Review Article

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Applications and Challenges of Virtual Reality in Medical Sciences Education: A Systematic Review

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Abstract

Introduction: Virtual reality (VR) technologies are interactive multimedia environments that serve as popular educational tools for teaching various groups. This study aimed to explore the applications of VR in the education of different medical science groups, including medicine, medical residents, dentistry, nursing, pharmacy, etc., in a systematic review format. This technology provides unique opportunities for learners to immerse themselves in experiences, leading to increased understanding and practical skills in the field of medical sciences. Therefore, this study was conducted in 2023 to examine the applications and challenges of VR in medical science education through a systematic review.

Methods: This study systematically extracts published articles through keyword searches from 1970 until March 14, 2023, in Web of Science, Scopus, Science Direct, Cochran Library, PubMed, ProQuest and IEEE. To evaluate the methodological quality of the included studies, we used the STROBE checklist. All stages were carried out by two researchers, and the final selected articles were summarized in tables.

Results: This review included 26 studies from an initial pool of 22,160 identified articles. The analysis revealed six key themes regarding the use of these technologies: their impact on learning outcomes, increased student motivation, enhanced self-confidence, improved teamwork, their role as tools for curriculum integration, and associated challenges. Collectively, the reviewed studies suggest that such technologies contribute positively to learning satisfaction, academic performance, public speaking confidence, and collaborative skills. Additionally, they serve as effective supplementary tools in educational settings. Nevertheless, several studies reported potential side effects, including dizziness, nausea, and eye strain.

Conclusion: This study showed that the use of technologies like VR improved learning, motivation, and teamwork, but there were challenges in their implementation. It is recommended that these technologies should be integrated into the curriculum and training workshops should be held for their effective use. Additionally, policymakers should provide financial resources and national guidelines to support the expansion of these technologies.

Keywords: Virtual reality, Education, Medicine, Healthcare, Technology

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Introduction

The rapid advancement of Internet-based technology has significantly transformed teaching methodologies and approaches. Recently, virtual reality (VR) technologies have emerged as effective educational tools that significantly enhance student engagement and learning outcomes (1). VR employs computer technology to create interactive three-dimensional images or environments, offering a highly engaging multimedia experience. These tools and applications can be categorized into three primary types: screen-based VR, immersive VR environments, and virtual worlds (2, 3). Screen-based VR features an interface connected to mechanical devices or touch units and can be displayed on any desktop screen. It is often used for developing psychomotor skills, such as in laparoscopic surgery, due to its repeatability and minimal setup time. In contrast, immersive VR creates a virtual environment that disconnects the user from the real world, typically achieved through head-mounted displays (HMDs) like the Oculus Rift or HTC Vive; however, it has fewer training applications (4, 5). Virtual worlds provide opportunities for active participation by allowing instructors to use simulations in immersive environments. These opportunities for active participation are crucial, as students' competencies improve significantly when they actively engage in the learning process (6). For example, at the Faculty of Veterinary Medicine at RAS University (RUSVM), SL, which is the most widely used virtual world, was employed as an educational platform for first-year students to practice clinical reasoning in a simulated veterinary clinical environment. In each simulated SL environment, users interact with other avatars in real-time (5, 7, 8).

While many universities and educational organizations worldwide are adopting these technologies, leading to a paradigm shift in education delivery, there is a need for a systematic understanding of VR's specific applications and demonstrated outcomes across the diverse disciplines within medical sciences (9, 10). Integrating digital health approaches such as VR and the metaverse in medical education and clinical performance enables healthcare professionals and medical students to understand human physiology and anatomy in a risk-free environment (11). VR technology has been utilized in various medical disciplines, including medicine, surgery, dentistry, nursing, pharmacy, etc. in numerous studies (12-18). In a study by Pather et al., anatomy instructors and master's students used VR Learning for skull anatomy teaching and compared different delivery methods. According to the students' experiences, both VLR delivery methods were engaging and captivating (19). Learning theories suggest that students learn better when they practice skills in suitable learning environments (20).

