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VIRTUAL REALITY IN MEDICAL EDUCATION: A SYSTEM REVIEW

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ВІРТУАЛЬНА РЕАЛЬНІСТЬ У МЕДИЧНІЙ ОСВІТІ: СИСТЕМНИЙ ОГЛЯД

Abstract. This article review explores the transformative role of virtual reality (VR) and augmented reality in medical education, driven by the global shift to distance learning during the COVID-19 pandemic. While VR in medical education dates back to the 1990s, recent technological advancements, particularly in the 2010s, have revitalized its potential. A comprehensive literature review, including 52 studies conducted since 2010, reveals the versatility of VR applications, from surgical simulators to emergency response training.

Respondent feedback highlights positive assessments, especially for surgical VR simulators, immersive medical scenarios, and virtual dissection tables. VR demonstrates a positive impact on education quality, interactivity, and distance learning effectiveness. However, challenges such as high costs, technological failures, and physical side effects require strategic considerations.

Critics raise concerns about potential negative impacts on human connections and reality perception. Striking a delicate balance between harnessing technological advancements and preserving essential human elements is of paramount importance. In navigating this intersection, it becomes imperative to leverage the benefits of cutting-edge technology while safeguarding the fundamental aspects of human experience and interaction.

Despite the formidable challenges encountered, VR is unmistakably establishing itself as a transformative force within the realm of medical education. It not only provides a spectrum of diverse learning experiences but also yields positive educational outcomes. Recognizing the need for continuous advancements, ongoing research, and strategic planning become imperative to unlock and maximize the full potential of VR in education. This is especially crucial in preparing the next generation of medical professionals, particularly in the evolving landscape of distance learning. By navigating these challenges and embracing the opportunities that VR presents, the medical education sector can ensure a seamless integration of technology to enhance learning outcomes and better equip healthcare professionals for the complexities of their roles.

Key words: medical education; virtual reality; augmented reality; distance learning; COVID-19.

Анотація. У статті досліджено трансформаційну роль віртуальної реальності та доповненої реальності в медичній освіті, що зумовлена глобальним переходом до дистанційного навчання під час пандемії COVID-19. Хоча віртуальна реальність у медичній освіті з'явилася ще в 1990-х рр., нещодавній технологічний прогрес, особливо починаючи з 2010-х рр., значно активізував її, недооцінений на той час, потенціал. Всебічний огляд літератури, що включає 52 наукових дослідження, починаючи з 2010 р., показує багатогранність застосування даної технології – від високоточних хірургічних симуляторів до тренінгів із реагування на надзвичайні ситуації, які важко або ж практично неможливо відтворити в симуляційному навчанні.

Відгуки респондентів висвітлюють позитивні оцінки, особливо щодо хірургічних VR-симуляторів, імерсивних медичних сценаріїв і віртуальних препарувальних столів. Віртуальна реальність демонструє позитивний вплив на якість освіти, інтерактивність та ефективність дистанційного навчання. Однак такі проблеми, як висока вартість, технологічні збої та фізичні побічні ефекти, є досі, на середині третього десятиліття XXI століття, актуальними та вимагають подальших стратегічних міркувань. Критики висловлюють занепокоєння щодо потенційного негативного впливу на людські зв'язки та сприйняття реальності.

Досягнення балансу між технологічним розвитком і збереженням важливих людських вербальних та невербальних елементів має вирішальне значення. Незважаючи на виклики, віртуальна реальність стає трансформаційною силою в медичній освіті, пропонуючи різноманітний навчальний досвід і позитивні освітні результати. Постійні дослідження та стратегічне планування необхідні для максимального використання потенціалу вказаної технології і вирішення проблем у підготовці наступного покоління медичних працівників, особливо в контексті дистанційного навчання.

Ключові слова: медична освіта; віртуальна реальність; доповнена реальність; дистанційне навчання; COVID-19.

