Original Article

Access this article online
Quick Response Code:
Website:
www.jehp.net
DOI:
10.4103/jehp.jehp_1874_23

Identifying key drivers affecting the future of virtual reality in medical education

Zeinab Mohammadi[1,2], Rita Mojtahedzadeh[3], Arash Najimi[4], Maryam Alizadeh[5], Aeen Mohammadi[3,6]

[1]Department of Medical Education, Tehran University of Medical Sciences, Tehran, Iran, [2]Education Development Center, Aja University of Medical Science, Tehran, Iran, [3]Department of E-Learning in Medical Education, Center of Excellence for E-learning in Medical Education, School of Medicine, Tehran University of Medical Sciences, Dolatshahi Alley, Naderi St, Keshavarz Blvd, Tehran, Iran, [4]Medical Education Department, Medical Education Research Center, Isfahan University of Medical Education Sciences, Isfahan, Iran, [5]Department of Medical Education, School of Medicine and Health Professions Education Research Center, Tehran University of Medical Sciences (TUMS), Tehran, Iran, [6]Health Professions Education Research Center, Tehran University of Medical Sciences, Tehran, Iran

Address for correspondence:
Dr. Aeen Mohammadi, Department of E-Learning in Medical Education, School of Medicine, and Health Professions Education Research Center, Tehran University of Medical Sciences, Dolatshahi Alley, Naderi St, Keshavarz Blvd, Tehran, 14166-14741, Iran.
E-mail: aeen_mohammadi@tums.ac.ir

Received: 16-11-2023
Accepted: 22-01-2024
Published: 28-03-2025

Abstract:

BACKGROUND: Policymakers must have a forward-looking mindset. Future studies are valuable tools for monitoring upcoming developments and identifying the driving forces that shape the future. This research aimed to identify the drivers or key influencing factors in the future of virtual reality in medical education.

MATERIALS AND METHOD: This study was conducted in 2021–2023 in three phases: conducting literature review, interviewing with experts, and categorizing these results within the STEEPV (Social, Technological, Economic, Environmental, Political, and Values) framework.

RESULTS: Content analysis of the literature review resulted in 273 codes and seven categories. Interviews with 15 experts were analyzed, which led to 220 codes and 30 sub-categories. Ultimately, the results of the two aforementioned stages were categorized within the STEEPV framework, including six, seven, six, two, four, and five drivers in the categories of social, technological, economic, environmental, political, and values drivers, respectively.

CONCLUSION: To successfully introduce virtual reality in universities, it is essential to create a supportive environment, adjust policies, and establish ethical guidelines. This will require initial investments, cost-reduction strategies, and collaboration with knowledge-based companies. In addition, it is vital to leverage existing technology, provide training, and enhance digital literacy to ensure effective utilization. The future of virtual reality in medical education will be influenced by technological advancements, economic factors, environmental concerns, political frameworks, and value-driven approaches.

Keywords:

Forecasting, medical education, virtual reality

Background

The rapid pace of change in medical practice has necessitated adaptations in medical education, leading to appropriate education and preparation of future clinicians. Traditional rote learning has been replaced by more clinically relevant and practical teaching methods. Consequently, problem-based learning, communication skills training, and simulation-based learning have been integrated into curricula to enhance the application of knowledge in patient care. Simulation, in particular, has gained momentum as an effective method for experiential learning. Simulation offers a powerful educational intervention that yields immediate and lasting results by creating realistic scenarios, allowing learners to act as they would in real-life situations, and providing them with feedback and debriefing. It is recognized as superior to traditional clinical education owing to addressing the challenges of providing adequate clinical learning experiences.[1,2]

Simulation-based training has become an integral part of medical education, providing learners with realistic scenarios

How to cite this article: Mohammadi Z, Mojtahedzadeh R, Najimi A, Alizadeh M, Mohammadi A. Identifying key drivers affecting the future of virtual reality in medical education. J Edu Health Promot 2025;14:97.

in a safe environment. In this regard, virtual reality (VR) is an important simulator that provides immersive and interactive experiences for medical education. High-fidelity simulators, such as patient mannequins, replicate human anatomy and physiology, allowing students to practice clinical procedures and receive realistic feedback.[3]