Unfortunately, the limited time for clinical practice affects the students' opportunities to gain real clinical experience with patients (21), and this lack of clinical training can lead to increased medical errors and jeopardize patient safety (20). Traditional hospital-based learning faces challenges like cost, ethical constraints, and logistical limitations (22-24) Modern medical education strategies are shifting towards the use of virtual patient simulations (VP) as they are more flexible and replicable. They can simultaneously respond to multiple students, provide consistent clinical scenarios, and simulate rare but important clinical situations that are difficult to encounter in reality (25). One of the VR programs used in medical education is MIST VR (Minimally Invasive Surgery Trainer - VR), specifically designed to provide trainees with a realistic and assessable environment for skills development, especially in laparoscopy (26). Additionally, it is extensively included in nursing education, especially when it comes to teaching critical thinking, clinical decision-making, communication, leadership, health assessment, and disaster triage (27).

According to a study conducted by Shouri, et al. in Singapore, it was shown that combined attitudes towards interacting with virtual patients and recognizing the benefits of virtual patient simulation have the potential to be effective in teaching communication skills to nursing students (28). The educational objectives of using technology in medical education include facilitating the acquisition of fundamental knowledge, improving decision-making, enhancing cognitive diversity, improving skills coordination, practicing for rare or critical events, team-based learning, and enhancing psychomotor skills (26). This study distinguishes itself from prior reviews, such as those focusing specifically on health professions education broadly, effects on specific programs, or protocols for scoping reviews, by systematically synthesizing evidence on the diverse applications and challenges of VR across multiple specific disciplines within medical sciences (medicine, nursing, dentistry, etc.) published up to early 2023. The innovative contribution lies in providing a consolidated overview of how VR is being implemented and perceived across this breadth of fields, identifying common themes and challenges relevant to an international audience grappling with VR integration in health education.

Methods

Search strategies and eligibility criteria

The current systematic review has been designed and implemented in 2023.

Search Strategy: The protocol of this study was registered in PROSPERO with the identification number of CRD42023408017.

The systematic review search method was conducted based on the PRISMA guidelines. A systematic search was performed in peer-reviewed publications from 1970 to March 14, 2023, in English language texts relevant to the research question: "The application of VR in the education of universities in the medical sciences group." Although the MeSH method was used in the PubMed database, we deliberately selected additional author-defined keywords to capture emerging trends. Initially, a quick and general search was conducted in the Cochrane Library to ensure that no systematic review existed in this area. No similar article was found. The search was then carried out in electronic databases including PubMed, Cochrane Library, Scopus, Science Direct, ProQuest, Web of Science, and IEEE. The search used the "AND" operator between groups of words considered as separate concepts. Additionally, the "OR" operator was used among synonymous words. The search was performed in the "Title, Abstract, and Keyword" sections of the articles. The search strategy used is presented in Table 1. Since there was no comparison group in this study, the PICO framework did not include the "C" or comparison group. The search keywords were selected by the researchers. Finally, the factors were extracted from the selected articles. In the next step, a complete list of references for all articles was prepared, and the titles of the articles were reviewed by the researchers, and articles that were not relevant to the study objective were excluded. For further assurance, all search stages were repeated. ENDNOTE software version X9 was used for resource management.

Inclusion Criteria

- Articles reporting on the application of VR in any field of medical sciences education (medicine, nursing, dentistry, pharmacy, etc.).
- Quantitative, qualitative, and mixed-method studies that had undergone peer review.
- Studies whose title, abstract, or keywords reflect relevance to the research question.

Exclusion Criteria

- Articles that had variables unrelated to the research question were excluded.
- Review articles, unpublished articles (grey literature), editorials, protocols, conference papers, guidelines, and reports from organizations, as well as articles without full-text access, were excluded.