Introduction. Over the past three years, the global scientific community has faced complex challenges related to the ongoing COVID-19 pandemic, leading to a rapid surge in distance learning (DL) [1]. This phenomenon has become a necessity to ensure safety and continuity in education during periods of social restrictions, prompting a reevaluation of new approaches to learning. In this context, digital technologies and virtual reality (VR) have gained particular significance in medical education [27].

VR is an immersive technology that plunges users into another, simulated reality through specialized devices and software. While the term became popular in the 1980s, early attempts to create virtual reality date back to the 1960s [21].

In 1975, Myron Krueger pioneered the development of the inaugural interactive VR platform, known as "video place". This innovative system captured users' images, enabling them to witness computer-generated silhouettes mirroring their movements on 2D screens (Krueger & Wilson, 1985). Additionally, Thomas Furness contributed to the field with VCASS in 1982, aiming for an enhanced flight simulator. NASA also made strides with the development of VIVED – the Virtual Visual Environment Display – in 1984, specifically designed for astronauts.

Throughout the few past decades, VR system advancements have been numerous, including notable creations like the DataGlove (1985), HMD (Head-Mounted Display (1988)), BOOM (1989), CAVE (1992), and Augmented Reality (1990s). Despite the dedicated efforts of early researchers and companies, the technological advancements in computer efficiency fell short of creating widely appealing VR systems until around 2010 [22].

Since then, VR systems, encompassing Augmented Reality (AR), have found applications across various fields. Due to Gaggioli et al, The global sales forecast for VR products and services, featuring Oculus Rift by Oculus VR and Facebook, HTC Vive by HTC and Valve Corporation, PlayStation VR by Sony Corporation, Samsung Gear VR by Samsung Electronics, and HoloLens by Microsoft Corporation, anticipates exceeding $162 billion in 2020 [20].

The initial use of VR in education has also deep roots. In the 1990s, it was first employed in medical education, allowing students to interact with 3D models of organs and physiological processes. However, technological progress and the high cost of technology limited its widespread adoption, making it more of a technological and historical achievement. VR experienced a resurgence after significant technological advancements in the 2010s, with the emergence of new three-dimensional (3D) and five-dimensional (5D) screens, enhanced multinuclear processors capable of processing billions of times more information than in the 1980s, and other technical innovations laying the foundation for truly interactive and accessible use. Changes in multimedia technologies elevated VR to a new level, making it not only experimental but also prospective for future applications [21, 22, 26].

This transformation became particularly relevant in the early 2020s when the world faced lockdown conditions, resulting in students losing opportunities for hands-on skills, live interaction, and real patient examinations. Presently, in the era of DL, digital technologies and VR play a key role in providing effective and innovative medical education. Currently, the use of digital technologies and VR in education is widespread in many countries. According to statistics, North America, Europe, and Asia lead the way in this direction, with the United States, Canada, Germany, Japan, and China defining trends in the development of VR in medical education [30].

The aim – to investigate the use of digital technologies and VR in medical education, with a focus on enhancing learning quality in the evolving landscape of education.

Methods. We conducted an extensive literature review by utilizing various electronic databases, including but not limited to MEDLINE (Ovid), Cochrane Central Register of Controlled Trials (Wiley), the Education Resources Information Centre (Ovid), Scholar (Google), Scopus and Embase (Elsevier). Additionally, searches were conducted on PubMed (National library of medicine) to ensure a thorough exploration of relevant scholarly materials.

We assessed the eligibility of studies based on the following criteria:

Inclusion Criteria:

– Studies involving undergraduate or preregistration medical students in any geographical location.

– Research encompassing the utilization of virtual reality in conjunction with other modalities, such as immersive virtual reality, virtual reality–based serious gaming, virtual reality–based virtual patients and Augmented Reality (AuR).

– Studies specifically exploring alternative reality (AlR) applications, recognizing the distinct advantages and disadvantages of this subset within the broader realm of VR.

– Consideration of all primary studies, irrespective of study design, and pertinent systematic reviews.