Research has shown that utilizing high-fidelity simulators in medical education improves clinical competency and learner satisfaction.[3] Another type of simulator is VR, an innovative technology that creates a simulated environment through computer-generated visuals, sounds, and haptic feedback to replicate real-world scenarios. In medical education, VR provides unique opportunities for learners to engage in realistic clinical simulations, virtual patient encounters, and surgical procedures. VR-based training enables students to practice complex procedures repeatedly in a controlled environment, improving hand–eye coordination, spatial perception, and decision-making skills. Additionally, VR offers a safe learning environment where learners can make mistakes without endangering patient safety. Research demonstrates the effectiveness of VR in enhancing procedural skills, reducing errors, and increasing learners' confidence and competence. Moreover, VR facilitates scalability and accessibility, enabling remote learning and collaboration among medical professionals.[4,5]

Medical education does not exist in isolation; it is part of an open system that interacts with its surrounding environment and is influenced by it. Thus, the key to the vitality and dynamism of this system lies in its interaction with the environment and its ability to adapt and align with it. An essential requirement for such adaptability is the development of a future-oriented culture and a comprehensive analysis of issues and problems, aiming to identify the influential forces that impact medical education. The evaluation and prospects of VR technologies and methodologies are the most important in the field of medical education, so that is important to understand the value of studying and envisioning the future of these technologies to plan and prepare effectively. By exploring the potential of VR, researchers and educators can discover innovative approaches that meet the changing demands of medical training and education. Researchers and educators can facilitate the successful integration and utilization of VR in medical curricula by acknowledging the significance of VR in enhancing training experiences, improving patient outcomes, and addressing existing challenges.[6] Recently, future studies have been widely used in many areas of development and the findings of these studies have been utilized by governments and private organizations. The advancements in technology and society have emerged a fresh perspective on the future, and decision-makers have to cultivate new skills to adapt to these transformations. Considering the current swift and unpredictable shifts in the environment, it is progressively crucial to anticipate and become prepared for potential future change. It is recommended that future research should adopt an inter-disciplinary approach. Social science, as an inter-disciplinary field, draws on various aspects to derive conclusions and hypotheses. In a practical sense, social science provides individuals with information essential for informed actions to shape the future. Despite the ongoing specialization and segregation of disciplines and professions, the landscape of future research is evolving. The field of foresight encompasses diverse sectors such as culture, economy, politics, health, technology, and arts. With forthcoming changes, the prominence of these domains is on the ascent. The primary step in foresight involves the identification of the factors influencing the future. Although studies have been conducted on the use of VR in medical education, there is a noticeable lack of evidence, especially in the field of future research in medical education.[7-10]

Understanding the desirable and probable future of VR in medical education in terms of its impacts on educational and research activities can serve as a tool and support for all students, faculty, and educational administrators in all educational and non-educational systems to anticipate unpredictable future events and shape desirable futures. This enables the utilization of its full potential in medical education and all learning and educational centers to seek maximum benefits. However, as far as the search for researchers has shown, no research has identified the key drivers affecting the future of VR in medical education. This research aimed to identify the key drivers or influential factors in the future of VR in medical education. Therefore, a complete understanding of the environment, a thorough understanding of the challenges ahead of the planning environment, and the driving forces affecting the future of VR in medical education will be obtained, enabling future studies to be conducted.

Materials and Methods

Study design and setting

This practical and analytical future study was conducted in 2021–2023. As the study focus was on VR in medical education, universities of medical sciences, as the main stakeholders for implementing VR, were the focus of the study.

Study participants and sampling

Participants in this research were members of the academic faculty of medical universities across the country, who were selected using a purposive sampling method with maximum diversity. The experts in this study were selected from individuals who met the following conditions: specialists in e-learning and medical education with at least 4 years of experience as academic faculty, specialists in other fields who had published educational research on simulation using VR, or at least one reputable article in this field.

Data collection tool and technique

Data of this research were collected in three phases including a literature review, expert interviews, and categorization of the social, technological, economic, environmental, political, and values (STEEP V) framework [Diagram 1].

First phase: Literature review

Research related to VR was extracted through a systematic search of four databases including Web of Science, PubMed, Scopus, Embase, and Google Scholar search engines up to December 31, 2022. After extracting the relevant studies, two investigators (ZM and AM) screened the titles and abstracts of the articles. A total of 3643 studies were identified from the databases mentioned. After removing duplicates and reviewing titles and abstracts, 118 studies remained. In the next step, the full text of the studies was examined using the inclusion criteria. Of the 118 remaining studies, 55 were excluded because they did not meet the inclusion criteria [Table 1: Search Strategy].

In addition, by reviewing the reference list of these 63 studies, 17 additional studies were included in our review. Finally, 80 studies remained for full-text evaluation [Figure 1: PRISMA diagram].

