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Article

The Digital Revolution in medical education: exploring the transformative role of digital tools

La Revolución digital en la educación médica: explorando el papel transformador de las herramientas digitales

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Abstract

In medical education, the digital revolution denotes the shift from traditional to digital learning methodologies, enabling flexible learning without time and location restrictions, incorporating various digital tools to enhance teaching and learning processes. The objective aims to comprehensively analyze the available evidence on the transformative role of digital tools in medical education, including online learning platforms, virtual medical simulators, mobile medical education applications, and augmented and virtual reality technologies. The methodology responds to a systematic literature review. The results provide a comprehensive view of the impact of various digital tools in medical education, highlighting their potential benefits in terms of improving access, quality and effectiveness of medical learning. In conclusion, digital tools not only improve the accessibility of medical education, but also facilitate more efficient and engaging learning opportunities for students. In particular, virtual and augmented reality have emerged

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as promising innovations that enable the replication of authentic clinical environments and thus support the practice of skills and the development of clinical competence in a safe and controlled environment.

Keywords: Digital tools, medical education, online learning platforms, simulators, mobile apps, virtual reality, augmented reality

Resumen

En la educación médica, la revolución digital denota el cambio de las metodologías de aprendizaje tradicionales a digitales, posibilitando un aprendizaje flexible sin restricciones de tiempo y ubicación, incorporando diversas herramientas digitales para mejorar los procesos de enseñanza y aprendizaje. El objetivo pretende analizar de manera exhaustiva la evidencia disponible sobre el papel transformador de las herramientas digitales en la educación médica, incluyendo las plataformas de aprendizaje en línea, los simuladores médicos virtuales, las aplicaciones móviles de educación médica y las tecnologías de realidad aumentada y virtual. La metodología responde a una revisión sistemática de la literatura. Los resultados proporcionan una visión integral del impacto de diversas herramientas digitales en la educación médica, destacando sus beneficios potenciales en términos de mejorar el acceso, la calidad y la eficacia del aprendizaje médico. En conclusión, las herramientas digitales no solo mejoran la accesibilidad de la educación médica, sino que también facilitan oportunidades de aprendizaje más eficientes y cautivadoras para los estudiantes. En particular, la realidad virtual y aumentada se han convertido en innovaciones prometedoras que permiten reproducir entornos clínicos auténticos y, por lo tanto, apoyan la práctica de habilidades y el desarrollo de la competencia clínica en un entorno seguro y controlado.

Palabras clave: Herramientas digitales, educación médica, plataformas de aprendizaje en línea, simuladores, aplicaciones móviles, realidad virtual, realidad aumentada

Introduction

The digital revolution refers to the transformative shift from mechanical and analog technologies to digital technologies, leveraging mainly the Internet (Grazian, 2005; Salmela-Aro & Motti-Stefanidi, 2022).. This revolution has affected several sectors, such as the economy, innovation, education, health and governance,

at an accelerating pace (Belostecinic & Jomir, 2023; Fraser, 2020; Hoehe & Thibaut, 2020).. It has led to significant changes in households, industry, cities, smart territories and hospitals (Pencarelli, 2020) by integrating devices with Internet of Things platforms (Sriram & Subrahman, 2020). (Sriram & Subrahmanian, 2020).. Despite being both a positive and negative force since 1980, the digital revolution was especially prominent during the pandemic of COVID-19 (Keesara et al., 2020)where digital solutions were rapidly adopted thanks to restriction and containment measures (Hantrais et al., 2020). (Hantrais et al., 2021; Wimmer, 2020).. Therefore, the digital revolution signifies the shift from mechanical to digital technologies, specifically those that rely on the Internet, which profoundly influence the lives of young people through the use of digital media at home and during their educational trajectory.

The digital revolution in the field of health sciences, encompasses the fusion of digital technologies such as artificial intelligence, virtual reality, and metaverse (Mohammed-Nasir et al., 2023; Nesterenko, 2022; Shotarov, 2023).. These advances have resulted in substantial improvements in healthcare delivery, including improved access to clinical care, reduced costs, and better physician-patient communication (Kala, 2022). In addition, the use of digital tools such as e-health, telemedicine, and mobile health has revolutionized medical education by introducing innovative pedagogical approaches and preparing students for upcoming changes in the field of medicine (Mondal & Mishra, 2022)..