Exclusion Criteria:

– Studies solely focusing on virtual patient simulation, augmented reality, mixed reality, or serious gaming, without any incorporation of virtual reality.
– Studies published before the year 2010.
– Studies written in languages other than English.
– Exclusion of opinion pieces, viewpoints, conceptual frameworks, and conference abstracts.

Following our criteria, we identified and included 52 relevant studies for analysis. In the course of our review, we identified key areas for improvement in the existing literature, which will be discussed in subsequent sections. The selected studies provide a diverse range of insights into the integration of virtual reality in medical education, offering a comprehensive foundation for our analysis and discussion.

Our inclusion criteria encompassed all primary studies, comprising experimental, observational, and qualitative designs, to ensure a comprehensive evaluation of the available literature. Additionally, systematic reviews and meta-analyses were included to integrate synthesized evidence into our analysis. A rigorous selection process, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [10], was employed to exclude studies that did not meet our predefined criteria. Details of the exclusion process are visualized in Figure 1.

Results. Our initial searches yielded a total of 547 studies, and after eliminating duplicates, 171 studies (31.3 %) underwent a comprehensive full-text review. Among these, 119 studies (69.6 %) did not meet the predefined inclusion criteria. Consequently, our scoping review incorporated 52 studies (30.4 %) that successfully met the established criteria, contributing valuable insights to our analysis. The selected studies form the basis for the following comprehensive examination of the role of virtual reality in medical education. An insightful overview of the study characteristics is presented in

