How effective is AR in classroom teaching? A review of the impacts of augmented reality teaching tools in health professional education

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ABSTRACT

Objective: Augmented Reality (AR) has successfully facilitated clinical training in health professional education. This technology can also accelerate non-clinical classroom education by improving students' spatial understanding and mental rotation skills, essential for many professional health education programs, including dental hygiene. However, this area is relatively less explored and less evaluated. This review investigates the effectiveness of AR-based tools in non-clinical, didactic teaching. **Methods:** A literature search was conducted in three databases using the search terms 'Augmented Reality' AND 'classroom teaching' AND 'health professional education.' Articles were screened first by the title and then by full-text review to include reports that match our inclusion criteria and are relevant to our research questions. **Results:** Nineteen articles were included in the narrative review. Our results found AR Magic Mirror and ARBOOK to be the two most used AR tools in didactic teaching. AR-based teaching tools can reduce cognitive loads and improve knowledge acquisition, spatial understanding, mental rotation skills, attention, motivation, confidence, and satisfaction. **Discussion:** AR tools can significantly improve students' learning experiences compared to the traditional teaching method in health professional education. As most AR-based teaching tools are focused on teaching anatomy, many other health professional educations can benefit from these tools. However, reports on qualitative exploration of student and faculty perspectives and development costs are absent from the literature pool. **Conclusion:** Didactic learning of basic science concepts like anatomy is essential to many health professional educations, including dental hygiene. Dental hygiene can largely benefit from incorporating AR-based teaching tools in classroom education.

Keywords: augmented reality; dental education, teaching; dental hygiene; education; educational activities; educational technique; teaching method

CDHA Research Agenda category: capacity building of the profession

INTRODUCTION

Augmented reality (AR) is an emerging interactive technology incorporating digital data, including three-dimensional models, images, videos, and audio recordings, into the real-world space.[1] The application of AR has started a new era in gaming and entertainment and has become a valuable tool in education, healthcare, manufacturing, marketing, tourism, architecture, and engineering.[2-5]

AR, being interactive and immersive, can be defined in many ways. Craig[6] defines AR as an experience where the participants engage in an activity in the physical world, where additional digital information is added using technology. On the other hand, Carmigniani et al.[7] define AR as a real-time direct or indirect view of a physical environment that has been augmented by adding computer-generated information. Currently, most AR systems include a display system, either from a smartphone, tablet, or head-mounted display. When looked through the display, the user can see their surrounding world with the additional digital component, which is not physically present in the real world (Figure 1). Although head-mounted displays can be used by both virtual reality (VR) and AR systems, VR completely immerses users in a simulated environment, whereas AR blends the virtual content with the real world.[5]

The concept of AR is not new. The advancements and availability of modern head-mounted displays like Google Glass and Microsoft HoloLens have helped expand the development of many VR and AR-based applications for education and entertainment. AR adaptability of smartphones

and tablets has also expanded the use of this technology in health professional education, where various AR applications have been developed to facilitate clinical skill development, knowledge acquisition, and image training.[2,5,8-13]

Studies reporting the impact of AR-based technology in health professional education are primarily focused on the impact of this technology on surgical skill development.[14] AR has immense potential to aid in non-clinical classroom education, which has been explored and evaluated less in health professional education. Some examples of AR-based teaching tools in non-clinical health professional education include the 'Augmented Reality magic mirror' developed to supplement regular anatomy dissection courses,[8] ARBOOK to reinforce the spatial understanding of anatomical structures[15] and AR flashcards to facilitate the learning of oral histology.[16] Application of interactive AR tools can augment students' experiences of traditional didactic learning by incorporating interactive objects, videos, and virtual 3D models to improve spatial understanding, engagement, and satisfaction.[15,16]

Students of the Dentistry and Dental Hygiene (DH) program extensively study oral and facial anatomy, tooth morphology, radiology, and oral histology as part of their curricula. A significant part of dental education is focused on foundational science, which is traditionally taught in the classroom. Spatial orientation, the ability to generate, retain, retrieve, and transform well-structured visual images,[17] is integral to health education, specifically dental and medical education. Growing evidence suggests the impact of AR-based teaching tools on improving spatial

understanding and mental rotation scores,[18,19] indicating that dental education can potentially benefit from the application of AR technology.