Now, specifically in medical education, the digital revolution denotes the shift from traditional learning methodologies to digital ones (Jun Xin et al., 2021), which allows for flexible learning without time and location constraints, benefiting student motivation and outcomes (Yeung et al., 2022)The use of digital tools to enhance teaching and learning processes, such as podcasts, social networks and videoconferencing, is a key feature of these new technologies (Minter et al., 2022). (Minter et al., 2021)(Minter et al., 2021), cutting-edge tools such as virtual patients, augmented reality, and interactive platforms such as Google Forms and YouTube for live streaming (Park et al., 2021)Also, it involves a transition to the use of 3D printing, augmented reality (AR), virtual reality (VR), web-based programs, and tablet and smart phone-based applications for advanced and interactive anatomical training (Adnan & Xiao, 2023)..

From the previous paragraph, it is evident the need to understand in depth the transforming effects of the digital tools provided by the

digital revolution for medical education. This raises questions about their effectiveness, the quality of the educational content offered, student participation and academic achievement in the field of medicine. In addition, it is necessary to analyze the obstacles and limitations related to the incorporation and acceptance of these technologies, and to pinpoint the areas that require further research to improve their incorporation and use in medical education.

Therefore, the aim of this systematic review is to comprehensively analyze the available evidence on the transformative role of digital tools in medical education, including online learning platforms, virtual medical simulators, mobile medical education applications, and augmented and virtual reality technologies. As such, this systematic review will contribute to advances in this field by presenting a comprehensive synthesis of existing evidence, identifying knowledge gaps, and highlighting key research areas. Enabling educators, educational institutions and policy makers with information on optimal strategies to leverage these digital tools, which could ultimately result in substantial improvements in the training of healthcare professionals and the quality of medical services provided.

Materials and methods

The study was carried out by means of a systematic review of the literature. The research is characterized as descriptive and cross-sectional, and strictly adheres to compliance with the stipulations of the protocols described in the PRISMA statement (Kitchenham, 2004, 2007; Moher et al., 2009; Pardal-Refoyo & Pardal-Peláez, 2020)..

What is the role of digital tools in transforming medical education, including online learning platforms, virtual medical simulators, mobile medical education apps, and augmented and virtual reality technologies?

The exhaustive literature search was performed in SCOPUS, Web of Science, PubMed, Scielo databases using search terms related to digital tools and medical education. The key descriptors for the search were: digital tools, educational technology, educational technologies, instructional technology, instructional technologies, e-learning platforms, augmented reality, augmented realities, mixed reality, mixed realities, mixed realities, virtual reality, educational virtual realities, instructional virtual realities, instructional virtual

reality, instructional virtual reality, educational virtual reality, virtual medical simulators, mobile medical education applications, medical education, online medical training.

Only original full-access articles published between 2019 and 2023 will be considered for the study, there will be no language distinction, the research area will be medicine.

All manuscripts that do not refer to the practical application of technological tools in medical education will be excluded.

Individual search strings were used to select the documents. The keywords were concatenated using Boolean operators AND and OR (see Table 1). Each of the final search equations was adapted to the parameters and commands imposed by each database (see Table 2).

Table 1. *Search strings for each main term*

Group	Search string
Digital tools	"digital tools" OR "educational technology" OR "educational technologies" OR "instructional technology" OR "instructional technologies" OR "e-learning platforms" OR "augmented reality" OR "augmented realities" OR "mixed reality" OR "mixed realities" OR "virtual reality" OR "educational virtual realities" OR "instructional virtual realities" OR "instructional virtual reality" OR "educational virtual reality" OR "virtual medical simulators" OR "mobile medical education applications".
Medical education	"medical education" OR "online medical training".

Source: Own elaboration.

The search equations for each scientific database are presented in Table 2, considering each individual search string.

