The impacts of augmented reality teaching tools in health professional education

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PRACTICAL IMPLICATIONS OF THIS RESEARCH

- Augmented reality (AR) has immense potential to facilitate non-clinical classroom education.
- The impact of AR-based tools on 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.

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 health professional education programs, including dental hygiene. However, this use has been relatively less explored and evaluated. This review investigates the effectiveness of AR-based tools in non-clinical didactic teaching. **Methods:** A literature search was conducted in 3 databases using the search terms "augmented reality," "classroom teaching," and "health professional education." Articles were screened first by the title and then by full-text review to identify reports that met the inclusion criteria and were relevant to the research questions. **Results:** Nineteen articles were included in the narrative review. AR Magic Mirror and ARBOOK were found to be the 2 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 traditional teaching methods in health professional education. As most AR-based teaching tools are focused on teaching anatomy, many health professional education programs can benefit from these tools. However, qualitative exploration of student and faculty perspectives and development costs are absent from the literature. **Conclusion:** Didactic learning of basic science concepts such as anatomy is essential to many health professional education programs, including dental hygiene. Dental hygiene can largely benefit from incorporating AR-based teaching tools into classroom education.

RÉSUMÉ

Objectifs : La réalité augmentée (RA) a réussi à faciliter la formation clinique dans le cadre de l'enseignement des professionnels de la santé. Cette technologie peut aussi accélérer l'enseignement non clinique en classe en améliorant la compréhension spatiale et les compétences de rotation mentale des étudiants, essentielles pour de nombreux programmes de formation professionnelle dans le domaine de la santé, y compris l'hygiène dentaire. Cependant, cette utilisation a été relativement moins explorée et évaluée. Cette revue examine l'efficacité des outils à base de RA dans l'enseignement didactique non clinique. **Méthodes :** Une recherche documentaire a été effectuée dans 3 bases de données à l'aide des termes de recherche « réalité augmentée », « enseignement en classe » et « formation des professionnels de la santé ». Les articles ont d'abord été triés selon leur titre, puis par un examen intégral afin de trouver les rapports qui répondaient aux critères d'inclusion et qui étaient pertinents aux questions de recherche. **Résultats** : Dix-neuf articles ont été inclus dans l'examen narratif. AR Magic Mirror et ARBOOK se sont avérés être les 2 outils de RA les plus utilisés dans l'enseignement didactique. Les outils pédagogiques à base de RA peuvent réduire la charge cognitive et améliorer l'acquisition des connaissances, la compréhension spatiale, les compétences de rotation mentale, l'attention, la motivation, la confiance et la satisfaction. **Discussion :** Les outils de RA peuvent améliorer considérablement l'expérience d'apprentissage des étudiants par rapport aux méthodes traditionnelles d'enseignement utilisées dans la formation des professionnels de la santé. Étant donné que la plupart des outils pédagogiques à base de RA sont axés sur l'enseignement de l'anatomie, de nombreux programmes de formation des professionnels de la santé peuvent profiter de ces outils. Cependant, l'exploration qualitative des points de vue des étudiants et des enseignants ainsi que les coûts de développement sont absents de la documentation. **Conclusion :** L'apprentissage didactique des concepts scientifiques fondamentaux tels que l'anatomie est essentiel à de nombreux programmes de formation des professionnels de la santé, y compris l'hygiène dentaire. L'hygiène dentaire peut largement bénéficier de l'intégration d'outils pédagogiques à base de RA dans l'enseignement en classe.