Didactic learning is an integral part of dental education. However, reports on AR-based teaching tools in non-clinical dental education are minimal. In this context, we mapped the current literature on the reported impact of AR-based teaching tools in classroom teaching across the entire health professional education, aiming to identify AR-based teaching tools potentially applicable in dental education. Our specific research questions are:

- What AR tools are used in didactic teaching in health professional education?
- Compared to traditional teaching, what is the impact of AR-based tools on didactic teaching in health professional education?

METHODS

A. Identification of potentially relevant studies

An extensive literature search was conducted in PubMed, CINAHL Plus, and Web of Science, with the search term 'Augmented Reality' AND 'classroom teaching' AND 'health professional education' (Figure 2A). The keyword 'health professional education' was chosen to explore literature from dental, medical, and all other allied health professional education. The search string ((Augmented Reality) AND (Classroom teaching)) AND (Health professional education) was used for all the databases.

B. Screening to select relevant studies

Inclusion and exclusion criteria were based on the research questions (Table 1), which was further refined during the screening process. Primary research articles written in English, published between 2014-2024, and relevant to our research questions were included. Articles were screened first by the title and then by full-text review to exclude reports that are not English, not available in full-text, did not include faculty or students from health professional education, applied the AR tool in clinical training, or did not conduct an evaluation to assess the impact of the AR-based teaching tool. Review studies, editorials, and perspective articles were excluded. Studies focusing on mixed reality or comparing augmented and virtual reality were also excluded. No restrictions were set on research methods. The literature screening procedure is outlined in Figure 2B.

C. Data extraction

After final inclusion, data was extracted from the included studies related to the year of publication, research method, study participants, AR-based teaching tool used in the classroom, and the key findings related to the impact of the AR-based teaching tool (Supplementary Table).

RESULTS

The initial search identified 2957 records from PubMed (n=7) CINAHL Plus (n=2936), Web of Science (n=5) and hand search (n=9). Duplicate removal (n=45) resulted in 2912 records to be screened by title. 2804 articles were excluded during the first round by screening by title, yielding 108 potentially eligible articles. After the second round of screening by full-texts, 19articles were included in this review. The primary goal of these 19 studies was to assess the impact of augmented reality teaching tools in didactic teaching of health professional education.

Fourteen studies used quantitative,[8,15,18,19,21,22,24,26-28,30-33] and the remaining five used mixed methods[3,20,23,25,29] for the research. Data collection tools included surveys, test scores, interviews, and focus groups. Students' acquisition of knowledge was the most widely measured outcome of the included studies. Other measured outcomes included attention, motivation, autonomous learning, spatial understanding, mental rotation, cognitive load, engagement, self-efficacy, and satisfaction. The content areas that used AR-based teaching tools included anatomy, neuroanatomy, pharmacy, dermatology, physiology, nutrition, structural biology, and tooth morphology. Key themes that emerged from the literature reviewed are discussed below:

A. AR-based tools used in education

Twenty-one percent of the studies in this review applied and evaluated ARBOOK (AR magic book) (n=4) for teaching anatomy.[15,20,22,25] The second most widely used and evaluated AR-based tool for didactic teaching was AR Magic Mirror (10.5%, n=2).[8,19] ARBOOK is an anatomical textbook available in printed and electronic versions for the study participants. Besides traditional text and images, ARBOOK also includes a card for each anatomical figure of the textbook that can be recognized by a digital webcam connected to a computer. A virtual AR image appears on the computer screen when the card is put in front of the camera.[15] AR Magic Mirror is an AR-based system where users can see a reflection of themselves with a virtual anatomical model superimposed on their digital mirror images.[19] This teaching tool contains a real-time tracking device, which enables this device to link a deposited section image to the projection of the user's body, generating a virtual anatomical model superimposed on the reflection. Using AR Magic Mirror, users can also interact and explore radiological images in different anatomical intersection planes.[8] Other AR-based applications include Anatomy 4D,[21] and stereoscopic 3D AR model,[18]

for anatomy, GreyMapp-AR for neuroanatomy,[3] SPECTO for cardiovascular anatomy and physiology,[24] ZapWorks to display 3D protein models for structural biology,[27] and AR virtual tooth identification test to study tooth morphology.[33] Multiple authors also used several mobile AR applications to teach dermatology,[28] nutrition,[29] heart failure,[31] food portions,[32] and Gunshot wounds[30] (Supplementary Table).

