



An Exploratory Study on the Use of Augmented Reality (AR) in Medical Education

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Abstract

The use of digital technology in the teaching and learning process has grown significantly in recent years. Augmented reality (AR) is a technology/software that allows the digital creation of three-dimensional representations that can be integrated with real stimuli in the environment. It is an interactive, real-time experience that combines reality with elements from the virtual world, leading to an augmented reality enriched with virtually generated information, based on human visual, auditory, olfactory and/or somatosensory input. The result is an image of reality modified by a computer program, which aims to improve the real-world experience, but does not replace the real world. It is not a 360° virtual world, but makes reality more manageable, amplifies it, mapping three-dimensional virtual objects in a real environment. Such AR programs can be used on various devices such as: smartphones, tablets, computers, AR glasses, headsets, etc.

Even though augmented reality (AR) was initially used for entertainment and gaming, its application has expanded into industry, healthcare, marketing, military, travel, architecture and engineering, but also in the medical education of students in medical schools. So far, we have not found global or regional statistics on the degree of use of AR in medical education, but there are a number of universities that use AR platforms or others that implement pilot studies or isolated modules. We have not identified any large-scale implementations or fully integrated implementations into core curricula. The obstacles to adopting this technology in medical education are mainly related to the high costs of implementing AR technology, the lack of

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adequate infrastructure in universities, the need to train teachers in the use of AR technology, access to technology (hardware).

The present paper is a theoretical-exploratory one in which we analyze a series of articles, identified through the associated search of 3 keywords, in different scientific databases, namely: "digital learning methods", "medical students" and "augmented reality". In this paper, we analyze to what extent AR can improve the learning experiences of medical students, through practical understanding and skills training, with examples of software already used in didactic training, such as: HoloHuman, OculAR SIM, Hololens, HoloPatient. Finally, we discuss the challenges of AR in learning and teaching, limitations in implementation, and propose future research directions.

In Romania, two universities stand out that implement AR technology in medical education, namely: the "Iuliu Hațieganu" University of Medicine and Pharmacy in Cluj-Napoca, which had a project to develop AR simulators for laparoscopic, robotically assisted, single incision surgery, using Hololens 2, and the University of Medicine, Pharmacy, Sciences and Technology in Târgu Mureș, which within the Center for Simulation and Practical Skills has a department dedicated to "Virtual and Augmented Reality". In Europe there is growing interest, through pilot projects and elective courses, involving AR, but it is not yet a widespread use in standard curricula at all medical schools. Worldwide, the adoption of AR technology in medical education is taking place especially in highly prestigious universities with good financial resources. Finally, as a case study, we focused on Romania. We conducted a search on the official websites of the eleven major universities in the country that provide education and training for future medical professionals, with the aim of identifying programs or any references related to the use of AR technology in their medical education curricula. The findings for Romania reveal that among the eleven universities providing medical training programs, only five have established simulated learning centers employing VR technologies for students, whereas one university has initiated two minor VR technology acquisition projects within the last two years. *Conclusion.* In the field of medical education, the adopting of augmented reality (AR) could provide both students and



teachers with significant advantages, including a stimulating learning environment, immersive practical experience, and opportunities for distance learning.

Keywords: augmented reality, medical education, digital technology, teaching methods, students, learning

1. Introduction

Augmented reality (AR) has been applied in medicine mainly in two areas: clinical programs (for patients, therapies, rehabilitation, surgery) and educational programs (for teaching and training in universities). This review focuses on the educational side, where AR enhances knowledge, learning, and skill development.

AR is an interactive technology that superimposes computer-generated three-dimensional objects and information onto real-world environments in real time. By integrating virtual elements with sensory inputs (visual, auditory, tactile, or olfactory), AR enriches reality by creating an enhanced perception of the physical world. Unlike fully immersive virtual reality, AR maintains the user's connection to the real environment while amplifying it through digital overlays. Its applications are accessible across multiple platforms, including smartphones, tablets, computers, head-mounted displays, and AR glasses.

2. Literature Review

Although AR was initially developed for entertainment and gaming, its applications have expanded into diverse fields such as industry, healthcare, marketing, the military, tourism, architecture, and engineering, as well as into the medical education of university students (Zhu et al., 2014).