The qualitative analysis including identification, categorization, open coding, code summary, and axial coding of the last 80 articles was performed according to the method of Graneheim and Lundman[11] using MAXQDA 10.[12] The Peer check process was conducted by providing the extracted codes and themes to two colleagues involved in the research. Agreement on the selected codes and theme categorization was reached. Any selected codes or theme categorizations that lacked consensus were revisited by referring back to the article texts and re-evaluated by colleagues.

Phase 2: Expert interview

The second phase is to identify the driving forces considered in conducting interviews with experts. Data were collected via semi-structured interviews; after completing the informed consent form, the interviews were arranged. The duration of the interviews varied between 15 and 60 minutes. All interviews were recorded, and notes were taken alongside. Then, the interview texts were studied and initial codes were extracted. The initial codes were then organized so that similar codes were categorized and placed in specific categories. For each new interview, the previous categories were reviewed. Then, by grouping all categories into generalizable phrases within the themes, the final themes were identified. Data collection ended when researchers reached saturation, and no new codes were extracted. In the end, we interviewed 15 people whose characteristics are listed in Table 2.

Phase 3: Categorization of the STEEP V framework

Finally, to fully cover the emerging driving forces, the results of the previous two stages were categorized based on the STEEP V framework.[13] By examining these variables, it is possible to assess issues and trends to gain a comprehensive understanding of VR, identify

Table 1: Search strategy

Database	Search Query	Number of articles
Embase	'virtual reality':ab, ti AND 'drive force':ab, ti AND 'Key factor'; ab, ti	111
Scopus	(TITLE-ABS-KEY (key factor) OR TITLE-ABS-KEY (driver force) AND TITLE-ABS-KEY (virtual reality) AND TITLE-ABS-KEY (medical education))	163
PUBMED	((key factor[Title/Abstract]) OR (driver force[Title/Abstract])) AND (virtual reality[Title/Abstract]))	11
Google Scholar	allintitle: "virtual reality" AND "medical education" OR "medical student" OR "Education, Medical" OR "resident" OR "medical Trainees" AND "driver force" OR "key factor"	1756
Web of Science	(TS=(key factor AND virtual reality AND drive force)) AND DOCUMENT TYPES: (Article)	133

Table 2: Participants' Interview Information

Code	Specialized field	Gender	Academic Teaching Experience
001	Ph.D. in Medical Education	male	5
002	Specialist in oral and maxillofacial diseases	male	12
003	Specialist in internal medicine	male	25
004	Medical Microbiology	male	20
005	Ph.D. in Medical Informatics	male	11
006	Clinical pharmacist specialist	male	17
007	Ph.D. in Distance Education Planning	male	22
008	Ph.D. in Medical Informatics	male	8
009	Ph.D. in Health Education and Promotion	male	16
010	Ph.D. in Medical Informatics	male	12
011	Health Information Management	male	9
012	Psychiatrist specialist	female	11
013	Ph.D. in Medical Informatics	female	18
014	Ph.D. in Distance Education Planning	male	19
015	Ph.D. in Medical Education	female	15