Screening

Initially, duplicate studies were removed through primary screening using EndNote software. Then, the titles of all articles from the databases were reviewed by the authors. In the next stage, the selected article abstracts were read by two authors (S.S.T. & F.GH.), and they reached a consensus with the third author (M.A.M). Subsequently, articles that were fully in the same line with the study objectives and inclusion criteria were selected, and the full text of the articles was read and evaluated by the authors. Finally, articles that referred to the application of VR in medical sciences education were selected. The overall quality of all entered articles was assessed by using the STROBE checklist by two evaluators. The latest version of STROBE includes 22 items for evaluating five main domains, including title, abstract, introduction, methods, results, discussion, and other information, each of which including different sub-sections (29). The checklist consists of a minimum score of 0 and a maximum score of 44. The articles were ranked on a three-point scale based on the checklist results.

Table 1. Search strategy employed for the practical application of VR in medical sciences education at universities

PIO	#1 AND #2 AND #3	Strategy
P	Academy OR Academic medical center OR Academic medical centers OR College OR Education departments OR Faculty OR Institute OR School OR University OR Universities	#1
I	3d internet OR Artificial reality OR Augmented Reality OR Avatar OR Avatarverse OR avatar-based world OR avatar-based worlds OR brain–machine interface OR brain–machine interfaces OR Computer simulation OR Computer simulations OR Digital Twins OR Extended Reality OR Haptic OR Immersion OR Immersive virtual reality OR Metaverse OR Mixed Reality OR MR OR Multisensory OR Second Life OR Sensor OR Sensory feedback OR Sensory feedbacks OR Simulation OR Simulated reality OR Video 360 OR Virtual community OR virtual environment OR virtual environment OR Virtual Reality OR virtual reality OR Virtual World OR Virtual Worlds OR Wearable OR XR	#2
O	Coaching OR Education OR Educational Activities OR Educational Activity OR E-learning OR E-learnings OR Instruction OR Learning OR Literacy Program OR Literacy Programs OR Teaching OR Training OR Training Program OR Training Programs OR Tutoring OR Workshop	#3

The keywords in this search strategy are arranged in alphabetical order.

Articles with a score of less than 16 were classified as low quality, 16 to 30 as moderate quality, and 30 or higher as high quality. Studies with quality scores higher than 16 were included in the study (30). Any disagreements between the two authors were resolved through discussion and consultation with a third party as an arbitrator. Citation and publication bias were also considered, and articles with high citations were carefully evaluated. All of the mentioned stages were repeated twice.

Data Extraction

After carefully reading the articles, we extracted and collected the required information based on a summarization and data extraction form. This form included sections such as title, corresponding author, study objective, study population, study sample, country, study period, study design, instrument, methodology, results, and conclusion. The data extraction forms were completed for each selected article. Two researchers analyzed all the forms and presented them in a table. Finally, any conflicting issues in the articles were reviewed by the third researcher involved in this study. These forms were prepared in Microsoft Word 2016 software.

Thematic analysis

Following the identification of the final studies for the systematic review, a thorough thematic analysis of the content of the studies was manually conducted using the Graneheim and Lundman approach, in order to identify the applications and challenges of virtual reality in medical sciences education as reported in previous research. During the coding process, themes corresponding to applications and challenges were developed. The data extracted from the systematic review were reviewed several times by the researcher, ultimately leading to the identification of the final themes. This process continued until the desired content framework was developed.

Ethics statement

As no human subjects were involved, the study did not require ethical approval or informed consent (IR.SUMS.NUMIMG.REC.1402.124).

Results

Search results and study characteristics

Based on the information provided, a total of 75,396 citations were identified through electronic database searches. Of them, 27,886 were duplicates. After screening the titles and abstracts, 47,409 articles were excluded, and 101 full-text articles were retrieved for further evaluation. Finally, 41 articles were found to be relevant to the study objective, and after assessment using the acceptance checklist, 26 articles (70%) obtained the required score. The selection and identification process of the studies are summarized in Figure 1.

All of the articles were original research studies. Out of the included articles, 16 (61.54%) were interventional studies, 5 (19.23%) were qualitative studies, 3 (11.54%) were mixed-method studies, 1 (3.85%) was a descriptive study, and 1 (3.85%) was a cohort study. Most of the studies (4;15.38%) were conducted in South Korea, and 4 (15.38%) were carried out in the United States. The sample sizes varied from 14 to 607 in different fields, including nursing, dentistry, medicine, biomedical engineering, and medical imaging. The majority of the participants in the studies (11; 42.31%) were from the medical field. The most commonly used technology in these studies was VR, with 8 articles (30.77%) utilizing it (Table 2).