Traditionally, medical education relied on textbooks, lectures, cadavers, anatomical models, and patient practice. In the early 1990s, computer-assisted anatomy tools and multimedia resources appeared. With advances in hardware, software, such as PowerPoint replaced blackboards, while the internet enabled large-scale projects like the Visible Human and Visible Embryo. Mid-1990s



technologies also introduced stereoscopy for 3D visualizations. Although head-mounted displays (HMD) existed since the 1968, "The Sword of Damocles" is considered the world's first augmented reality system, widespread use of VR/AR in medical education became possible only with modern devices such as Google Glass, Microsoft HoloLens, HoloHuman, HoloPatient, Oculus Rift, and Samsung Gear VR, Ocular SIM (Dhar et al., 2021). This narrative review by Dhar et al. (2021) explored the role of AR in medical education, focusing on its influence on students' experiences, knowledge acquisition, practical competence, and social skills. A comprehensive literature search was conducted in PubMed, Scopus, and Google Scholar, targeting English-language publications from 2010 to 2020. Unlike a systematic review, article selection relied on author discretion, allowing a broader inclusion of relevant themes and evidence.

Findings demonstrate that AR-based learning holds significant promise in enhancing medical education by creating immersive and interactive environments that replicate real clinical settings. AR enables learners to visualize complex anatomical structures dynamically and to practice procedural and surgical skills safely before performing them on patients. Studies showed that AR applications improved theoretical understanding, procedural accuracy, and psychomotor skills, while also minimizing adverse effects such as discomfort or disorientation often associated with virtual reality (VR).

Beyond technical training, AR also contributes to the development of social and interprofessional competencies. Simulation-based AR scenarios were found to strengthen teamwork, communication, and decision-making under pressure - skills critical to modern medical practice. Despite these benefits, the current body of evidence remains fragmented, with most studies focusing on feasibility and face validity rather than long-term educational outcomes.

This review indicates that major challenges to large-scale adoption include high implementation costs, limited hardware access, and the need for faculty training. The review highlights future directions such as the use of AR textbooks, wearable devices, and mobile learning platforms to enhance accessibility and engagement. Emerging collaborations between academia and industry -



such as those led by the University of Southern California's Medical Virtuality Lab - are paving the way for the integration of AR in medical curricula.

Another recent research by Tang et al. (2020) evaluated the existing augmented reality applications (ARAs) used in the training of medical students and proposed an analytical model for assessing their effectiveness and readiness for curricular integration. The study methodology included an extensive literature search in PubMed, Embase, Web of Science, Cochrane Library, and Google Scholar databases, conducted in accordance with PRISMA guidelines, covering publications from 2000 to 2018. Out of 100,807 initially identified articles, 36 met the inclusion criteria and were classified into three main categories: surgery, anatomy, and other areas of application. The analysis revealed a generally low methodological quality among the studies and a lack of comprehensive validity assessments for AR applications. The findings suggest that, although AR technology is developing rapidly, the level of research available at that time did not yet support large-scale implementation in medical education. The proposed analytical model may serve as a valuable foundation for standardizing evaluation methods and defining the role of augmented reality in medical education.

A meta-analysis by Baashar et al. (2022) evaluated the effectiveness of augmented reality (AR) applications in medical education and training. Following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, the authors analyzed 13 experimental studies published between 2013 and 2021, encompassing a total of 654 participants from ten countries. The included studies assessed AR interventions across various medical disciplines, comparing them with traditional teaching and learning methods.

The review focused on five primary outcome measures: knowledge acquisition, skills development, confidence, performance time, and learner satisfaction. Statistical analysis revealed that AR training significantly improved participants' confidence ($P=.02$), performance time ($P<.001$), and satisfaction ($P=.006$) compared with conventional methods. However, no statistically significant differences were observed in knowledge or skill acquisition between AR-based and traditional training approaches.



Despite its promising outcomes, the study noted substantial heterogeneity among trials and highlighted methodological weaknesses such as small sample sizes, inconsistent study designs, and limited reporting of randomization and blinding procedures. Nevertheless, the findings suggest that AR can be a valuable supplementary tool in medical education, particularly for enhancing learner engagement, confidence, and procedural efficiency.

According to Bashar et al. (2021) AR shows strong potential to enrich medical training and reduce performance time, further high-quality, large-scale, randomized studies are required to confirm its long-term educational benefits and integration into medical curricula.

Harrington (2024) conducted a study about the transformation of preclinical medical education during and after the COVID-19 pandemic prompted the integration of e-learning tools into traditionally lecture-based curricula. In response to this educational shift, the MedMicroMaps system was developed as an interactive, visual, and spatially organized digital learning resource for teaching microbiology and infectious diseases. Designed around mind mapping and the Method of Loci pedagogical principles, MedMicroMaps utilizes color-coding, directional organization, and hyperlinking to structure information by disease onset, anatomical location, and microbial classification.