B. Impacts of the AR-based teaching tools on learning experiences

AR-based teaching tools have a positive impact on knowledge acquisition

Knowledge acquisition refers to extracting, structuring, and organizing new information from various sources.[34] Most studies (89.4%, n=17) in this review evaluated the knowledge acquisition of the study participants who used AR-based tools for their education.[3,15,18-20,22-33] The included studies took two main approaches to measure learning:

(i) By comparing test scores between control and experimental groups, where the control group did not use the AR technology (n= 8 studies).[3,15,20,22- 24,27, 30]

(ii) By comparing the pre-and post-test scores before and following learning sessions with the AR tool (n= 9 studies).[18,19,21,25-28,31-32]

Fifty eight percent of the included studies (n = 11) reported a significant improvement in knowledge acquisition in participants who used AR-based tools for learning.[15,18-20,22,25,28-32] Five studies (26%, n = 5) evaluating knowledge acquisition reported no significant differences between the control and the experimental groups.[18,24,26-28] These findings indicate that AR-based teaching

tools are as helpful as or better than traditional teaching methods for knowledge acquisition among health professional students.

AR-based teaching tools can improve spatial understanding and mental rotation

Spatial intelligence, the ability to develop mental models by generating and transforming visual images, is an essential skill for health professionals.[35] AR tools can facilitate this skill by enabling users to visualize a 3D object from multiple angles and interact with the virtual models to form robust mental models.

Twenty-one percent of the included studies (21%, n = 4) examined the effect of AR in developing spatial intelligence.[3,15,22,23] All four studies reported significant improvement in spatial understanding in study participants who used AR-based tools for learning. Three studies evaluated the mental rotation skills of the participants using the Mental Rotation Test (MRT).[8,18,19] Students with lower MRT scores benefited from using AR-based tools and achieved higher scores in MRT.[18,19] However, Henssen et al.[3] reported no significant difference in MRT between the control group and the group of learners who used AR-based tools for learning.

Application of AR technology can reduce Cognitive Loads

Only eleven percent of the included studies (10.5%, n =2) examined the cognitive loads of learners who used AR-based tools compared with control groups with equivocal results.[3,20] The term 'cognitive load' by definition refers to the amount of information that our working memory

can process at any given time.[36] Küçük et al.[20] reported significantly lower cognitive loads because of AR tool use, whereas no significant differences were reported by Henssen et al.[3]

AR improves attention, motivation, confidence, and satisfaction

Several studies evaluated the impact of AR-based teaching tools on students' motivation, [3,15,21-24] satisfection,[21,25-27,31] attentaion,[15,21,22] and engagement.[8] When using AR tools as learning aids, students scored higher in all aspects of metacognitive perception, including attention, motivation, confidence, and autonomous learning.[3,21,22] However, Norgaard et al.[23] and Henssen et al.[3] found no significant differences in motivation between control and experimental groups. Student surveys and written feedback represented a high degree of student satisfaction, perceived engagement, and enjoyment from using AR-based learning tools.[25-27]

C. Potential applications of AR in dental hygiene education

Didactic learning of basic science concepts is essential to dental and dental hygiene (DH) education. However, the application of cutting-edge technologies in classroom teaching is rare. Previous reviews on the application of AR-based teaching tools in dental education only include studies applying AR to clinical training and skill development. Although there are reports on the application of AR in the clinical training of DH students,[37] no reports of the application and evaluation of this technology in the classroom teaching in DH programs were found. Besides oral structures, DH students also study whole-body anatomy and physiology, nutrition, and oral health counseling, which are fundamental subject areas of the curriculum.[38] Our review found reports of AR-based teaching tools in many health professional education programs, including nursing,

medicine, pharmacy, and dentistry. Based on the findings of this review, a list of AR-based teaching apps is created that can be implemented in DH classroom education (Table 2).

DISCUSSION

AR, being interactive and immersive, has become an excellent teaching and learning tool. The benefit of AR is well-established in medical education as a tool for teaching clinical skills, including surgery, patient interaction, and clinical image detection. Didactic learning of basic science concepts is integral to all health professional education, including dental and dental hygiene education. However, the application of this technology in didactic non-clinical teaching is limited and less evaluated. Our review aimed to investigate the current literature to identify the application of AR in didactic teaching in health professional education.