Table 2. *Search equation.*

Database	Search equation
SCOPUS	TITLE-ABS-KEY("digital tools" OR "educational technology" OR "educational technologies" OR "instructional technology" OR "instructional technologies" OR "e-learning platforms" OR "augmented reality" OR "augmented realities" OR "mixed reality" OR "mixed realities" OR "virtual reality" OR "educational virtual realities" OR "instructional virtual realities" OR "instructional virtual reality" OR "instructional virtual reality" OR "educational virtual reality" OR "virtual medical simulators" OR "mobile medical education applications") AND TITLE-ABS-KEY ("medical education" OR "online medical training") AND PUBYEAR >2018 AND PUBYEAR<2024 AND (LIMIT-TO(SRCTYPE, "j")) AND (LIMIT-TO(OA , "all")) AND (LIMIT-TO(SUBJAREA , "MEDI")) AND (LIMIT-TO(DOCTYPE, "ar")) AND (LIMIT-TO(LANGUAGE, "English") OR LIMIT-TO(LANGUAGE , "Spanish"))
WoS	TS=("digital tools" OR "educational technology" OR "educational technologies" OR "instructional technology" OR "instructional technologies" OR "e-learning platforms" OR "augmented reality" OR "augmented realities" OR "mixed reality" OR "mixed realities" OR "virtual reality" OR "educational virtual realities" OR "instructional virtual realities" OR "instructional virtual reality" OR "educational virtual reality" OR "virtual medical simulators" OR "mobile medical education applications") AND TS=("medical education" OR "online medical training") and Open Access and 2023 OR 2022 OR 2021 OR 2020 OR 2019

	(Publication Years) and Article (Document Types) and Education Educational Educational Research (Research Areas)
PubMed	("digital tools"[Title/Abstract] OR "educational technology"[Title/Abstract] OR "educational technologies"[Title/Abstract] OR "instructional technology"[Title/Abstract] OR "instructional technologies"[Title/Abstract] OR "e-learning platforms"[Title/Abstract] OR "augmented reality"[Title/Abstract] OR "augmented realities"[Title/Abstract] OR "mixed reality"[Title/Abstract] OR "mixed realities"[Title/Abstract] OR "virtual reality"[Title/Abstract] OR "educational virtual realities"[Title/Abstract] OR "educational virtual realities"[Title/Abstract] OR "instructional virtual realities"[Title/Abstract] OR "instructional virtual reality"[Title/Abstract] OR "educational virtual reality"[Title/Abstract] OR "virtual medical simulators"[Title/Abstract] OR "mobile medical education applications"[Title/Abstract]) AND ("medical education"[Title/Abstract] OR "online medical training"[Title/Abstract])
Scielo	("digital tools" OR "educational technology" OR "educational technologies" OR "instructional technology" OR "instructional technologies" OR "e-learning platforms" OR "augmented reality" OR "augmented realities" OR "mixed reality" OR "mixed realities" OR "virtual reality" OR "educational virtual realities" OR "instructional virtual realities" OR "instructional virtual reality" OR "educational virtual reality" OR "virtual medical simulators" OR "mobile medical education applications") AND ("medical education" OR "online medical training") AND ("medical education" OR "online medical training")

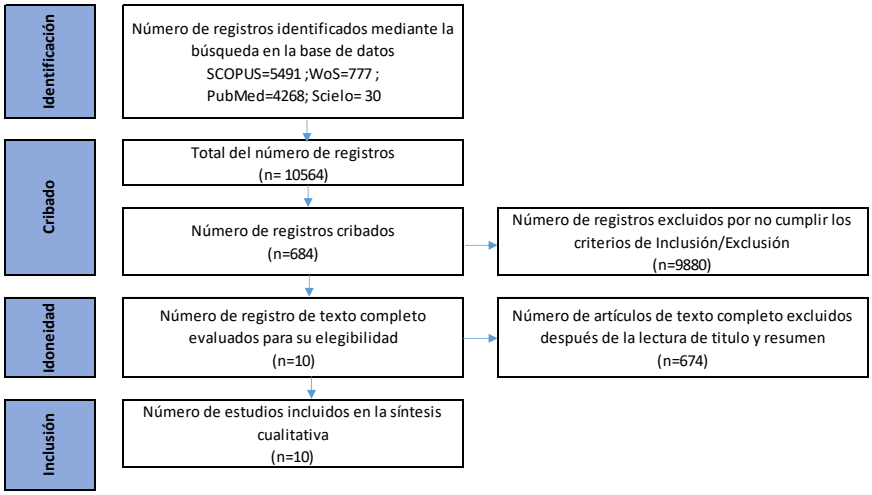
Source: Own elaboration.