Each module within MedMicroMaps is organized by organ system and guides learners through differential diagnoses, epidemiological factors, and diagnostic algorithms using decision tree logic. The resource aims to enhance student engagement and retention through self-directed, visually oriented learning pathways.

A pilot study conducted at St. George's University, Grenada, included 865 medical students in hybrid courses during 2022. Website analytics revealed over 16,000 views within 14 months, with peak engagement occurring before examinations. Survey feedback (n = 79, 9.1% response rate) indicated high satisfaction levels, particularly for the Microbe Biology MedMicroMaps module (75% "Extremely Satisfied"). Students most frequently used the tool for exam preparation and integration with practice questions.

The findings support MedMicroMaps as an effective supplemental e-learning resource for microbiology education. Future developments include cross-platform expansion into immersive



learning environments such as virtual and augmented reality (XR), with applications across multiple biomedical disciplines. A longitudinal study is planned to evaluate its impact on both short-term and long-term knowledge retention.

3. Objectives and Method

The present paper is a theoretical-exploratory study aimed at analyzing the role of Augmented Reality (AR) in enhancing the learning experience of medical students. For the purpose of this theoretical analysis, the PubMed database was used to perform a combined search based on specific keywords appearing in the titles of articles: “digital learning methods”, “medical students”, and “augmented reality”, covering the period 2014–2025. The search identified 23 results corresponding to previous research studies. Out of these, five articles were selected as relevant and closely aligned with the proposed topic, serving as the foundation for the documentation and analysis conducted in this paper. The objective is to determine the extent to which AR technologies can improve medical students’ educational outcomes, focusing on both cognitive understanding and practical skill development.

In the last 11 years, the increasing integration of digital technologies in higher education has led to significant pedagogical transformations, especially in medical training. Augmented Reality, which overlays digital information and 3D visualizations onto the real-world environment, offers a unique opportunity to bridge the gap between theoretical knowledge and clinical practice. Unlike traditional e-learning tools, AR provides an immersive and interactive experience that enables students to visualize anatomical structures, physiological processes, and clinical scenarios with unprecedented realism.

This paper provides an overview of AR technologies successfully applied in medical student education, highlighting platforms such as HoloHuman, Ocular SIM, Microsoft HoloLens, and HoloPatient.

HoloHuman allows students to examine detailed, full-scale 3D anatomical models that can be manipulated in real time, improving spatial understanding of the human body.



OculAR SIM focuses on ophthalmology, offering interactive simulations that help learners understand complex eye disorders and surgical procedures.

HoloLens, a mixed-reality headset developed by Microsoft, enables users to interact with holographic patients and virtual organs while maintaining awareness of their physical surroundings, thus combining hands-on learning with digital enhancement.

HoloPatient provides realistic patient scenarios in which learners can observe symptoms, make diagnostic decisions, and practice communication and empathy - key competencies in clinical education.

Integrating AR supports experiential learning, active engagement, and multimodal cognition, aligning with constructivist and experiential learning theories. Furthermore, AR facilitates collaborative learning environments, allowing multiple students to interact simultaneously with the same virtual object or patient case.

However, despite its potential, the implementation of AR in medical education faces several challenges. High costs associated with hardware and software development, limited technical expertise among educators, and unequal access to technology across institutions remain significant barriers. Additionally, there are ongoing concerns regarding cognitive overload, data security, and the validation of AR-based assessment methods.

4. Results and Discussions

No comprehensive data were found concerning the total number of universities worldwide that offer medical education programs employing AR technologies. The studies identified in our search on PubMed, that we mentioned provide information only about certain pilot projects. Carle Illinois College of Medicine (USA) is the first medical school to integrate the AR-MediView XR90 platform (Carle Illinois College of Medicine, 2025). The University of Cambridge and Cambridge University Hospitals have collaborations for holographic simulations through GigXR, University of Michigan Health collaborates with GigXR for mixed/augmented reality curriculum (ISPR, 2022). The University of Bradford (UK) has implemented AR headsets for medical students (Study in UK, n.d.).



Finally, as a case study, we focused on Romania. We conducted a search on the official websites of the eleven major universities in the country that provide education and training for future medical professionals, with the aim of identifying programs or any references related to the use of AR technology in their medical education curricula. The results obtained are summarized in

Table 1.