Keywords: augmented reality; dental education, teaching; dental hygiene; education; educational activities; educational technique; teaching method
CDHA Research Agenda category: capacity building of the profession

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INTRODUCTION

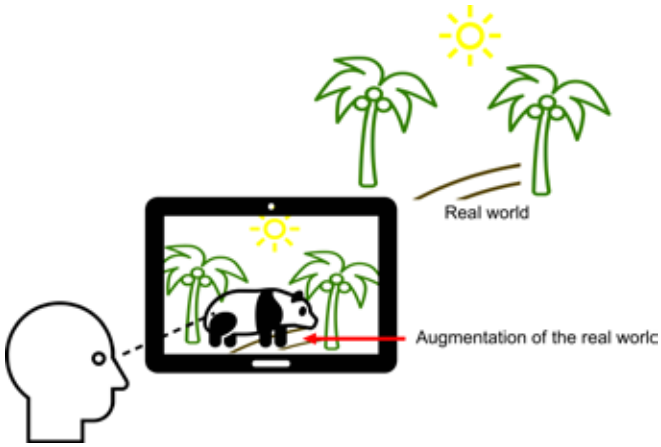
Augmented reality (AR) is an emerging interactive technology incorporating digital data, including 3-dimensional models, images, videos, and audio recordings, into the real-world space.[1] The application of AR has started a new era in gaming and entertainment and has become a valuable tool in education, health care, 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. In contrast, 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—a smartphone, tablet or head-mounted device for display. Through the display system, the user can see their surrounding world with the addition of a digital component that is not physically present (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 such as 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 on health professional education are primarily focused on the impact of this technology on surgical skill development.[14]

Figure 1. The experience of augmented reality. When users look through the display, they can see their surrounding world with the additional digital component, which is not physically present.



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 in dentistry and dental hygiene programs 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 that AR-based teaching tools improve spatial understanding and mental rotation scores,[18,19] indicating that dental and dental hygiene education may benefit from the application of AR technology.

Didactic learning is an integral part of dental and dental hygiene education. However, reports on AR-based teaching tools in non-clinical dental and dental hygiene education are minimal. In this context, the literature on the reported impact of AR-based teaching tools on classroom teaching across the entire health professional education spectrum was mapped, aiming to identify AR-based teaching tools potentially applicable in dental and dental hygiene education. The specific research questions underpinning this review were as follows:

