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ORIGINAL ARTICLE

Immersive learning in medical education

El aprendizaje inmersivo en la formación médica

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Abstract

Background: *In the past, learning was acquired through direct experience. However, due to a changing world, such learning began to be acquired in increasingly abstract ways. Today, immersive technologies represent the opportunity to reconnect learning with experience through various innovative tools, which have had an impact on health education.* **Objective:** *To conduct a review to identify the most relevant benefits and limitations of immersive technologies in the field of health education, and to provide clear recommendations for their implementation in future academic programs.* **Material and methods:** *A comprehensive search of articles was conducted in PubMed, Cochrane, and Epistemonikos databases. Nine relevant articles were identified and analyzed by the reviewers to determine similarities and differences among them.* **Results:** *Multiple articles highlight immersive technologies' benefits, such as: 40% improvement in the acquisition of surgical skills, improvements in the theoretical teaching of abstract topics, which benefit from the application of 3D technologies, as well as, a positive impact student motivation, confidence, self-satisfaction, in addition to improving the accessibility of education in underserved areas.* **Conclusions:** *Immersive technologies positively impact medical education. Their implementation faces multiple barriers, but formally introducing them into medical education programs represents the first step toward obtaining future benefits for patients.*

Keywords: *Immersive learning. Medical education. Virtual reality. Augmented reality.*

Resumen

Antecedentes: *En el pasado, el aprendizaje se adquiría con la experiencia directa. Sin embargo, un mundo cambiante hizo que el aprendizaje fuera adquirido de manera abstracta. Actualmente, las tecnologías inmersivas representan la oportunidad de reconectar aprendizaje y experiencia mediante herramientas innovadoras que impactan la educación en salud.* **Objetivo:** *Identificar beneficios y limitaciones relevantes de las tecnologías inmersivas en educación en salud, proporcionando recomendaciones para su implementación en futuros programas académicos.* **Material y métodos:** *Se realizó una búsqueda exhaustiva de artículos en bases de datos PubMed, Cochrane y Epistemonikos. Nueve artículos relevantes fueron identificados y analizados por los revisores para determinar similitudes y diferencias entre ellos.* **Resultados:** *Múltiples artículos destacan los beneficios de las tecnologías inmersivas, como: mejora del 40% en la adquisición de habilidades quirúrgicas; mejoras en la enseñanza teórica de temas abstractos, que se benefician de tecnologías 3D; y un impacto positivo en motivación estudiantil, confianza y autosatisfacción, además de mejorar la accesibilidad educativa en áreas desatendidas.* **Conclusiones:** *Las tecnologías inmersivas tienen un impacto positivo en la educación médica. Su implementación enfrenta múltiples barreras, pero su introducción formal en los programas de educación médica representa el primer paso hacia la obtención de beneficios futuros para los pacientes.*

Palabras clave: *Aprendizaje inmersivo. Educación médica. Realidad virtual. Realidad aumentada.*

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Introduction

Since the beginning of humanity, human learning has been widely related to direct experience, which means knowledge was acquired through observation, imitation, and practice. However, over time, the advancement and development of civilization created the need for knowledge to be distributed more efficiently and, therefore, for learning to be transmitted in a more rapid manner. Thus, learning became detached from its physical context and direct experience, leading to the transmission of knowledge through storytelling, poetry, theatrical works, and later through writing, printed media, and abstract academic formats[1]. These new methods of transmitting knowledge demonstrated several advantages, therefore, learning continued to move away from contextual experience over time. Nevertheless, these new learning methods did not necessarily represent the most effective way to acquire knowledge, especially when seen from the perspective of human nature, which highlights the importance of experiential, contextual, and interactive elements.

In recent decades, significant advances in communication technologies, computing, and artificial intelligence (AI) have created an innovative opportunity for learning to recover what it once lost: experience. These technologies have demonstrated the advantage of reintroducing the experiential dimension into learning without compromising safety, accuracy, or effectiveness. Among the digital tools that stand out most prominently in the field of education are the metaverse, virtual reality (VR), augmented reality (AR), immersive classrooms, holograms, and AI[2]. These concepts are frequently used incorrectly in everyday contexts; therefore, they are defined in this article, emphasizing their similarities and differences.

VR is defined as a technological system based on computer tools capable of generating three-dimensional digital environments that represent real or fictional settings, in which the user can experience varying levels of immersion depending on the sensory stimuli provided and the availability of specialized devices (three-dimensional headsets, headphones, haptic gloves, etc.)[3].