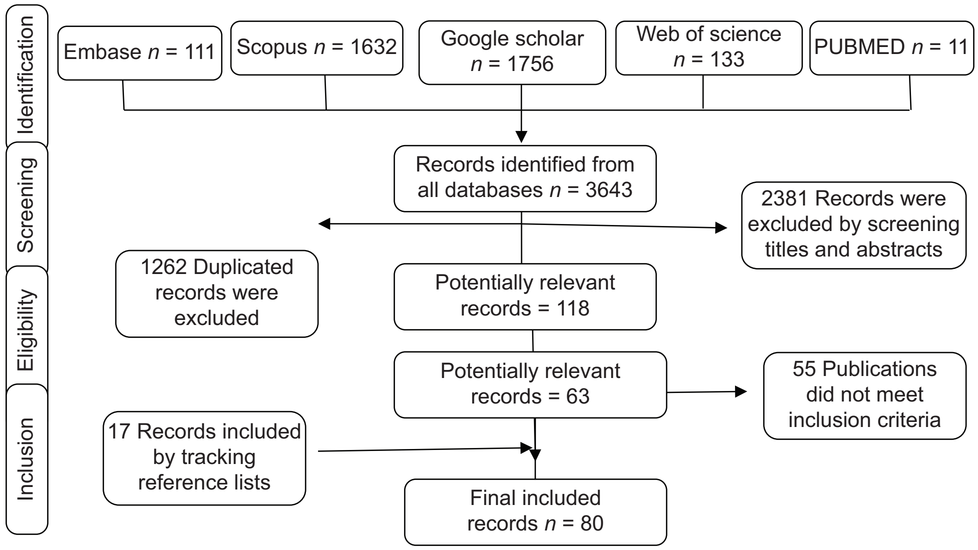

Figure 1: PRISMA diagram

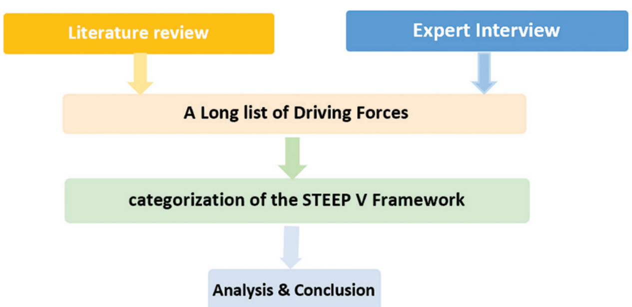

Diagram 1: Study steps

emerging models and patterns, and infer potential future drivers and capacities.

Ethical consideration

Ethics committee approval was obtained from the Ethics Committee of Tehran University of Medical Sciences (No: IR.TUMS.MEDICINE.REC.1400.615). Participants were enlightened about the aim of the study, the ethical charter of the research, and the rights of the participants and participated voluntarily. The participants were given an information leaflet of the research and informed consent for the participation by signing to indicate that they had read the research information leaflet and questions had been answered. The findings were used confidentially and anonymously for discussion and publication. Participants were free to withdraw from the study at any time, and collected data and results were used only for research purposes. In addition, all steps of the study and methods were carried out according to the principles of the Helsinki Declaration.

Results

In the literature review phase, after merging similar themes and removing duplicates, a total of 273 codes and seven categories were extracted. In the expert interview phase, 2531 initial codes were extracted until reaching the saturation of data; finally, after removing repetitive codes and categorizing them, 220 codes were identified in 30 sub-categories. Ultimately, the results of the two aforementioned stages were categorized into 6 STEEP V framework [Table 3].

In the category of social drivers, six key drivers were identified as essential for successfully implementing VR technology in medical education. The findings indicate that a shift in the attitudes and mindset of stakeholders, including students, educators, healthcare professionals, and industry experts, is necessary. However, resistance to change poses a significant challenge in adopting VR in medical education as educators may be hesitant due to factors such as unfamiliarity, cost concerns, and feasibility. According to the literature, comprehensive training and support for stakeholders are crucial to effectively adopt and utilize VR technology.[14]

In the category of technological drivers, seven main drivers were identified. As indicated in Table 3, a suitable infrastructure is a key driver of technological advancements, leading to higher productivity and efficiency. Organizations that prioritize infrastructure upgrades are better equipped to develop and deploy VR applications that meet the needs of customers and employees. Investing in robust infrastructure allows organizations to fully leverage VR technology, achieving optimal performance and user satisfaction.[15] Recent technological advances, including artificial intelligence (AI), big data analysis, cloud computing, and block chain, have enhanced the potential of VR in medical education. For example,

Table 3: Key drivers affecting the future of virtual reality categorized in STEEP V categories

Category	key Drivers Affecting the Future of Virtual Reality
Social	Enhancing digital maturity in organizations
	Developing digital literacy among individuals
	The digital divide in society
	Changing attitudes and generational shift
	Education and empowerment in virtual reality
	Development of interdisciplinary communications
Technology	Technology improving hardware and software infrastructure
	Expanding the use of the Internet
	Converging technologies
	Virtual reality content
	Growth of innovative educational technologies
	Robotics and AI industries
	Internet of Things and smart wearables
Economic	Increase in investments
	Tendency to reduce costs
	Globalization of the economy
	Currency fluctuations
	Growth of knowledge-based companies
	Economic divide
Environmental	Diseases
	Increased energy consumption
Political	Changes in government policies
	Creation of consortia consisting of multiple universities
	International sanctions
	International interactions
Values	Identity crises
	Increased need for educational justice
	Professional commitment and increased organizational responsibility
	Intellectual and moral property rights
	Laws and regulations

AI personalizes learning by adapting the content to individual needs, big data analysis identifies areas for additional support, cloud computing enables remote access to VR simulations, increasing accessibility, and block chain ensures secure storage of student records.[16]