After executing the search equations in each database, a total of 10564 documents were obtained in the four scientific databases. After applying the inclusion and exclusion criteria and eliminating duplicates, 684 articles were preselected, and then the titles, abstract and keywords of all the full access documents were read and 10 manuscripts were selected to form part of the study.

Results

Figure 1 below presents the flow chart that shows the selection process of the 10 manuscripts that were part of the study.

Figure 1. Flowchart (PRISMA Method)



Source: Own elaboration

Table 3 below shows the purpose reported by the 10 articles and their bibliographic characteristics. In addition, it is emphasized that the thorough research delves into a varied perspective regarding the use of digital resources in medical education. There is a mutual trend to investigate the capabilities of virtual reality (VR) and augmented reality (AR) to enhance medical student education and establish clinical competency benchmarks (Lilly et al., 2019; Sultan et al., 2019; Zackoff et al., 2021).. In addition, the integration of innovative educational approaches, such as virtual anatomical dissection and clinical tele-simulation, occupies a prominent place, aiming to revolutionize the methodology of medical instruction (Almousa et

al., 2021; Darras et al., 2020).. The transition to e-learning has also been studied amid the outbreak of COVID-19, highlighting the importance of addressing technological and infrastructural impediments (O'Sullivan et al., 2021)..

Table 3. *Purpose and bibliographic characteristics of the studies that address the topic of Digital tools and medical education.*

ID	Author	Title	Purpose of the study	Target population (n)
1	Lilly et al. (2019).	Creating a new "reality" for medical education: the Nexus Reality Lab for virtual reality	• Explore the integration of virtual reality (VR) in medical education. • Evaluate the use and impact of virtual reality technology in education.	Medical students, faculty and staff.
2	Sultan et al. (2019).	An Experimental Study On Usefulness Of Virtual Reality 360° In Undergraduate Medical Education	• To evaluate the utility of 360° Virtual Reality in undergraduate medical education. • Compares the impact of virtual reality simulation with conventional experiential learning methods. • Evaluate the level of perception, MCQs score, OSCE score, satisfaction level and evaluation score.	Fourth-year medical students (492).
3	Antoniou et al. (2020)	Biosensor real-time affective analytics in virtual and mixed reality medical education serious games: Cohort study.	• The study aims to evaluate portable biosensors for the detection of effects in education. • Evaluate real-time affective analysis in virtual reality and MRI medical education resources. • Investigate biosignal recordings to detect emotional state in learning activities.	Medical students, postgraduates and physicians specializing in neurosurgery (11).

4	Darras et al. (2020)	Virtual Dissection with Clinical Radiology Cases Provides Educational Value to First Year Medical Students	• Develop a virtual dissection curriculum for first-year medical students. • Evaluate the educational value and preferred pedagogy for learning with new technologies.	First-year medical students.
5	Zackoff et al. (2021)	Establishing Objective Measures of Clinical Competence in Undergraduate Medical Education Through Immersive Virtual Reality	• Establish objective measures for clinical competence in undergraduate medical education. • Uses immersive virtual reality to set proficiency standards for medical students	Fourth year medical students.
6	O'Sullivan et al. (2021)	Lessons Learned Transitioning from Traditional Premedical and Medical Education to E-learning Platforms during the COVID-19 Pandemic within the United Arab Emirates	• Assess the impact of the transition to e-learning and develop best practices.	Medical students. Educators and administrators.
7	Almousa et al. (2021)	Virtual Reality Technology and Remote Digital Application for Tele-Simulation and	• Develop a proof-of-concept prototype for clinical telesimulation training. • Transforms traditional medical	Physician trainees in developing countries and rural areas.