AR is a technological system that integrates digital elements into the physical environment, enabling simultaneous interaction between the real world and computer-generated virtual objects. Similar to VR, this technology depends on the availability of specialized devices such as smartphones, tablets, cameras, or smart glasses that project information or three-dimensional models onto the tangible space. These technologies allow users to visualize, in real time, virtual content superimposed on their immediate surroundings, thereby expanding perception and facilitating new forms of experiential learning[3].

AI is a concept coined by John McCarthy in 1955, who defined it as "the science and engineering of making intelligent machines." With current technological advances, AI is defined as technological systems that employ advanced computational resources to develop methods, algorithms, and applications capable of simulating, extending, enhancing, and optimizing cognitive processes similar to those of human intelligence. These technologies have evolved rapidly and currently play an important role across diverse professional fields[4].

The implementation of these technologies in educational settings has increased in recent years and accelerated following the 2020 pandemic. This has led to the development of immersive classrooms, which are innovative educational spaces that integrate and utilize VR and AR to create digital learning environments that allow students to explore complex concepts in an active and practical manner. These classrooms enhance interaction between educators and students by reconnecting learning with direct experience[5].

Material and methods

An umbrella review was conducted with the aim of synthesizing the available evidence from systematic reviews and meta-analyses regarding the use of immersive technologies in medical education. A comprehensive search was performed in PubMed, the Cochrane Database of Systematic Reviews, and Epistemonikos. MeSH terms were used, including: ("immersive learning" OR "immersive teaching" OR "immersive classrooms" OR "virtual reality" OR "augmented reality") AND ("medical education"), as well as their English translations. This search yielded a total of 77 articles, which were subsequently screened to include only those focused on the application of immersive technologies in medical education in general. After the screening process was completed, nine relevant articles were identified and comparatively analyzed in order to determine the main similarities and differences regarding the benefits and limitations of these technologies.

Results

Immersive technologies represent a major innovation in the field of medical education. Although these technologies have been implemented and their benefits and limitations reported by various authors, it is essential to evaluate their applications in a systematic and comparative manner in order to identify the most consistently reported advantages and drawbacks and subsequently provide relevant recommendations for their implementation in medical education overall. This section outlines the main benefits and limitations reported by the most relevant articles in the field of medical education.

Barteir et al.[6] explore the application of head-mounted devices (HMDs) in medical education. They highlight their capacity to create complex, detailed, and reproducible simulations that positively impact medical training, particularly in surgery and ophthalmology. The authors identify multiple advantages of immersive technologies in medical education, including a reduction in procedural errors and emotional benefits such as decreased stress and increased confidence and motivation. They also mention the positive impact on educational accessibility in low-resource countries. Reported disadvantages include adverse health effects such as nausea, as well as current technical limitations and the oversimplification of immersive technologies in highly complex procedures[6].

Ryan et al.[7] focus on the application of VR, AR, and mixed reality technologies. These technologies are reported to be more effective than traditional education due to their positive impact on knowledge acquisition and retention. Benefits for clinical practice are also emphasized, as these tools allow for increased practice opportunities by creating safe and repeatable scenarios, as well as innovative 3D environments that enhance learning in areas such as anatomy and embryology. In addition, improvements in students' mindset are highlighted, particularly increased self-satisfaction and enhanced educational engagement. However, limitations in current research are noted, including methodological heterogeneity and a lack of validity due to the absence of standardized scales for the objective evaluation of immersive technologies[7].

Tene et al.[8] demonstrate that the application of immersive technologies in the medical field has led to multiple advantages, including hands-on learning through realistic, safe, and flexible scenarios. The authors also note that their effectiveness has been more clearly demonstrated in theoretical areas, particularly anatomy, resulting in increased student motivation. Regarding limitations, the study underscores the importance of designing a solid pedagogical framework and establishing evaluation criteria to ensure the appropriate use of these technologies in medical education. It also highlights the need for further research and consideration of economic and logistical barriers to implementation[8].

Kim and Kim[9] report that VR can enhance both skills and knowledge in educational settings by promoting greater student autonomy and self-directed learning. Furthermore, its use contributes to reducing the anxiety commonly experienced during academic training. However, due to methodological variability and the lack of standardized measurement instruments, the findings are not statistically significant, limiting the strength of the conclusions[9].

Khakpaki[10] evaluated the application of immersive technologies (VR, chatbots, adaptive platforms, etc.) and highlighted positive effects on physicians' technical and cognitive skills, particularly in the surgical field, where a 40% improvement in procedural success was reported. AI also demonstrated benefits, including more objective assessments, rapid feedback, and autonomous learning. Nevertheless, limitations persist, such as high implementation costs and restricted access to the necessary infrastructure and resources[10].

