do computer simulations of laboratory practicals meet learning needs? Trends in Pharmacological Sciences. 2001;22(2):71-4. doi: https://doi.org/10.1016/S0165-6147(00)01605-9.
40. Badyal DK, Desai C. Animal use in pharmacology education and research: the changing scenario. Indian journal of pharmacology. 2014;46(3):257-65. doi: 10.4103/0253-7613.132153.
41. Arcoraci V, Squadrito F, Altavilla D, Bitto A, Minutoli L, Penna O, et al. Medical simulation in pharmacology learning and retention: A comparison study with traditional teaching in undergraduate medical students. Pharmacol Res Perspect. 2019;7(1):e00449. doi: 10.1002/prp2.449.
42. Brinkman DJ, Tichelaar J, Okorie M, Bissell L, Christiaens T, Likic R, et al. Pharmacology and Therapeutics Education in the European Union Needs Harmonization and Modernization: A Cross-sectional Survey Among 185 Medical Schools in 27 Countries. Clin Pharmacol Ther. 2017;102(5):815-22. doi: 10.1002/cpt.682.
43. Andrews LB, Barta L. Simulation as a Tool to

Illustrate Clinical Pharmacology Concepts to Healthcare Program Learners. Curr Pharmacol Rep. 2020;6(4):182-91. doi: 10.1007/s40495-020-00221-w.
44. Coelho AC, Garcнa Dнez J. Biological Risks and Laboratory-Acquired Infections: A Reality That Cannot be Ignored in Health Biotechnology. Front Bioeng Biotechnol. 2015;3:56-. doi: 10.3389/fbioe.2015.00056.
45. Wildan A, Cheong BH-P, Xiao K, Liew OW, Ng TW. Growth measurement of surface colonies of bacteria using augmented reality. Journal of Biological Education. 2020;54(4):419-32. doi: 10.1080/00219266.2019.1600571.
46. Haji Z, Arif A, Jamal S, Ghafoor R. Augmented reality in clinical dental training and education. JPMA The Journal of the Pakistan Medical Association. 2021;71(Suppl 1)(1):S42-s8.
47. Pottle J. Virtual reality and the transformation of medical education. Future healthcare journal. 2019;6(3):181-5. doi: 10.7861/fhj.2019-0036.
48. Dhar P, Rocks T, Samarasinghe RM, Stephenson G, Smith C. Augmented reality in medical education : students ' experiences and learning outcomes. Medical Education Online. 2021;26. doi: 10.1080/10872981.2021.1953953.
49. Henssen DJHA, van den Heuvel L, De Jong G, Vorstenbosch MATM, van Cappellen van Walsum AM, Van den Hurk MM, et al. Neuroanatomy Learning: Augmented Reality vs. Cross-Sections. Anatomical Sciences Education. 2020;13:353-65. doi: 10.1002/ase.1912.
50. Torralba JF-tJ. ARBOOK : Development and Assessment of a Tool Based on Augmented Reality for Anatomy. 2015:119-24. doi: 10.1007/s10956-014-9526-4.
51. Bork F, Lehner A, Eck U, Navab N, Waschke J, Kugelmann D. The Effectiveness of Collaborative Augmented Reality in Gross Anatomy Teaching: A Quantitative and Qualitative Pilot Study. Anatomical Sciences Education. 2021;14:590-604. doi: 10.1002/ase.2016.
52. Haowen J, Vimalesvaran S, Kyaw BM, Car LT. Virtual reality in medical students ' education : a scoping review protocol. 2021. doi: 10.1136/bmjopen-2020-046986.
53. Darras KE, Spouge R, Hatala R, Nicolaou S, Hu J, Worthington A, et al. Integrated virtual and cadaveric dissection laboratories enhance first year medical students' anatomy experience: A pilot study. BMC Medical Education. 2019;19:1-6. doi: 10.1186/s12909-019-1806-5.
54. Farag A, Hashem D. Impact of the Haptic Virtual Reality Simulator on Dental Students ' Psychomotor Skills in Preclinical Operative Dentistry. 2022:17-26.
55. Maresky HS, Oikonomou A, Ali I, Ditkofsky N, Pakkal M, Ballyk B. Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. Clin Anat. 2019;32(2):238-43. doi: 10.1002/ca.23292.