Table 3 highlights the third category of economic drivers, which includes six main drivers. The integration and globalization of national economies have significantly influenced the growth and development of VR technology in medical education. Global interactions, regional policies, medical tourism, and foreign direct investment have all contributed to the expansion of VR technology. The global market for VR is expected to experience substantial growth, with a projected market size of $44.7 billion by 2024.[17]

Table 3 indicates that the category of environmental drivers consists of two main drivers. Weather phenomena, environmental changes, and the emergence of infectious diseases have been challenging in recent times, with the potential to exacerbate both infectious and non-infectious diseases. It is crucial to monitor health and medical events closely and take appropriate measures to minimize potential harm to the community. The ongoing COVID-19 pandemic has further highlighted the need for transformative changes in medical education, including the adoption of VR technology for remote and immersive learning experiences.[18]

Table 3 shows that the fifth category of political drivers includes four main drivers. Economic and political conditions in each country can affect the availability and accessibility of VR technology in medical education. Sanctions and regulations may limit access to advanced medical technologies, hindering their integration.[19] International interactions enable the sharing of VR resources and expertise, promoting the efficient use of the technology.[20] Knowledge and best practice exchange between countries can enhance understanding of healthcare issues and drive innovation.[21]

The last category is value drivers. VR technology in medical education offers simulated experiences that closely resemble real-life scenarios, aiding students in developing practical skills and confidence. However, it can also lead to a crisis of identity as students may struggle to differentiate between virtual and real-life situations, potentially impacting patient empathy and understanding.

Discussion

This study aimed to investigate the influential drivers of the future of VR in medical education. The study utilized a combination of text review and expert interviews to identify and extract the key components. These components were then categorized into six groups: economic, social, technological, political, environmental, and values (STEEP V). In total, 30 components were identified as significant drivers that would shape the future of VR in medical education. The application of the STEEP V framework provides educators with a comprehensive approach to assess and address various factors influencing the successful implementation of VR technology. By considering the social, technological, economic, environmental, political, and values drivers, educators can make informed decisions and enhance the integration of VR in medical education.

Social drivers in VR encompass various aspects that contribute to its successful integration and impact on society. One of the key social drivers is the analysis of changing attitudes toward VR. As society becomes more accepting and open to embracing this technology, it creates greater opportunities for its application in education and training. Additionally, promoting digital literacy and increasing individual awareness about VR are crucial social factors. By improving people's knowledge and understanding of VR, they become better equipped to engage with and benefit from this immersive technology. Education and empowerment in the realm of VR are also important social drivers. Providing individuals with access to VR-based educational experiences and empowering them to explore and learn in virtual environments can have profound effects on their knowledge acquisition and skill development. Furthermore, the development of inter-disciplinary communications plays a vital role in ensuring that the integration of VR aligns with societal expectations. This involves effective collaboration between different fields, such as education, technology, and ethics, to address the social implications and ethical considerations associated with VR implementation.[22]

On the other hand, technological drivers are instrumental in the context of VR-based medical education. Educators need to stay updated on the advancements in VR hardware, software, and interactive simulations to make informed decisions. Being aware of the latest technological developments enables educators to select appropriate VR platforms that align with their educational goals. Moreover, the updated knowledge allows them to create realistic medical scenarios within the virtual environment, enhancing the authenticity of the learning experience for medical students. By leveraging technological drivers, educators can enhance learners' engagement and procedural skills as they can practice and simulate complex medical procedures in a safe and controlled VR environment.[23] By addressing social drivers and staying abreast of technological drivers, VR can revolutionize education by providing immersive and effective learning environments that meet societal expectations and equip learners with essential skills.

Economic drivers involve assessing the costs associated with VR implementation, including equipment acquisition, software development, and maintenance. Institutions need to carefully analyze the economic drivers to make informed decisions about resource allocation, funding strategies, and the long-term sustainability of VR-based medical education programs.[24] Investing in VR technology in medical education offers benefits such as improved student performance, increased confidence, and cost savings.[25] The rising popularity of VR has attracted investment from both private and public sectors. Advancements in technology, including hardware and software improvements, have made VR more accessible and affordable, leading to increased adoption and investment.[26] Studies have shown that VR simulation for surgical training can result in cost savings by reducing errors and minimizing the need for additional surgeries.[27] However, the initial investment for implementing VR technology can be high. Many knowledge-based companies have revolutionized VR-based medical education by offering innovative solutions that address traditional teaching challenges. These knowledge-based companies have significantly contributed to reducing healthcare costs by providing affordable alternatives to expensive simulation equipment. Their growth highlights the increasing significance of technology in medical education and the potential benefits of VR as a teaching tool.[28]