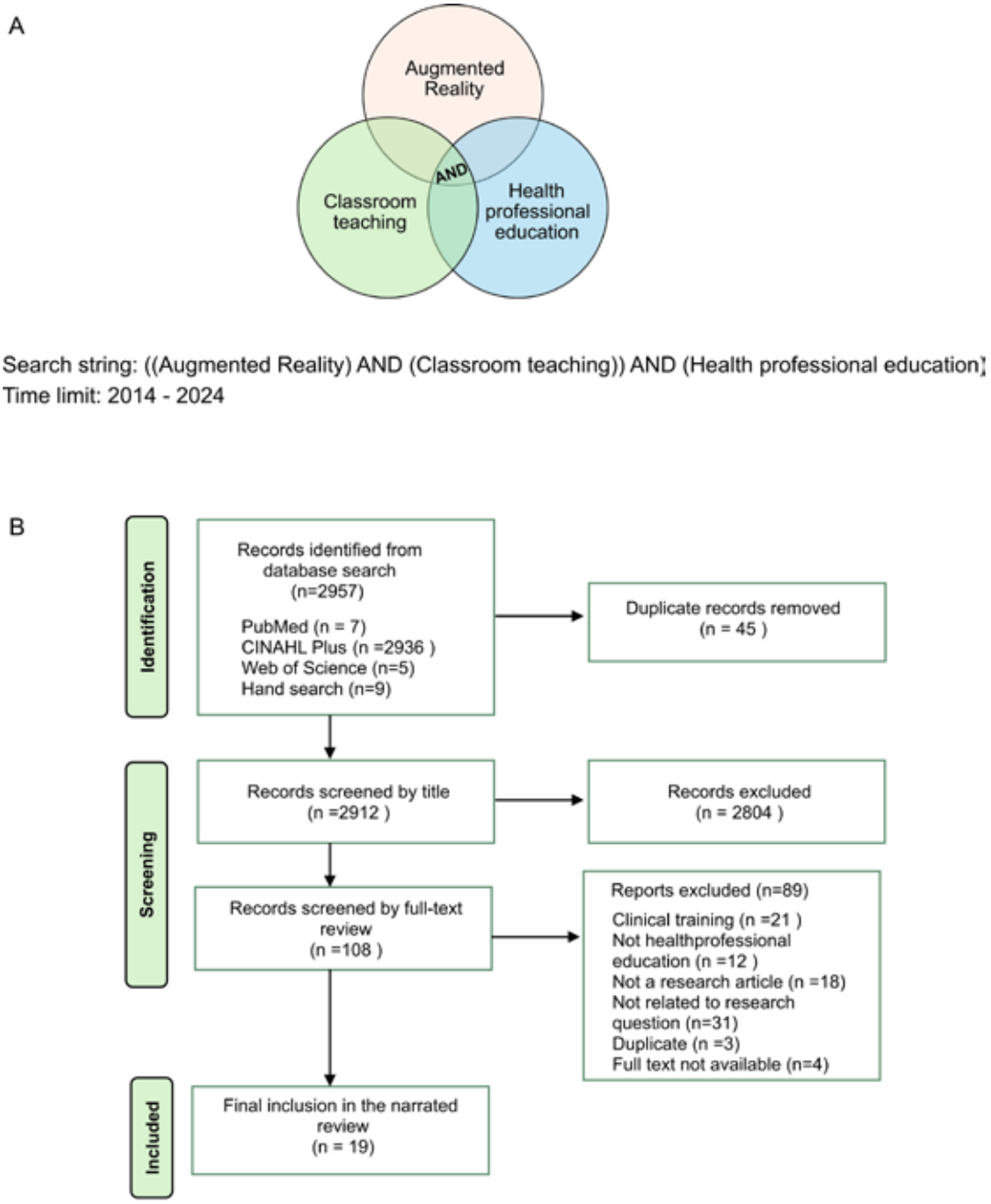
- What AR tools are used in didactic teaching in health professional education?
- Compared to traditional teaching, what is the impact of AR-based tools on didactic teaching in health professional education?

METHODS

Identification of potentially relevant studies

An extensive literature search was conducted in PubMed, CINAHL Plus, and Web of Science, using the search terms "augmented reality," "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 programs. The search string ((augmented reality) AND (classroom teaching)) AND (health professional education) was used for all 3 databases.

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



Screening to select relevant studies

Inclusion and exclusion criteria were based on the research questions (Table 1), which were further refined during the screening process. Primary research articles written in English, published between 2014 and 2024, and relevant to the research questions were included. Articles were screened first by the title and then by full-text review to exclude reports that were not in English, not available in full text, did not include faculty or students from health professional education programs, 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.

Table 1. Inclusion and exclusion criteria

	Inclusion	Exclusion
Language	English	Non-English
Year of study	Studies published between 2014 and 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

Data extraction

Data were 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 of the impact of the AR-based teaching tool (Supplementary Table S1).

RESULTS

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

Fourteen studies used quantitative[8,15,18,19,21,22,24,26-28,30-33] and the remaining 5 studies 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 studies. Other measured outcomes included attention, motivation, autonomous learning, spatial understanding, mental rotation, cognitive load, engagement, self-efficacy, and satisfaction. AR-based teaching tools were used to enhance instruction in anatomy, neuroanatomy, pharmacy, dermatology, physiology, nutrition, structural biology, and tooth morphology. Key themes that emerged from the literature reviewed are discussed below.

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 print 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 the tool 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 a 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 S1).

Impacts of the AR-based teaching tools on learning experiences

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 2 main approaches to measure learning:

1. 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]
2. Comparing the test scores before and following learning sessions with the AR tool (n = 9 studies).[18,19,21,25-28,31-32]

Fifty eight percent (58%) 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%) 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.