56. Birbara NS, Sammut C, Pather N. Virtual Reality in Anatomy: A Pilot Study Evaluating Different Delivery Modalities. Anatomical Sciences Education. 2020;13:445-57. doi: 10.1002/ase.1921.
57. Du YC, Fan SC, Yang LC. The impact of multi-person virtual reality competitive learning on anatomy education: a randomized controlled study. BMC Medical Education. 2020;20:1-10. doi: 10.1186/s12909-020-02155-9.
58. Nakai K, Terada S, Takahara A, Hage D, Tubbs RS, Iwanaga J. Anatomy education for medical students in a virtual reality workspace: A pilot study. Clinical Anatomy. 2022;35:40-4. doi: 10.1002/ca.23783.
59. Ann M, En M, Chue S, Jong M, Wye H, Benny K, et al. Clinical instructors ' perceptions of virtual reality in health professionals ' cardiopulmonary resuscitation education. 2018. doi: 10.1177/2050312118799602.
60. Hudson K, Taylor LA, Kozachik SL, Shaefer SJ, Wilson ML. Second Life simulation as a strategy to enhance decision-making in diabetes care: a case study. Journal of clinical nursing. 2015;24:797-804.
61. Moussa R, Alghazaly A, Althagafi N, Eshky R, Borzangy S. Effectiveness of Virtual Reality and Interactive Simulators on Dental Education Outcomes: Systematic Review. Eur J Dent. 2022;16(1):14-31. doi: 10.1055/s-0041-1731837.
62. Pohlenz P, Grobe A, Petersik A, von Sternberg N, Pflesser B, Pommert A, et al. Virtual dental surgery as a new educational tool in dental school. J Craniomaxillofac Surg. 2010;38(8):560-4. doi: 10.1016/j.jcms.2010.02.011.
63. Ang ET, Chan JM, Gopal V, Li Shia N. Gamifying anatomy education. Clin Anat. 2018;31(7):997-1005. doi: 10.1002/ca.23249.
64. Zafar S, Lai Y, Sexton C, Siddiqi A. Virtual Reality as a novel educational tool in pre-clinical paediatric dentistry training: Students' perceptions. Int J Paediatr Dent. 2020;30(6):791-7. doi: 10.1111/ipd.12648.
65. Reymus M, Liebermann A, Diegritz C. Virtual reality: an effective tool for teaching root canal anatomy to undergraduate dental students - a preliminary study. Int Endod J. 2020;53(11):1581-7. doi: 10.1111/iej.13380.
66. Collaco E, Kira E, Sallaberry LH, Queiroz ACM, Machado M, Crivello O, Jr., et al. Immersion and haptic feedback impacts on dental anesthesia technical skills virtual reality training. J Dent Educ. 2021;85(4):589-98. doi: 10.1002/jdd.12503.
67. Weeks JK, Pakpoor J, Park BJ, Robinson NJ, Rubinstein NA, Prouty SM, et al. Harnessing Augmented Reality and CT to Teach First-Year Medical Students Head and Neck Anatomy.

Acad Radiol. 2021;28(6):871-6. doi: 10.1016/j.acra.2020.07.008.
68. Bork F, Lehner A, Eck U, Navab N, Waschke J, Kugelmann D. The Effectiveness of Collaborative Augmented Reality in Gross Anatomy Teaching: A Quantitative and Qualitative Pilot Study. Anat Sci Educ. 2021;14(5):590-604. doi: 10.1002/ase.2016.
69. Liu L, Zhou R, Yuan S, Sun Z, Lu X, Li J, et al. Simulation training for ceramic crown preparation in the dental setting using a virtual educational system. Eur J Dent Educ. 2020;24(2):199-206. doi: 10.1111/eje.12485.
70. Zhang J, Xing J, Zheng M, Sheng J, Zhang K, Zhang B. Effectiveness of virtual simulation and jaw model for undergraduate periodontal teaching. BMC Med Educ. 2021;21(1):616. doi: 10.1186/s12909-021-03064-1.