No .	University Name	Use in Medical Education	AR/VR simulation mentioned	Details
1	Carol Davila University of Medicine and Pharmacy, București	eHealth Centre	VR simulation mentioned, no explicit AR use	https://umfcd.ro/general/comunicat-de-presa-umf-carol-davila-din-bucuresti-initiaza-activitatil-e-centrului-de-inovatie-si-e-health-cieh/
2	Iuliu Hațieganu University of Medicine and Pharmacy, Cluj-Napoca	Centre for Practical Skills and Simulation in Medicine	VR simulation mentioned, no explicit AR use	https://umfcluj.ro/en/medicin/education/students/centre-practical-skills-simulation-medicine/
3	Grigore T. Popa University of Medicine and Pharmacy, Iași	VR Simulation Center	VR simulation mentioned, no explicit AR use	https://www.umfiasi.ro/academic/Pagini/Centrul-de-Simulare.aspx
4	Victor Babeș University of Medicine and Pharmacy, Timișoara	Partial, MedSimVR FDI 2024, VRPlus FDI 2025	VR simulation mentioned, no explicit AR use	https://www.umft.ro/ro/medsimvr-fdi-2024/ https://www.umft.ro/ro/vrplus-fdi-2025/
5	University of Medicine and Pharmacy of Craiova	Center for Applied Simulation in Medicine	VR simulation mentioned, no explicit AR use	https://www.umfev.ro/ro/cercetare/centre-de-cercetare/centrul-de-simulare-aplicata-in-medicina
6	George Emil Palade University of Medicine, Pharmacy, Science and Technology, Târgu Mureș	Simulation and Practical Skills Center	VR and AR simulation mentioned	https://umfst.ro/centrul-de-simulare-si-abilitati-practice/departamente/reabilitate-virtuala-si-augmentata/
7	Ovidius University, Constanța	Not specified	Not specified	Not specified
8	Dunărea de Jos University, Galați	Not specified	Not specified	Not specified
9	Vasile Goldiș Western University, Arad	Not specified	Not specified	Not specified
10	Titu Maiorescu University, București	Not specified	Not specified	Not specified
11	Lucian Blaga University, Sibiu	Not specified	Not specified	Not specified

Table 1. Information based on official university websites. (accessed October 2025)



As indicated in the table above, the University of Medicine, Pharmacy, Science, and Technology of Târgu Mureș is the only institution in Romania that explicitly states on its official website the implementation of AR technology in medical student education, within its Simulation and Practical Skills Center, has a dedicated department for 'Virtual and Augmented Reality.' This Center explicitly mentions that its equipment includes 20 pairs of Microsoft HoloLens 2 glasses, applications such as HoloPatient (150 licenses) and HoloHuman (150 licenses), and specific hospital ward furniture for simulations (University of Medicine, Pharmacy, Science, and Technology of Târgu Mureș, n.d.)

In the study 'Digital Health Training, Attitudes and Intentions to Use It among Romanian Medical Students: A Study Performed during COVID-19 Pandemic', Lotrean et al. (2023) analyzed the responses of 306 students from the 5th and 6th years of the Faculty of Medicine at the 'Iuliu Hațieganu' University of Medicine and Pharmacy, Cluj-Napoca. The results indicate that 'less than half' of the students reported having received training or practical examples during their medical education regarding the use of digital tools in various medical fields. The majority of students would like more training. AR is not explicitly mentioned as a separate technology in the study.

The findings for Romania reveal that among the eleven universities providing medical training programs, only five have established simulated learning centers employing VR technologies for students, whereas one university has initiated two minor VR technology acquisition projects within the last two years.

5. Conclusion

AR holds significant transformative potential in medical education, offering immersive, interactive, and flexible learning environments that can bridge the gap between theoretical instruction and practical experience. By enabling realistic simulation, enhanced visualization, and distance learning opportunities, AR serves as a powerful pedagogical tool for both students and educators. However, despite its promise, current research remains fragmented and lacks standardized evaluation frameworks. Future empirical studies should rigorously examine the



long-term effects of AR-based instruction on knowledge retention, psychomotor skill acquisition, and clinical reasoning, while also addressing issues of scalability, accessibility, and pedagogical integration. Moreover, the convergence of AR with emerging technologies such as artificial intelligence and virtual reality could further advance personalized and adaptive medical education. This study contributes to the growing body of literature on digital transformation in healthcare education and underscores the role of AR as a catalyst for immersive, student-centered, and competency-driven learning.

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