The results obtained from the extraction of article findings indicated six main concepts of these technologies, including “impact on learning,” “increase motivation,” “increase self-confidence,” “enhance teamwork,” “curriculum support tools,” and “challenges.”

Impact on Learning

In the studies reviewed, participants demonstrated significantly higher learning satisfaction and higher grades after exposure to technology (31-43). Students’ experiences of the VR skill learning process included “rapid skill learning process,” “stress-free learning environment,” “friendly with the environment,” and “lack of a sense of reality” (44). Participants reported positive feedback regarding the acceptability, feasibility, and usability of VR simulation with artificial intelligence capabilities (45). The time to achieve penetration significantly improved after practice compared to before training (46). Most students agreed that VR could quickly convey complex issues (47). Students found VR helpful in enhancing their knowledge in patient positioning and equipment for manual imaging tasks (48). There was an expansion in the level of immersive learning and clinical reasoning (36, 38, 49, 50).

Increase Motivation

Using VR simulators led to increased learning and higher motivation among students. Motivational variables were developed using attention, relevance, satisfaction, and confidence indicators, with noteworthy outcomes (51). VR enhanced interest and motivation in students and effectively supported knowledge retention and skill acquisition (34).

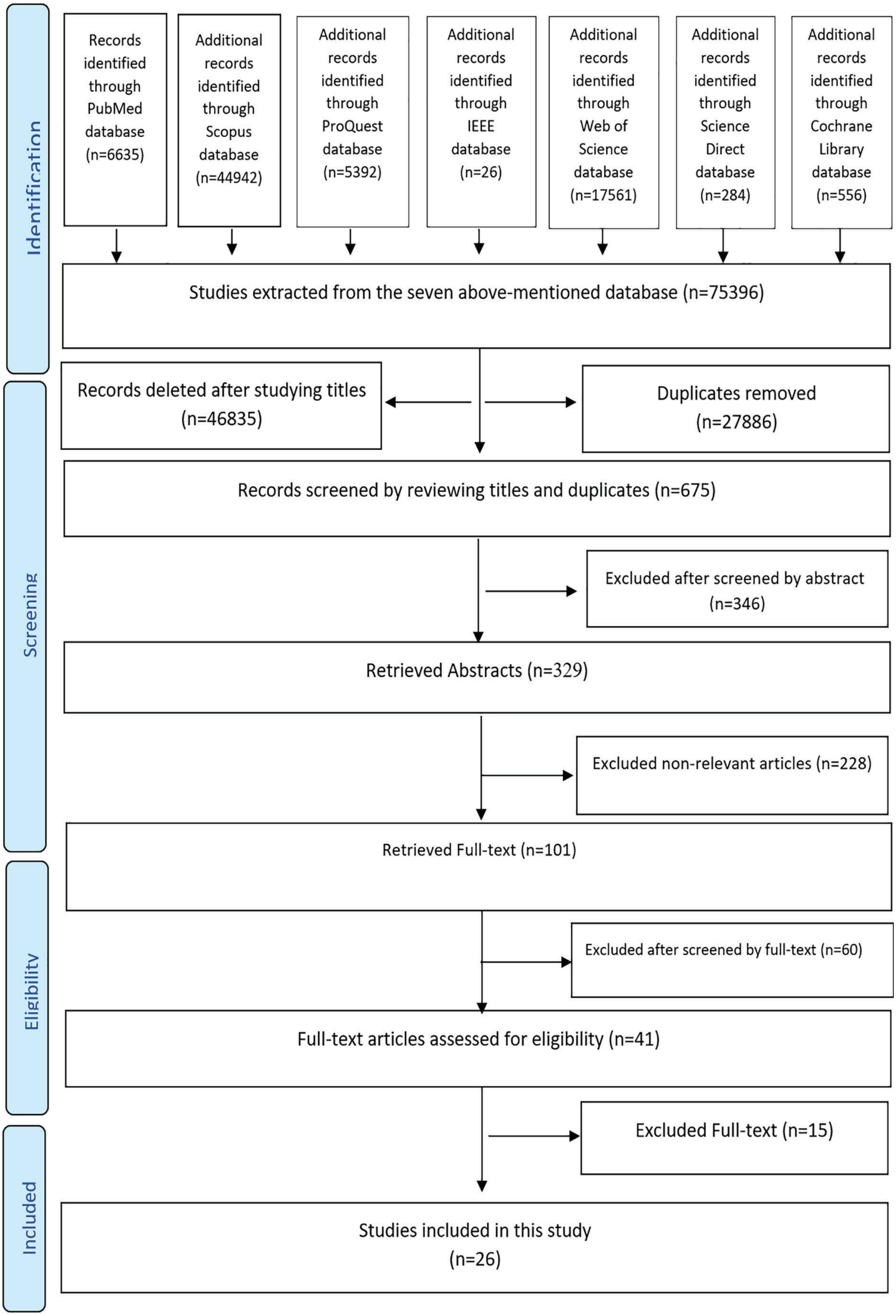

Figure 1. PRISMA flow diagram for the systematic review process

Table 2. Characteristics of the included studies

Study Design	Intervention	16	61.54	Field of Study	Nursing	10	38.46
	Qualitative	5	19.23				
	Mixed	3	11.54		Dentistry	2	7.69
	Descriptive	1	3.85		Medicine	11	42.31
	Cohort	1	3.85		Biomedical Engineering	1	3.85
Type of Technology	VR	8	30.77		Medical Imaging	2	7.69
	Haptic VR	4	15.38	Country of Study	South Korea	4	15.38
	Game	4	15.38		Saudi Arabia	3	11.54
	Mixed Reality	1	3.85		Spain	3	11.54