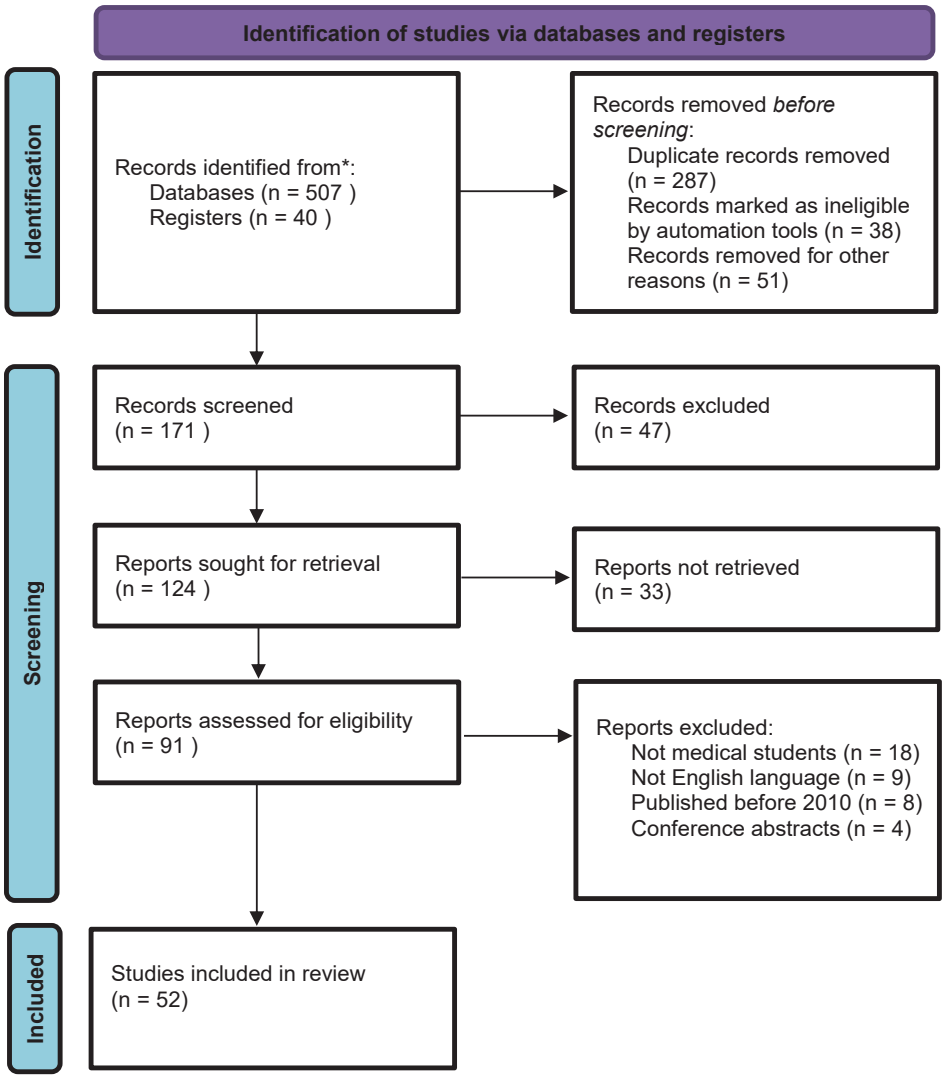

Fig. 1. PRISMA 2020 study selection flow diagram.

Table 1, providing a detailed snapshot of the diverse research landscape included in our scoping review.

Analyzing the data from 52 studies and considering participant feedback and evaluations, it becomes evident that, in the majority of cases, respondents expressed a favorable assessment of the presented information and its comprehension. Specifically, when employing virtual reality headsets (including goggles and helmets), the following devices and studies received the highest ratings:

1. Surgical VR simulators: These devices garnered positive feedback for their immersive and realistic surgical training environments, contributing to enhanced psychomotor skills among medical students.

2. Immersive medical scenarios: Virtual reality experiences simulating medical scenarios were well-received, providing participants with realistic, interactive, and contextually rich clinical environments.

3. Virtual dissection tables: Tools that facilitate virtual dissection experiences received commendation for their effectiveness in teaching anatomy, allowing students to explore and understand complex structures in a dynamic and engaging manner.

4. Interactive medical imaging simulations: Applications that enable interactive exploration of medical imaging, such as CT scans and MRIs, were praised for enhancing diagnostic skills and promoting a deeper understanding of medical imaging modalities.

5. Patient interaction simulations: Virtual reality scenarios simulating patient interactions and medical

Table 1. Characteristics of Included Studies (N=52)

Domain and Feature	Values, n (%)	Domain and Feature	Values, n (%)
Study Design:	52 (100)	*Input Devices (mono or combine)**	
– Randomized controlled trial	21 (40,4)	Headset (including VR glasses)	47
– Experimental	23 (44,2)	Touch screen	30
– Cross-sectional studies	4 (7,7)	Haptic tools	19
– Cases studies and case series	3 (5,8)	Mouse	18
– Meta-analysis	3 (5,8)	Game controllers	14
		VR gloves	12
		Joysticks	12
		Others	25
Location (by country)	52 (100)	*Subject Taught*	52 (100)
United States	12 (23,1)	Anatomy	19 (36,5)
United Kingdom	9 (17,3)	Surgical psychomotor skills	14 (26,9)
Germany	7 (13,5)	Clinical management	10 (19,2)
Japan	7 (13,5)	Nonsurgical psychomotor skills	3 (5,8)
Canada	5 (9,6)	Radiology	2 (3,8)
China	5 (9,6)	Communication	1 (1,9)
Others	7 (13,5)	Others	3 (5,8)
Number of participants	52 (100)	*Duration of the study*	52 (100)
0–100	22 (42,3)	<1 day	5 (9,6)
101–500	21 (40,3)	1 day to 1 month	15 (28,8)
501–1000	13 (25,0)	1–6 months	19 (36,5)
>1001	8 (15,4)	6–12 months	8 (15,4)
		>1 year	5 (9,6)
VR Modalities Used		*Study setting*	52 (100)
3D anatomical model	11	University	44 (84,6)
Surgical VR simulator	8 (15,4)	Hospital	8 (15,4)
Virtual dissection table	8 (15,4)		
Mobile VR	8 (15,4)		
Procedural VR simulations	7 (13,5)		
Clinical case simulations	5 (9,6)		
Virtual patient consultations	5 (9,6)		
Emergency response training	4 (7,7)		
Virtual laboratories for medical experiments	4 (7,7)		
Others	3 (5,8)		

Note. * – the cumulative percentage may exceed 100 % due to the simultaneous use of multiple devices.

consultations were highlighted for their ability to enhance communication skills, empathy, and bedside manner among medical professionals.