Tudor et al.[11] report that the use of VR, AR, and mixed reality improves practical and clinical skills in 97% and 100% of cases, respectively, as well as theoretical knowledge acquisition in 80% of cases. Additional benefits include increased student engagement and participation, as well as improved objectivity and efficiency in assessments. However, current studies primarily evaluate short-term learning outcomes, present methodological heterogeneity, and lack validation, limiting reproducibility, cross-study comparability, and the credibility of reported findings[11].

Pedram et al.[12] indicate that the use of VR and HMDs enables the creation of virtual scenarios that would be impossible to replicate in real life, which is particularly valuable for emergency training and clinical procedures. These technologies positively impact technical skills, teamwork, leadership, and communication, and contribute to long-term patient safety improvements. Nonetheless, limitations include the absence of long-term studies, insufficient haptic feedback, low visual quality, user health concerns (dizziness and visual fatigue), high implementation costs, lack of specialized technical support, and the absence of curricular standardization in educational institutions[12].

Siddiqui et al.[13] report that VR, AR, and mixed reality increase student motivation and engagement, reduce errors and procedural times in surgical settings, and facilitate the visualization of 3D structures, positively impacting the learning of abstract concepts such as anatomy.

Additional benefits include improved accessibility to education in underserved regions. However, these technologies face limitations such as high hardware and software costs, the need for high-speed internet, adverse physical effects (nausea, headaches, and cognitive overload), and a lack of standardization and global representation in current studies. Therefore, replacing traditional methods exclusively with these technologies does not appear to provide additional benefit in medical education[13].

Kalantari et al.[14] identify that the integration of AI, VR, and AR in medical education enhances practical skill development and knowledge acquisition, reduces errors, improves procedural efficiency, and increases student engagement and motivation. However, the author acknowledges limitations such as an excessive focus on psychomotor skills at the expense of theoretical knowledge acquisition, a lack of evidence regarding skill transfer to real-world settings and patient outcomes, and the need for systemic integration of these technologies into clinical curricula to assess their large-scale impact[14].

Discussion

After analyzing the nine selected articles, it becomes evident that most authors reach a consensus regarding the benefits of implementing immersive technologies in medical education. Similarly, there is agreement concerning current limitations and areas of opportunity for their practical implementation.

Benefits of immersive technologies in medical education

Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Kim and Kim,[9] Tudor et al.,[11] Pedram et al.,[12] Siddiqui et al.,[13] and Kalantarion et al.[14] agree that the use of immersive technologies is particularly valuable for the development of practical and surgical skills. This is because these technologies enable the creation of immersive scenarios that allow for repetitive, safe, and controlled practice of both basic and complex clinical procedures. Following their implementation in this context, objective benefits have been identified, including a marked reduction in user errors, as well as a significant decrease in the time required to complete practiced procedures. In addition, objective improvements include increased participation, heightened interest, and greater confidence among users when performing procedures and interacting with real patients. Specifically, Tudor et al.[11] report improvements in practical and clinical skills in 97% and 100% of the cases addressed, respectively. Likewise, Khakpaki[10] highlights that VR can increase surgical procedure success rates by 40%.

Similarly, Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Tudor et al.,[11] Siddiqui et al.,[13] and Kalantarion et al.[14] present comparable findings regarding the acquisition and retention of theoretical knowledge. They identify that immersive technologies are not only beneficial for the development of practical skills but also for learning theoretical content, particularly in areas that benefit from 3D visualization, such as anatomy and embryology[1-9]. Specifically, Tudor et al.[11] quantify this improvement, reporting enhanced theoretical knowledge acquisition in 80% of the studied cases.

Another widely recognized benefit is the impact on student motivation and engagement. Additionally, Barteir et al.,[6] Ryan et al.,[7] Tene et al.,[8] Kim and Kim,[9] Tudor et al.,[11] and Siddiqui et al.[13] identify benefits that extend to students' psychological domains. They report that immersive technologies create learning environments that are more interactive, engaging, and dynamic than traditional methods, positively influencing motivation, interest, engagement, and student satisfaction. Furthermore, Khakpaki[10] and Pedram et al.[12] emphasize that such scenarios foster the development of communication, leadership, and teamwork skills, which are essential for physicians. Benefits are also observed in assessment processes, as Khakpaki[10] and Tudor et al.[11] indicate that AI has the potential to enable more objective evaluations and improve grading efficiency.

These technologies also offer benefits beyond the classroom. Tene et al.[8] and Siddiqui et al.[13] highlight their social potential to standardize education and improve accessibility in remote, underserved, and marginalized regions.