While economic factors are crucial, environmental drivers focus on the physical setup and utilization of VR systems in medical education. Planners have been evaluating safety protocols, ergonomic designs, and the environmental impact of VR technology in terms of energy consumption and waste management.[29] Compared to traditional computer-based learning methods, VR simulations can consume up to 10 times more energy due to the computational power and specialized hardware required, thereby raising environmental concerns.[30] As VR becomes more widespread, its energy consumption could contribute to increased greenhouse gas emissions. Addressing these environmental concerns is crucial in the adoption and implementation of VR technology in medical education.[31]

On the other hand, political drivers shape the regulatory landscape surrounding VR in medical education. Typically, the drivers involved navigate legal and ethical guidelines set by healthcare regulatory bodies and institutions to ensure compliance, address privacy concerns, and advocate for the integration of VR technology into medical education curricula.[32,33] Policy changes have implications for the development and ownership of VR technology in medical education.[34] Therefore, intellectual property laws and ethical considerations should be taken into account when integrating VR technology.[35] In the same vein, collaborative learning and research should be conducted ethically with proper digital content management.[34] It is essential to establish policy frameworks that support the ethical and effective implementation of VR technology in medical education.[36]

Values drivers, on the other hand, emphasize ethical considerations and student-centeredness in VR-based medical education. Educators promote discussions on professional integrity, patient privacy, and ethical decision-making in virtual medical scenarios to develop learners' ethical foundation and a patient-centric approach.[37] VR experiences can influence self-concept, social identity, and moral values. Thus, integrating

VR technology requires careful consideration to shape students' identities positively and promote empathetic care.[38] Mazzone *et al*.'s[39] study found positive effects on clinical skills and confidence; however, they emphasized the need for students to be aware of VR limitations and maintain a balance between virtual and real-life experiences.

To promote the responsible use of technology, organizations should establish codes of conduct, provide training programs, and implement regulatory frameworks.[40] Clear guidelines should be established to determine ownership and ensure proper compensation for creators. Educational institutions must obtain the necessary permissions and licenses to use copyrighted material in VR simulations. Intellectual property rights and patent laws play an important role in the development and commercialization of VR technology for medical education.[34] However, legal issues surrounding VR and AR technologies are complex and require comprehensive laws. Existing laws on user data protection may be insufficient for virtual and augmented reality, necessitating legal discussions on content management, infrastructure access, publishing, taxation, pricing, rights, privacy, digital identity, signature, and cybersecurity. Thus, appropriate laws should be enacted to monitor services, protect rights, and address privacy and cybersecurity concerns. Yet, a gap in current laws, particularly in integrating simulation-based medical education into curricula and accreditations, is observed.[41]

By considering these drivers, educators can assess and address the factors that influence the successful implementation of VR technology in medical education. This comprehensive approach ensures that VR integration is socially acceptable, technologically optimized, economically feasible, environmentally conscious, politically compliant, and ethically grounded, leading to enhanced learning experiences for medical students and improved patient outcomes.

VR technology has the potential to shape the future of medical education; therefore, identifying the influential drivers in economic, social, technological, political, environmental, and values domains is crucial for effective implementation. By considering these drivers, educators can make informed decisions and enhance the integration of VR in medical education. Digital maturity and the cultivation of digital literacy skills are essential for the effective utilization of VR technology. The digital divide should be addressed to ensure equal opportunities for all learners. Overcoming resistance to change and revising teaching methods are necessary for successful VR implementation. Moreover, collaboration, inter-disciplinary approaches, suitable infrastructure, and carefully designed content are integral parts of the implementation process.

Strengths and limitations

In future studies, the influence of current assumptions and paradigms can potentially limit the analyses and predictions. Understanding and analyzing complexities can pose a challenge, requiring precision, experience, and deep knowledge of the relevant science and research methods.