71. Murbay S, Neelakantan P, Chang JWW, Yeung S. 'Evaluation of the introduction of a dental virtual simulator on the performance of undergraduate dental students in the pre-clinical operative dentistry course'. Eur J Dent Educ. 2020;24(1):5-16. doi: 10.1111/eje.12453.
72. Guetterman TC, Sakakibara R, Baireddy S, Kron FW, Scerbo MW, Cleary JF, et al. Medical Students' Experiences and Outcomes Using a Virtual Human Simulation to Improve Communication Skills: Mixed Methods Study. J Med Internet Res. 2019;21(11):e15459. doi: 10.2196/15459.
73. Mahrous A, Elgreatly A, Qian F, Schneider GB. A comparison of pre-clinical instructional technologies: Natural teeth, 3D models, 3D printing, and augmented reality. J Dent Educ. 2021;85(11):1795-801. doi: 10.1002/jdd.12736.
74. Liebermann A, Erdelt K. Virtual education: Dental morphologies in a virtual teaching environment. J Dent Educ. 2020;84(10):1143-50. doi: 10.1002/jdd.12235.
75. Nakai K, Terada S, Takahara A, Hage D, Tubbs RS, Iwanaga J. Anatomy education for medical students in a virtual reality workspace: A pilot study. Clin Anat. 2022;35(1):40-4. doi: 10.1002/ca.23783.
76. Atli K, Selman W, Ray A. A Comprehensive Multicomponent Neurosurgical Course with use of Virtual Reality: Modernizing the Medical Classroom. J Surg Educ. 2021;78(4):1350-6. doi: 10.1016/j.jsurg.2020.11.003.
77. Plessas A. Computerized Virtual Reality Simulation in Preclinical Dentistry: Can a Computerized Simulator Replace the Conventional Phantom Heads and Human Instruction? Simul Healthc. 2017;12(5):332-8. doi: 10.1097/SIH.0000000000000250.
78. Merchant Z, Goetz ET, Cifuentes L, Keeney-Kennicutt W, Davis TJ. Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. Computers & Education. 2014;70:29-40. doi: 10.1016/j.compedu.2013.07.033.
79. Bell JT, and H. Scott Fogler. Virtual reality in chemical engineering education. Proceedings of the 1995 Illinois/Indiana ASEE Sectional Conference. 1995.
80. Ray AB, Deb S. Smartphone Based Virtual Reality Systems in Classroom Teaching — A Study on the Effects of Learning Outcome. 2016 IEEE Eighth International Conference on Technology for Education (T4E)2016. p. 68-71.
81. Wu H-K, Lee SW-Y, Chang H-Y, Liang J-C. Current status, opportunities and challenges of augmented reality in education. Computers & Education. 2013;62:41-9. doi: 10.1016/j.compedu.2012.10.024.
82. Boling EC, Hough M, Krinsky H, Saleem H, Stevens M. Cutting the distance in distance education: Perspectives on what promotes positive, online learning experiences. The Internet and Higher Education. 2012;15(2):118-26. doi: https://doi.org/10.1016/j.iheduc.2011.11.006.
83. Choi DH, Dailey-Hebert A, Estes JS. Emerging Tools and Applications of Virtual Reality in Education. 2016.
84. Kinateder M, Ronchi E, Nilsson D, Kobes M, Mьller M, Pauli P, et al. Virtual reality for fire evacuation research. 2014 Federated Conference on Computer Science and Information Systems2014. p. 313-21.
85. Hussein M, NΔtterdal C. The Benefits of Virtual Reality in Education- A comparision Study. 2015.
86. Klopfer E, Squire K. Environmental Detectives—the development of an augmented reality platform for environmental simulations. Educational Technology Research and Development. 2007;56(2):203-28. doi: 10.1007/s11423-007-9037-6.
87. Baker SC, Wentz RK, Woods MM. Using Virtual Worlds in Education: Second Life® as an Educational Tool. Teaching of Psychology. 2009;36(1):59-64. doi: 10.1080/00986280802529079.
88. Pantelidis V. Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. Themes in Science and Technology Education. 2009;2(1):59-70.
89. Huang H-M, Liaw S-S, Lai C-M. Exploring learner acceptance of the use of virtual reality in medical education: a case study of desktop and projection-based display systems. Interactive Learning Environments. 2016;24:19 - 3.