	Virtual Patient Simulators	1	3.85		Singapore	1	3.85
	Virtual Simulation Platform	2	7.69		United States	4	15.38
	VR Software	3	11.54		Qatar	1	3.85
	Augmented Reality	1	3.85		Taiwan	1	3.85
	VR and Mannequin	1	3.85		Japan	1	3.85
	VR Software Platform	1	3.85		France	1	3.85
					China	1	3.85
					India	1	3.85
					Ireland	1	3.85
					Germany	2	7.69
					Australia	2	7.69

Increase Self-Confidence

These technologies may help instructors gain more self-confidence and, at the same time, strengthen the relationship between teachers, librarians, and students (51). Students perceive Second Life as an engaging and suitable environment where they gain self-confidence (52, 53) and feel less anxious about speaking in public (53). Simulation might lead to improved understanding of the required knowledge domain for clinical training among students who had lost their self-confidence (54).

Enhance Teamwork

The multi-user capability of these technologies can improve teamwork skills (33, 35, 40, 44, 53). VR provides a rich, interactive, and engaging learning environment that supports experiential learning (34). Participants showed significant improvements in communication awareness and professional self-efficacy after learning (45). They also described the virtual experience as a valuable group exercise (54).

Integrate curriculum support tools

Integration of VR simulation and technology into the curriculum as an instructional aid can be beneficial (32, 44, 55). Future considerations should include incorporating VR techniques into classical CPR training or vice versa to leverage the advantages of both teaching methods (56). VR serves as a useful complement to mannequin-based courses (47). Simulation provides an opportunity to develop technology skills and should be considered as a potential tool for future healthcare instructor preparation (54). Additionally, three themes emerged regarding the participants' experiences with virtual learning: "connection to the real world," "artificial intelligence vs. human intelligence," and "complementing face-to-face learning" (45).