6. Emergency response training: Virtual reality applications for emergency response training, including scenarios like trauma simulations and resuscitation drills, were found to be effective in providing a realistic and controlled environment for honing critical decision-making skills.

Of particular note is the distinct impact of VR, with notable positive feedback emerging prominently in works from 2020 onwards, coinciding with the onset of the COVID-19 pandemic. Through a comprehensive analysis of the literature, it becomes evident that medical students highlight the remarkable potential of VR to compensate for the lack of practical communication and patient examinations, such as auscultation and percussion (n=23). Additionally, students appreciate the opportunity for surgical simulation in situations where access to operating rooms is restricted (n=15). Beyond these key findings, it is noteworthy that VR has proven to be a valuable tool for immersive learning experiences, fostering skill development and clinical acumen in the absence of traditional hands-on opportunities. Furthermore, the adaptability of VR technologies to diverse medical disciplines has been underscored, showcasing its versatility as an educational aid.

Upon analyzing the gathered information, several key features of VR application in medical education have been identified:

1. Technology Types: Examining various technologies revealed a broad spectrum of digital technology and VR applications in medical education. From immersive VR systems immersing students in virtual environments to augmented reality providing additional real-world information, the dynamics and technological approaches showed considerable improvement.

2. Learning Quality: A positive impact of digital technologies and VR on the quality of medical education has been established. These technologies not only assist students in safely mastering the material but also contribute to a profound understanding and the development of practical skills.

3. Interactivity: High levels of interactivity provided by digital technologies and VR have been highlighted. This significantly enhances student engagement and positively influences the course of learning.

4. Distance Learning Effectiveness: The results lead to the conclusion that digital technologies and VR significantly enhance the effectiveness of distance learning, a crucial aspect in contemporary conditions.

5. Trends and Dynamics: The rapid growth in the utilization of digital technologies and VR in medical education indicates their considerable potential for future development. Changes observed over the past decade signify important trends in medical education.

Despite the significant advantages of digital technologies and virtual reality in medical education, there are certain drawbacks and challenges that need consideration:

1. High Initial Costs: The initial investment in VR technology, including hardware, software, and training, may be prohibitive for some medical institutions.

2. Potential Technological Failures: Like any technology, VR may suffer from errors, glitches, or malfunctions.

3. Physical Side Effects: Prolonged use of VR may induce physical side effects such as dizziness, nausea, and adverse effects on vision and vestibular apparatus.

4. Equipment Connectivity and Accessibility: Successful utilization of VR in education requires specific conditions, including connectivity, availability of equipment, IT support, and proficiency in basic digital skills by both students and educators.

These challenges warrant further research and the development of strategies to overcome them, ensuring the maximal utilization of the potential of digital technologies and virtual reality in medical education.

Transitioning from the extensive exploration of VR applications in medical education to the broader overview of advancements, challenges, and considerations, it becomes evident that virtual reality (VR) is not merely a technological innovation but a transformative force.

The comprehensive analysis of 52 studies in the realm of VR application in medical education unveils a landscape of both promise and challenges. The utilization of VR technologies in medical training, as evidenced by the characteristics of the selected studies, demonstrates significant advancements in enhancing the quality of education and fostering interactive learning experiences.

On one hand, the characteristics of selected studies underscore the significant strides made in enhancing educational quality through interactive learning experiences facilitated by VR technologies. On the other hand, as we delve into the impacts and considerations outlined in advancements in medical education, we encounter a complex interplay of features, trends, and challenges that shape the evolving narrative of VR's role in shaping the future of medical training.