Most of the literature included in our review used AR to teach anatomy, neuroanatomy, anatomy, and physiology. AR Magic Mirror and ARBOOK were the most widely used AR-based tools implemented to teach anatomy to health professional students. Our results revealed that AR-based tools can significantly improve students' spatial understanding, mental rotation score, and academic performance, as well as reduce the cognitive load of learning.

Spatial intelligence, or three-dimensional understanding, is integral to health professional education. Healthcare professionals need to use visual information from 2D images, like X-rays, MRI, and CT scans, to develop 3D mental models. Developing a mental model requires skill and often exerts a heavy cognitive load on students.[17,35] According to the Cognitive Load theory, the learning load of our working memory is affected by the underlying nature of the subject matter (intrinsic load) and how the topic is presented (extrinsic load). Although the intrinsic load of a

subject cannot be changed, the learning process can be eased by changing how the subject is being presented (extrinsic load).[36] It is possible that the teaching tools powered by AR technology provide an alternative scaffold for learners to produce the 3D mental model, thus reducing the cognitive load of learning.

Several educational theories support the incorporation of technology-infused teaching tools. Constructivist learning theory supports the use of interactive and immersive tools like the application of AR technology. According to the constructive theory, learning occurs when the individual interacts with their environment. AR incorporates digital content in a user's environment, allowing them to interact with the virtual object, and this interaction with learners' existing knowledge enables them to construct new meaning and understanding.[39] However, the study design, driven by educational theories, largely lacks the articles in the review.

Our review has revealed several gaps in the current research and identifies potential for improvement. Studies that were included in our review largely used quantitative research methods. It is essential to collect quantitative data from interviews and focus groups to better understand learners' perspectives on the benefits and limitations of using AR-based teaching tools. Faculty views, application of educational theories, and the cost of developing such teaching tools were also missing in these articles.

The foundational teaching in dental and DH education can largely benefit from the application of AR tools in the classroom. Based on the findings of this review, we have identified a list of AR-based teaching tools for the dental and DH students and educators (Table 2). The AR apps that are

used to teach anatomy, physiology, and nutrition as well as have been shown a significantly positive impact on knowledge acquisition, spatial rotation, satisfaction, attention, motivation, engagement, and confidence are chosen for the list. The DH students and educators are expected to benefit from the evidence-based application of AR tools in their didactic teaching and learning.

We acknowledge some limitations of this review. This literature review focused on AR only. Similar technologies like virtual reality (VR), mixed reality (MR) and extended reality (XR) are not included in this review. A small number of articles that matched the eligibility criteria and were relevant to our study question were included in this review. 'Dental hygiene' or 'Dental education' were not used as search terms, which may have excluded some discipline-specific studies. The quality of the studies was not assessed. Negative results may have been missed due to publication bias. All the studies included in our review used traditional evaluation methods. AR teaching tools can have benefits and drawbacks that are not effectively assessed using traditional methods.

CONCLUSION

This narrative review reveals the current state of augmented reality (AR) as a teaching tool for health professional students. AR tools significantly improve students' knowledge of the subject matter and spatial understanding. Most studies have found that AR technologies motivate students and reduce their cognitive load. However, the number of articles in this field is still limited, with the vast majority focusing on learning anatomy using AR. Further studies are needed in this area

to better understand the impact of AR technology on the cognitive perception of learners in other health science fields.

Practice Implications:

- Augmented Reality (AR) has an immense potential to facilitate non-clinical classroom education.
- The impact of AR-based tools in classroom teaching is not well-known in health professional education.
- This literature review investigates the effectiveness of AR-based tools in non-clinical, didactic teaching.

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FIGURES AND TABLES

Figure 1 The experience of Augmented Reality (AR). An AR system includes a display, which can be a smartphone, tablet, or head-mounted display. When users look through the display, they can see their surrounding world with the additional digital component, which is not physically present in the real world.