		Global Medical Education: An Innovative Hybrid System for Clinical Training	simulation training into a virtual experience.	Teachers and instructors who facilitate clinical training sessions.
8	Syed Abdul et al. (2022).	Virtual reality enhancing medical education and practice: Brief communication.	• Explore the challenges of adopting virtual reality technologies for medical training. • Improving medical education and training practices through virtual reality technology.	Medical students and health care providers.
9	Christopoulos et al. (2022)	The effects of augmented reality-supported instruction in tertiary-level medical education	• To foster students' knowledge of the components of the heart through augmented reality. • Quantitatively explore change in student performance and satisfaction with training.	First to third year students (60).
10	Gan et al. (2023)	Researching the application of virtual reality in medical education: one-year follow-up of a randomized trial	• Exploring the long-term impact of teaching with virtual reality simulators on medical students.	Medical students (108)

Source: Authors

An analysis of the papers selected for the research is presented in Table 4 below, these provide a comprehensive view of the impact of various digital tools on medical education, highlighting their potential benefits in terms of improving access, quality and effectiveness of medical learning.

Table 4. *Transformative role of digital tools in medical education.*

ID	Author	Digital tool (Application)	Device type	Field of education	How do they transform medical education?
1	Lilly et al. (2019).	Virtual reality (Immersive experiences)	HTC Vive headsets are used with MSi towers for games	Medical education.	• Improves medical education through the use of virtual reality technology. • Improves student engagement and educational outcomes within medical training. • Facilitates cooperative partnerships and innovative pedagogical approaches in medical education.
2	Sultan et al. (2019).	Virtual reality (Immersive experiences)	Smartphone-based virtual reality applications for medical education. Special camera for capturing 360° virtual reality videos	Medical Education (Undergraduate).	• Improve medical education through immersive experiences with virtual reality. • Confirms the effectiveness of virtual reality in undergraduate medical education.
3	Antoniou et al. (2020)	Virtual Reality, Augmented Reality, Mixed Reality (biosensors)	Portable biosensors for effect detection: HR, EDA, EEG signals. E4 wearable multisensory	Medical education.	• The use of biosensors makes it possible to identify emotional states in medical education through VR/MR. • Real-time affect analysis can enhance

			smart bracelet to detect stress.		learning experiences in virtual environments. • Incorporating biosensors into intelligent tutoring systems can reinforce medical instruction.
4	Darras et al. (2020)	Virtual Medical Simulators (Virtual Dissection Tables)	Virtual dissection table with touch screen technology. Manipulated 3D computed tomography images for learning anatomy and radiology.	Medical Education (Radiology)	• The implementation of virtual dissection improves medical students' understanding of anatomy and radiology. • Students perceive virtual dissection as a valuable tool for learning. • Technology integrates clinical cases and radiology content into preclinical educational environments. • Early exposure to radiology improves student engagement.
5	Zackoff et al. (2021)	Virtual reality (Simulation and immersive experiences)	Virtual reality (VR) platform to establish competency standards in medical education.	Medical Education (Undergraduate)	• Establishes objective criteria for evaluating performance in medical education. • Identifies key observable behaviors that correspond to overall performance evaluations. • Provides a method for

					defining objective performance metrics. • Demonstrates the use of immersive virtual reality to establish performance benchmarks.
6	O'Sullivan et al. (2021)	E-learning platforms (Not specified)	Not specified.	Medical education	• Sets out the challenges involved in the transition to e-learning in medical education. • Highlights technical barriers, learner reactions and didactic assessments in e-learning. • Emphasizes the importance of IT support in the deployment of new educational platforms.
7	Almousa et al. (2021)	Virtual Reality (Tele-simulation)	Oculus Quest is used as a portable, wireless, stand-alone head-mounted device.	Medical education.	• Develops and contributes a virtual reality-based system for clinical telesimulation training. • Promotes and improves access to simulation training worldwide, overcoming geographical restrictions. • Telesimulation provides opportunities for remote education,