According to X. Xu et al., VR and AuR provide a new experiential learning environment that has the potential to revolutionize medical education. These technologies offer limitless possibilities by effectively

providing an infinite number of anatomical models to support foundational medical education [30]. With the ongoing advancement of this technology, in the near future, treatments, simulations, and learning will no longer be constrained by geography [26].

Despite the growing support within the scientific community, it is essential to acknowledge the presence of critics highlighting the negative aspects of VR. Paula Hicks, for instance, not only points out financial considerations, which are expected to be addressed with future technological advancements, but also emphasizes concerns related to the deterioration of human connections and the potential loss of a sense of reality [12]. These challenges pose significant considerations, particularly in an era characterized by reduced social communication [17, 24].

Delving into the impacts and considerations outlined in advancements in medical education, we encounter a complex interplay of features, trends, and challenges that shape the evolving narrative of VR's role in shaping the future of medical training.

Advancements in Medical Education

The incorporation of VR, particularly through surgical VR simulators, has showcased a remarkable impact on medical education. The immersive and realistic surgical training environments offered by these simulators contribute substantially to the development of psychomotor skills among medical students. The positive reception of immersive medical scenarios, virtual dissection tables, interactive medical imaging simulations, and patient interaction simulations underlines the diverse and beneficial applications of VR in providing realistic and contextually rich clinical experiences [7, 11, 23].

Key Features Driving Educational Impact

Several key features have emerged as driving forces behind the educational impact of VR in medical training. The diverse range of technologies, from immersive VR systems to augmented reality, reflects a dynamic and evolving landscape. The observed high levels of interactivity significantly enhance student engagement, positively influencing the overall learning experience. Furthermore, the effectiveness of VR in distance learning has become increasingly evident, addressing a crucial need in contemporary educational settings [4, 5, 13].

Trends and Dynamics

The rapid growth in the utilization of digital technologies and VR in medical education indicates a transformative shift. The trends observed over the past decade suggest an ongoing evolution in medical education methodologies. As technology continues to advance, it is foreseeable that VR will play an increasingly pivotal role in shaping the future of medical training [16, 29].

Challenges and Considerations

Despite the evident advantages, certain challenges and considerations necessitate attention. The high initial costs associated with VR technology may pose a barrier to widespread adoption, especially for institutions with budgetary constraints. Additionally, the potential for technological failures and the occurrence of physical side effects in users underline the importance of carefully navigating the implementation of VR in medical education [6, 9, 18, 19].

Looking Forward

In moving forward, it becomes imperative to address these challenges strategically. Initiatives aimed at mitigating initial costs, improving technology reliability, and minimizing physical side effects are essential for the sustainable integration of VR into medical curricula. Moreover, ongoing research and development should focus on harnessing identified trends to maximize the benefits of digital technologies and virtual reality in medical education [2, 3, 25].

The versatility of virtual reality headsets, including goggles and helmets, showcased in these diverse applications underscores their potential as invaluable tools in various facets of medical education and training [8, 14, 15, 28].

Conclusions and Prospects for Research. In conclusion, the current discourse underscores the transformative potential of VR in medical education. The positive outcomes observed in diverse studies validate the efficacy of VR technologies in enhancing learning outcomes, interactive engagement, and distance education effectiveness. The identified challenges serve as opportunities for refinement and innovation, paving the way for a more immersive and technologically advanced era in medical education. Continued research, collaboration, and strategic planning are crucial in harnessing the full potential of VR to prepare the next generation of medical professionals effectively.

The use of digital technologies and VR in medical education is a promising and effective direction, especially in the context of DL. Cutting-edge technologies open up entirely new possibilities for medical education, allowing students to learn and practice in safe, controlled environments. They also facilitate DL, which is particularly crucial in the modern world. However, more research is needed to determine best practices for utilizing these technologies.

The use of digital technologies and virtual reality in medical education not only meets the challenges of our time but also serves as a prospective strategy for improving learning, developing practical skills, and preparing qualified medical professionals.

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