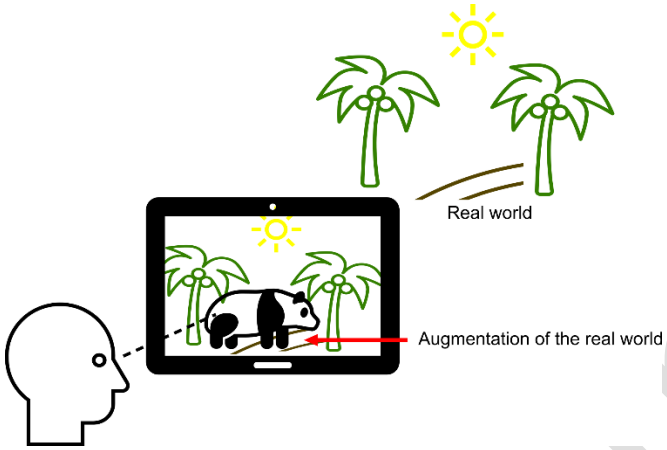
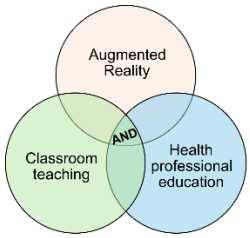


Figure 2 (A) Search parameters used in the narrative review. (B) A flow diagram of the literature screening procedure.

A



Search string: ((Augmented Reality) AND (Classroom teaching)) AND (Health professional education)
Time limit: 2014 - 2024

B

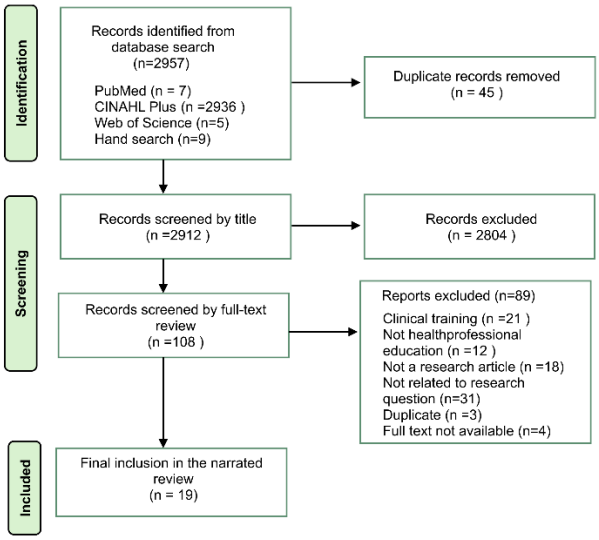


Table 1 Inclusion and exclusion criteria

	Inclusion	Exclusion
Language	English	Non-English
Year of Study	Studies published between 2014-2024	Studies published before 2014.
Study focus	Health professional education	Non-health professional education
	Classroom learning, lab-based non-clinical learning	Technical/motor/clinical skills Clinical training, simulation lab-based learning
	Undergraduate post-secondary education	K-12 education, graduate education
Study design	Any	Nil
Setting	Any	Nil

Table 2 Augmented Reality (AR)-based teaching apps that can be implemented in dental hygiene classroom education

AR app	Brief description	Impact
ARBOOK	An anatomical textbook that includes a card for each anatomical figure of the textbook. These figure-cards can be recognized by an AR camera and display system.[15]	ARBOOK has positive impacts on: • Knowledge acquisition • Attention • Motivation • Spatial understanding
AR Magic Mirror	AR Magic Mirror contains a real-time tracking device, which enables the system to link a deposited section image to the projection of the user's body. Using gesture input, the users can interact and explore radiological images in different anatomical intersection planes.[8]	AR Magic Mirror has positive impacts on: • Knowledge acquisition • Mental rotation • Engagement • Spatial understanding
Anatomical stereoscopic 3D AR model	The interactive virtual 3D anatomical model can be observed using HoloLens. Students can walk around the 3D model and explore it from all possible angles.[18]	Anatomical stereoscopic 3D AR model has positive impacts on: • Knowledge acquisition • Mental rotation
Anatomy 4D	Using Anatomy 4D uses can interact with anatomical pictures of the human body. The application uses a target image, when looked through the AR-enabled display, users can see and interact with an anatomical image of human body.[21]	Anatomy 4D has positive impacts on: • Motivation • Attention • Confidence • Satisfaction
AR tool for the estimation of food portions	Students need to download and print a fiducial marker to use this AR cellphone app. When the marker is scanned by the phone camera, the AR app allow students to view virtual images of food overlayed onto real world environments. [36]	The AR food portion app has positive impacts on • Knowledge acquisition
Mobile AR nutrition monitoring system	A mobile AR nutrition monitoring system can be used to monitor nutrient intake. Students can use their mobile devices to scan the food images for nutrient analysis.[33]	The mobile AR nutrition monitoring system has positive impacts on: • Knowledge acquisition