Improvements in 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

Table 2. Augmented reality (AR)-based teaching apps that could be used in dental hygiene classroom education

AR app	Brief description	Impact
ARBOOK	An anatomical textbook that includes a card for each anatomical figure in 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	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 users can see and interact with anatomical images of the 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 allows 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 food images for nutrient analysis.[33]	The mobile AR nutrition monitoring system has positive impacts on: • Knowledge acquisition

models to form robust mental models.

Twenty-one percent (21%) of the included studies (n = 4) examined the effect of AR in developing spatial intelligence.[3,15,22,23] All 4 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 benefitted from using AR-based tools and achieved higher scores in MRT.[18,19] However, Henssen et al.[3] reported no significant difference in MRT scores between the control group and the group of learners who used AR-based tools for learning.

Reduced cognitive loads

Only 11% 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" refers to the amount of information that an individual's 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]

Improvements in attention, motivation, confidence, and satisfaction

Several studies evaluated the impact of AR-based teaching tools on students' motivation,[3,15,21-24] satisfaction,[21,25-27,31] attention,[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 revealed a high degree of student satisfaction, perceived engagement, and enjoyment from using AR-based learning tools.[25-27]

Potential applications of AR in dental hygiene education

Didactic learning of basic science concepts is essential to dental and dental hygiene education. However, the application of cutting-edge technologies in classroom teaching is rare. Previous reviews of the application of AR-based teaching tools in dental and dental hygiene education only included studies applying AR to clinical training and skill development. Although there are reports of the application of AR in the clinical training of dental hygiene students,[37] no reports of the application and evaluation of

this technology in classroom teaching in dental hygiene programs were found. Besides oral structures, dental hygiene students also study whole-body anatomy and physiology, nutrition, and oral health counselling, which are fundamental subject areas of the curriculum.[38] The present 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 has been created to support implementation in dental hygiene classroom education (Table 2).

DISCUSSION

AR, being interactive and immersive, is 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 has been limited and less evaluated. The present review aimed to investigate the literature to identify the application of AR in didactic teaching in health professional education.

Most of the literature included in this review documented the use of AR to teach anatomy, neuroanatomy, and physiology. AR Magic Mirror and ARBOOK were the most widely used AR-based tools to teach anatomy to health professional students. This review's results reveal 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 3-dimensional understanding, is integral to health professional education. Health care professionals need to use visual information from 2D images, such as X-rays, magnetic resonance imaging, and computed tomography 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 Cognitive Load Theory, the learning load of an individual's 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 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 such as the application of AR technology. According to this theory, learning occurs when the individual interacts with their environment. AR incorporates digital content into 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, study designs driven by educational theories were largely absent from the articles included in this review.

The present review has revealed several gaps in the research and identifies potential areas for exploration. Studies that were included in the present review largely used quantitative research methods. It is essential to collect qualitative 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 dental hygiene education can largely benefit from the application of AR tools in the classroom. Based on the findings of this review, a list of AR-based teaching tools for dental and dental hygiene students and educators has been compiled (Table 2). The AR apps that are used to teach anatomy, physiology, and nutrition and have been shown to have a significantly positive impact on knowledge acquisition, mental rotation, satisfaction, attention, motivation, engagement, and confidence were chosen for the list. Dental hygiene students and educators are expected to benefit from the evidence-based application of AR tools in their didactic teaching and learning.

Limitations

This review has some limitations. First, it focused on AR only. Similar technologies such as virtual reality (VR), mixed reality (MR), and extended reality (XR) were not included. A small number of articles that matched the eligibility criteria and were relevant to the research questions were included in this review. "Dental hygiene" and "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 the present review used traditional evaluation methods. AR teaching tools may have benefits and drawbacks that are not effectively assessed using traditional methods.

CONCLUSION

This narrative review reveals the current state of AR as a teaching tool for health professional students. AR tools significantly improve students' knowledge of the subject matter and their 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.

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CONFLICTS OF INTEREST

The authors of this study have declared no conflicts of interest.

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