Conclusion

The field of medical education is experiencing rapid changes and advancements on a global scale, necessitating a pro-active approach from policymakers to address critical situations effectively. In this context, policymakers involved in medical education planning must possess a forward-thinking mindset and understand the inherent uncertainty of the future. Future studies have emerged as a valuable tool for monitoring future developments and identifying the driving forces that shape the future. This research proposes a process framework to identify the driving forces for the future implementation of VR technology in medical education. The study emphasizes the need for a comprehensive and multi-dimensional approach, considering social, technological, economic, environmental, political, and value drivers. It highlights the interplay between these factors for successful implementation and comprehensive changes in medical education. Creating an enabling environment and changing stakeholders' attitudes are crucial prerequisites for introducing VR technology in universities. Additionally, adjustments in government policies and the establishment of legal and ethical guidelines related to intellectual property rights, privacy protection, and integration of VR technology in medical education are essential. Adequate initial investments and cost reduction strategies, such as collaboration with knowledge-based companies and international interaction and establishing consortia, are necessary. Leveraging existing technological capabilities, providing continuous training programs, and enhancing digital literacy among professors and stakeholders are vital for effective VR utilization. Technological advancements, economic considerations, environmental concerns, political frameworks, and value-driven approaches collectively shape the future of VR in medical education. Scenario analyses encompassing various influential factors are recommended for future studies.

Acknowledgments

Researchers are thankful to all participants who have attended this study. This study was part of the Ph.D. In medical education dissertation (No: IR.TUMS. MEDICINE.REC.1400.615).

Authors' contributions

ZM, AM, and AN made substantial contributions to the conception and design of the manuscript and have drafted and revised the manuscript. ZM, MA, and AM undertook the acquisition of data. ZM, AM, and RM made substantial contributions to the analysis and interpretation of data. AN supervised and revised the final manuscript. All authors reviewed the entire manuscript for edits, feedback, and approval.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to the counter's data-sharing policy but are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

Ethics committee Approval was obtained from the Ethics Committee of Tehran University of Medical Sciences (No: IR.TUMS.MEDICINE.REC.1400.615). Participants were enlightened about the aim of the study, the ethical charter of the research, and the rights of the participants and participated voluntarily.

Financial support and sponsorship

This study was part of the Ph.D. dissertation and was supported by the Tehran University of Medical Sciences.

Conflicts of interest

There are no conflicts of interest.