Challenges

Although students recognized the use of simulation technology, such as VR, as a useful complement to support their pre-clinical education, the majority of students did not consider haptic VR simulation as a replacement for traditional pre-clinical simulation training (55). The nursing students' experience with pervasive VR for learning nursing skills showed that "it is convenient for practice but requires adaptation" (44). The movement impairment worsened after each training session but gradually improved with continuous practice using VR simulation. Furthermore, the subscale scores of the Simulator Sickness Questionnaire (SSQ) indicated that VR simulation caused nausea, disorientation, and eye strain, but eye strain significantly improved with repeated practice (46). The participants were asked about the suitability of VR for older individuals, and they reported minor technical issues and emphasized the importance of prior readiness in using this technology (49).

Discussion

The present study was conducted to explore the applications of VR in medical education. In this study, various researchers have utilized different technologies in their investigations, including VR, mixed reality, augmented reality, games, and simulation programs. In this study, based on specific studies, it was found that immersion and clinical reasoning had expanded in the use of VR and virtual patient simulation (36, 38, 49, 50). The study by Raith, et al. (2022), which focused on the use of VR in radiology, also shows that over time, more accessible and powerful hardware becomes available, and the use of higher-fidelity holograms and better utilization of real-world objects can enhance user immersion and technology acceptance (57). In the study by Porto, et al. (2020), medical students revealed significant improvement in their performance through repetitive simulation exercises, with surgical simulators being promising tools for medical education and surgical skill development (58). Jamieson's study (2008) indicates that participants who have intrinsic personal reasons for engaging with such technologies are likely to be more successful compared to those who have purely professional motivations. VR programs help the participants establish a personal connection with this experience (59). Based on the findings of this research, students experienced a stress-free learning environment in learning VR skills (44). In the study carried out by Leung, et al. (2011), it was also mentioned that virtual patient simulations provided a safe environment for practice (60). The findings of this study indicate that the use of virtual reality, by providing a safe and stress-free environment, can enhance the students' learning—an outcome that aligns with previous research. This effectiveness is attributed to the creation of a personalized and interactive experience, which not only increases psychological safety but also promotes more active engagement in the learning process. Furthermore, advancements in hardware and more realistic content design have improved the sense of presence, leading to greater acceptance of this technology.

VR increases motivation for students to learn more (34). In the study by Sattar, et al. (2020), it was observed that medical students' motivation in VR conditions was significantly higher compared to video and text-based learning conditions. VR ranked highest in user experience, perceived usefulness, and motivation for final-year medical students. This technology can play a significant role in teaching and learning methods in contemporary times for medical education professionals, allowing students to benefit from this technology (61). Furthermore, in the study conducted by Sattar, et al. (2019), it was stated that both theoretical and practical expertise were vital in medical studies, and practical training repetition could improve the professional competence of young doctors. VR is the best for medical students in terms of learning motivation and competence (61, 62). Virtual reality plays an important role in enhancing medical students' educational experience by increasing their motivation to learn. Findings show that, compared to traditional methods, VR not only is more engaging and effective but also improves both theoretical understanding and practical skills. By enabling repeated clinical practice, this technology can help strengthen the students' professional competence.

According to the findings, these technologies also enhance the relationship between professors and students (51). In the study by Kikuchi, et al. (2013), it was found that the overall scores of dental students in the intervention groups were significantly higher. The presence of a coach during the use of VR simulation for practice did not have a significant difference, while it reduced the preparation time in the initial stages. The results of this study demonstrated that the use of VR simulation systems improved the students' training for preparation (63). The findings of this study suggest that virtual reality technologies not only improve the learning process but also enhance the relationship between professors and students. These results align with the research by Kikuchi et al., which showed that the use of VR simulations improved educational interactions and reduced preparation time, without the need for continuous presence of a coach during the learning process.

After learning, participants showed significant improvements in communication awareness and self-efficacy in professional communication (45). In the study conducted by Hu, et al. (2019), the advantages of mixed reality in the medical field included the application of MR in medical education, preoperative communication between doctors and patients, discussion and formulation of operative plans, in-surgery guidance, remote consultation based on MR, and surgical guidance based on MR technology (64). The findings of the present study indicated that after training, participants showed significant improvements in communication awareness and self-confidence in professional communication. These results align with the study by Hu, et al. (2019), which showed that the use of mixed reality (MR) in medicine contributed to the improvement of education and communication. Both studies emphasize the positive impact of modern technologies in enhancing communication skills and improving professional performance.