					training and evaluation.
8	Syed Abdul et al. (2022).	Virtual reality (Simulation and immersive experiences)	Head-mounted display, sound and navigation devices	Medical education.	• Virtual reality enhances medical training and education in academic medical institutions. • Virtual reality simulations replaced traditional training techniques in the midst of the COVID-19 pandemic. • He identifies that collaboration between medical facilities and technology sectors is critical. • Virtual reality offers immersive experiences for medical students in a variety of scenarios.
9	Christo poulos et al. (2022)	Augmented Reality (Mobile applications)	HeArt mobile application.	Medical Education (Undergrad uate)	• Recognizes that augmented reality (AR) promotes knowledge acquisition and retention in medical education. • It states that educational materials must be compatible across all platforms for effective RA integration. • It suggests that augmented reality has the potential to

					enhance collaborative learning activities to explore concepts.
10	Gan et al. (2023)	Virtual Reality (simulation)	Virtual reality (VR) simulator used for teaching tendon suturing.	Medical education	• He argues that virtual reality teaching enhances professional development, learning motivation and clinical skills. • Scores on physical exams, suturing and knot tying improved due to virtual reality teaching. • The virtual reality teaching model promotes an effective learning approach for medical students.

Source: Authors

Discussion

The systematic review provides a comprehensive examination of the effects of various digital tools in medical education, both in their similarities and distinctions. Lilly et al. (2019) conducted a study focused on incorporating virtual reality (VR) in medical education, using HTC Vive headsets with MSi towers to gamify to optimize medical education through immersive experiences and improve student engagement by stressing the importance of cooperation and innovative teaching methodologies. Conversely, Sultan et al. (2019) explored the effectiveness of 360° virtual reality in undergraduate medical education, employing smartphone-based virtual reality applications. They contrast the influence of virtual reality simulation with traditional learning approaches by assessing various factors, such as perception levels, performance on various assessments, and satisfaction levels.

Darras et al. (2020) designed a virtual dissection curriculum for first-year medical students using "virtual dissection tables" and portable biosensors for impact detection. Their research focused on the educational merit of virtual dissection and how students perceive this tool as beneficial to their learning. Zackoff et al. (2021) used immersive virtual reality to establish objective benchmarks for clinical competence in medical students, employing wearable multisensory smart wristbands to identify stress levels. Their main objective was to establish a method for defining objective performance indicators and establishing performance benchmarks in medical education.

On the contrary, O'Sullivan et al. (2021) evaluated the effects of transitioning to e-learning during the COVID-19 outbreak in medical education using a virtual dissection table with touchscreen capability. They highlight technical hurdles and the importance of computer assistance when introducing new educational platforms. Almousa et al. (2021) developed a virtual reality-based clinical telesimulation system using 3D computed tomography images for anatomical and radiological education. Their aim was to improve access to medical simulation training and overcome geographical limitations.

Syed Abdul et al. (2022) delved into the obstacles and advantages of virtual reality in medical education, using a virtual reality platform to establish competency standards. They emphasized the essential nature of collaboration between medical institutions and technology sectors to improve medical training and education. Christopoulos et al. (2022) used augmented reality to improve students' understanding of cardiac anatomy, highlighting its potential to foster collaborative learning and knowledge retention. Finally, Gan et al. (2023) studied the lasting effects of teaching with virtual reality simulators on medical students, using Oculus Quest as a portable, stand-alone device. Their research revealed remarkable improvements in students' clinical and professional exploration skills.

From the above, it is evident that the literature reviewed offers a comprehensive perspective on the impact of digital tools in the transformation of medical education. Researchers such as Lilly et al. (2019) y Sultan et al. (2019) have highlighted the potential of virtual reality to improve educational engagement and outcomes. Meanwhile, research by Darras et al. (2020) y Zackoff et al. (2021) delved into the use of virtual medical simulators and virtual reality for assessment and setting clinical competency standards. O'Sullivan et al. (2021) y Almousa et al. (2021) addressed the shift toward e-

learning and clinical telesimulation, distinguishing technical barriers and the need for universal access to medical education. In addition, research conducted by Syed Abdul et al. (2022) analyzed the benefits of virtual reality to improve medical procedures. Christopoulos et al. (2022) y Gan et al. (2023) explored the potential of augmented reality and virtual reality to improve knowledge retention and clinical skills.

Therefore, a remarkable change in medical pedagogy and practice can be affirmed and recognized, which supports the decision to integrate digital tools to improve training and healthcare delivery.

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