Limitations and challenges of immersive technologies in medical education

The primary limitation identified across most articles is the heterogeneity of studies and the lack of standardized measurement instruments and validated indicators. Ryan et al.,[7] Kim and Kim,[9] Tudor et al.,[11] Pedram et al.,[12] and Siddiqui et al.[13] agree that this significantly reduces the credibility and validity of findings, limiting researchers' and educators' ability to objectively compare results across studies.

In addition, Tudor et al.[11] and Pedram et al.[12] note that current studies focus almost exclusively on short-term learning outcomes, largely omitting long-term evaluation.

This represents a significant bias, as demonstrating superiority over traditional learning methods requires long-term studies assessing skill retention and effective transfer to real clinical settings, an area that remains insufficiently explored. Furthermore, Kalantarion et al.[14] indicate that no studies have evaluated the ultimate objective of these technologies, including behavioral changes in real workplace environments or direct improvements in patient health following immersive technology-based education.

From a technological perspective, Pedram et al.[12] identify current technical limitations, including low visual quality and insufficient haptic feedback, which restrict the realism necessary for clinical scenarios. This directly affects the validity of simulations, particularly in surgical settings where realism and immediate feedback are critical for learning[7].

Regarding health considerations, Barteir et al.,[6] Pedram et al.,[12] and Siddiqui et al.[13] report that immersive technologies, especially when using HMDs, are not without risk and may produce adverse effects such as nausea, dizziness, headaches, visual fatigue, and stress.

In economic and logistical terms, Barteir et al.,[6] Tene et al.,[8] Khakpaki,[10] Pedram et al.,[12] and Siddiqui et al.[13] identify major barriers that directly affect accessibility and widespread adoption. These include high hardware and software costs, the need for robust technological infrastructure, and the availability of technical support in simulation centers and institutions, all of which are essential for proper implementation in educational settings. The authors note that populations unable to afford these resources are disproportionately affected, particularly in low- and middle-income countries[1-6,8].

Finally, differing perspectives emerge regarding the limitations and current focus of these technologies. Barteir et al.[6] and Pedram et al.[12] argue that current immersive technologies remain overly simplistic and lack sufficient realism for high-precision procedures, suggesting that future developments should address these shortcomings. In contrast, Kalantarion et al.[14] contend that current technologies disproportionately emphasize psychomotor skill development while neglecting cognitive skill development, which should be a central focus. In this context, Siddiqui et al.[13] note that the complete replacement of traditional teaching methods with immersive technologies has not demonstrated additional benefit. Therefore, immersive technologies should be viewed not as a substitute but rather as a complement, enhancing both practical and cognitive skill development.

Conclusion

The use of immersive technologies may be considered the next major step in the evolution of medical education. At present, research remains heterogeneous and is still in an early stage, where reported findings may be regarded as having limited validity. Nevertheless, most of the reviewed articles identify several benefits associated with the implementation of these technologies in medical education.

The primary benefits involve improvements in the teaching of practical skills, particularly in the surgical field, where a clear reduction in errors has been demonstrated following the implementation of these technologies, along with a decrease in the time required to perform surgical procedures. In addition, benefits extend to the theoretical domain of medicine, where 3D technologies and HMDs enable the creation of innovative scenarios that enhance students' acquisition of abstract knowledge. Furthermore, immersive technologies provide benefits beyond the classroom, directly influencing students' mindset by increasing motivation, strengthening engagement, and enhancing confidence. Several authors also highlight their potential social impact, noting that although these technologies require considerable investment, such investment may yield substantial benefits, including improved access to education in underserved regions.

The main disadvantages of implementing these technologies at present include the high technological costs of the required equipment, as well as limitations in institutional infrastructure, which necessitate specialized personnel for proper implementation. In addition, current research lacks standardized methods to evaluate the various applications of these technologies under uniform parameters, resulting in studies that are heterogeneous and of limited validity.

In light of these benefits and limitations, it is recommended that standardized evaluation instruments be developed and that these technologies be incorporated into formal educational programs in order to generate valid data that can be systematically compared and analyzed to support more robust recommendations. Based on current evidence, replacement of traditional methods is not advised; rather, the integration of immersive technologies into existing medical education programs is recommended, particularly in practical and abstract areas of training. Further research is also needed to assess the long-term impact of these technologies on learning outcomes and their direct effect on patient health.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of human subjects and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality, informed consent, and ethical approval. This study does not involve personal patient data, medical records, or biological samples, and does not require ethical approval. SAGER guidelines do not apply.

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