It has been determined that incorporating VR technology simulation as an auxiliary tool during training can be beneficial (32, 44, 55). Leung, et al. (2011) concluded that instructors should be able to assess the advantages and disadvantages of virtual patients in the curriculum and then integrate them (60).

Participants questioned the suitability of VR for elderly individuals. They reported minor technical issues and emphasized the importance of prior readiness in using this technology (49). However, in a study by Mayor Silva, et al. (2023), the intervention based on VR was found to be more effective than the conventional method, and it was stated that better results were observed for older students. There seems to be a greater sensitivity to skill development in older students compared to younger ones. Apparently, this is contrary to common sense as younger students are the primary users of such technologies. Nevertheless, the level of progress in students over 20 years of age compared to 18-year-old ones is significantly higher, suggesting that it is a recommended practice starting from the second year and not recommended for recently admitted students (65). The results of the present study emphasize the technical issues and the need for prior preparation for the use of VR in elderly individuals, while other studies have shown that VR can be more effective for elderly people compared to traditional methods. These differences highlight the need for a more thorough examination of the challenges and conditions for using VR across different age groups.

Limitation

The limitation of this study was the lack of access to the full text of some articles related to the subject of this study.

Conclusions

Given that the study results have demonstrated the impact on learning, increased motivation, self-confidence, teamwork, and the use of various technologies, including VR, as auxiliary tools in the educational program, there are also challenges in implementation. Therefore, it is essential to design an improvement program to address these challenges and integrate these technologies into the educational curriculum. Researchers hope that the findings of this study can contribute to understanding the practical applications of VR and, consequently, pave the way for addressing its issues through proper planning. At the university level, we suggest that institutions integrate these technologies as supplementary tools within their curricula to enhance student engagement, teamwork, and communication skills. Holding training workshops for faculty and students can facilitate more effective and confident use of such tools while mitigating challenges such as discomfort or distraction. At the broader higher health education system level, we recommend that policymakers and educational authorities develop national guidelines and provide funding opportunities for implementing immersive educational technologies. Additionally, evaluating the long-term educational and psychological impacts of such tools should be prioritized in future health education strategies. These recommendations aim to translate the synthesized findings into actionable strategies for educational improvement.

Suggestions for Future Research

Given the insights and limitations identified in this review, it is clear that further research is warranted to deepen and broaden our understanding of the role of virtual reality in medical sciences education. Future studies should consider tracking learners over longer periods to determine how virtual reality influences sustained knowledge, skill retention, and professional development in real-world settings. Comparative research that examines virtual reality alongside both traditional teaching methods and other digital learning tools could clarify its relative advantages and practical uses. Additionally, as learners differ in their technological aptitude and educational backgrounds, it would be beneficial to explore how VR experiences can be tailored to accommodate various needs and preferences—especially among older students or those less comfortable with digital platforms. There is also a need for investigations that address the costs, resource demands, and equitable access to VR technologies, particularly in environments with limited funding or infrastructure. Research focused on effective ways to train the faculty and incorporate VR into existing curricula can help educational institutions achieve smoother integration and better learning outcomes. Finally, developing reliable, standardized measures for evaluating VR-based teaching, as well as studying its potential side effects and barriers, will support evidence-based policymaking and better inform curriculum designers and decision-makers at both institutional and national levels.

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Authors' Contribution

MAM was responsible for the study conception and design. FGH and SSTF searched the relevant databases and included the appropriate articles according to the study objective. At the same time, Milad Ahmadi Marzaleh supervised the whole paper. All authors prepared the first draft of the manuscript. All authors did the data analysis, made critical revisions to the paper for important intellectual content, and supervised the study. RS revised article grammatically. All authors have read and approved the final manuscript.

Conflict of Interest

The authors have no conflict of interests to declare.

Declaration on the use of AI

The authors of this manuscript declare that no artificial intelligence (AI) was used during the writing process.

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