References

1. Pottle J. Virtual reality and the transformation of medical education. Future Healthc J 2019;6:181-5.
2. Vakilian A, Ranjbar EZ, Hassanipour M, Ahmadinia H, Hasani H. Theeffectiveness of virtual interactive video incomparison with online classroom in the stroke topicf theoretical neurology in COVID-19 pandemic. J Educ Health Promot 2022;11:219.
3. Weaver A. High-fidelity patient simulation in nursing education: An integrative review. Nurs Educ Perspect 2011;32:37-40.
4. Jiang H, Vimalesvaran S, Wang JK, Lim KB, Mogali SR, Car LT. Virtual reality in medical students' education: Scoping review. JMIR Med Educ 2022;8e34860. doi: 10.2196/34860.
5. Shahmoradi L, Almasi S, Ghotbi N, Gholamzadeh M. Learning promotion ofphysiotherapy in neurological diseases: Design andapplication of a virtual reality-based game. J EduHealth Promot 2020;9:234.
6. Palumbo A. Microsoft HoloLens 2 in medical and healthcare context: State of the art and future prospects. Sensors 2022;22:7709. doi: 10.3390/s22207709.
7. Bogár PZ, Tóth L, Rendeki S, Mátyus L, Németh N, Boros M, *et al*. The present and the future of medical simulation education in Hungary. Orvosi Hetilap 2020;161:1078-87.
8. Rizzetto F, Bernareggi A, Rantas S, Vanzulli A, Vertemati M. Immersive virtual Reality in surgery and medical education: Diving into the future. Am J Surg 2020;220:856-7.
9. Badash I, Burtt K, Solorzano CA, Carey JN. Innovations in surgery simulation: A review of past, current and future techniques. Ann Transl Med 2016;4:453. doi: 10.21037/atm.2016.12.24.
10. Alaraj A, Lemole MG, Finkle JH, Yudkowsky R, Wallace A, Luciano C, *et al*. Virtual reality training in neurosurgery: Review of current status and future applications. Surg Neurol Int 2011;2:52. doi: 10.4103/2152-7806.80117.
11. Graneheim UH, Lundman B. Qualitative content analysis in nursing research: Concepts, procedures and measures to achieve trustworthiness. Nurse Educ Today 2004;24:105-12.
12. Kyngäs H. Qualitative research and content analysis. In: Kyngäs H, Mikkonen K, Kääriäinen M, editors. The Application of Content Analysis in Nursing Science Research. Cham: Springer; 2020.
13. Mao C, Koide R, Brem A, Akenji L. Technology foresight for social good: Social implications of technological innovation by 2050 from a global expert survey. Technological Forecasting and Social Change, Elsevier, vol. 153(C). 2020;153. doi: 10.1016/j.techfore.2020.119914.
14. Cook DA, Hatala R, Brydges R, Zendejas B, Szostek JH, Wang AT, *et al*. Technology-enhanced simulation for health professions education: A systematic review and meta-analysis. JAMA 2011;306:978-88.
15. Slater M, Sanchez-Vives MV Enhancing our lives with immersive virtual reality. Front. Robot. AI. 2016;3:74. doi: 10.3389/frobt.2016.00074.
16. Chan K, Zary N. Applications and challenges of implementing artificial intelligence in medical education: Integrative review. JMIR Med Educ 2019;5:e13930. doi: 10.2196/13930.
17. Market, V. (2020). Virtual Reality Market with COVID-19 Impact Analysis by Offering (Hardware and Software). Technology, Device Type (Head-Mounted Display, Gesture-Tracking Device), Application (Consumer, Commercial, Enterprise, Healthcare) and Geography-Global Forecast to, 2025.
18. Almarzooq Z, Lopes M, Kochar A. Virtual learning during the COVID-19 pandemic. J Am Coll Cardiol 2020;75:2635-8.
19. Boulos MN, Brewer AC, Karimkhani C, Buller DB, Dellavalle RP. Mobile medical and health apps: State of the art, concerns, regulatory control and certification. Online J Public Health Inform 2014;5:229. doi: 10.5210/ojphi.v5i3.4814.
20. Amaechi CV, Adefuye EF, Kgosiemang IM, Huang B, Amaechi EC. Scientometric review for researchpatterns on additive manufacturing of lattice structures. Materials 2022;15:5323. doi: 10.3390/ma15155323.
21. David SA, Hill C. Curriculum innovation for postgraduate programs: Perspectives of postgraduate learners. Int J Innov Learn 2020;28:297-316.
22. Leung T, Zulkernine F, Isah H. The use of virtual reality in enhancing interdisciplinary research and education. 2018. doi: 10.48550/arXiv.1809.08585.
23. Pan Z, Cheok AD, Yang H, Zhu J, Shi J. Virtual reality and mixed reality for virtual learning environments. Comput Graph 2006;30:20-8.
24. Lok B, Ferdig RE, Raij A, Johnsen K, Dickerson R, Coutts J, *et al*. Applying virtual reality in medical communication education: Current findings and potential teaching and learning benefits of immersive virtual patients. Virtual Reality. 2006;10:185-95. DOI: 10.1007/s10055-006-0037-3 ·
25. Dedeilia A, Papapanou M, Papadopoulos AN, Karela NR, Androutsou A, Mitsopoulou D, *et al*. Health worker education during the COVID-19 pandemic: Global disruption, responses and lessons for the future — A systematic review and meta-analysis. Hum Resour Health 2023;21:13.
26. Wang K, Zhao Y, Gangadhari RK, Li Z. Analyzing the adoption challenges of the internet of things (IoT) and artificial intelligence (AI) for smart cities in China. Sustainability 2021;13:10983. doi: 10.3390/su131910983.
27. Yiannakopoulou E, Nikiteas N, Perrea D, Tsigris C. Virtual reality simulators and training in laparoscopic surgery. Int J Surg 2015;13:60-4.
28. Khot Z, Quinlan K, Norman GR, Wainman B. The relative

effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ 2013;6:211-5.

29. Hu-Au E, Lee JJ. Virtual reality in education: A tool for learning in the experience age. Int J Innov Educ 2017;4:215-26.
30. Podolefsky, N. S., Adams, W. K., Lancaster, K., and Perkins, K. K. (2010, October). Characterizing complexity of computer simulations and implications for student learning. In *AIP Conference Proceedings* (Vol. 1289, No. 1, pp. 257-260). American Institute of Physics. https://doi.org/10.1063/1.3515215.
31. Mughees A, Tahir M, Sheikh MA, Ahad A. Towards energy efficient 5G networks using machine learning: Taxonomy, research challenges, and future research directions. IEEE Access 2020;8:187498-522.
32. Kellmeyer P. Neurophilosophical and ethical aspects of virtual reality therapy in neurology and psychiatry. Camb Q Healthc Ethics 2018;27:610-27. doi: 10.1017/S0963180118000129.
33. Stamm O, Vorwerg S, Klebbe R. [Ethical implications in the development of functional training in mixed and augmented reality environments to treat hypertension in old age. Z Evid Fortbild Qual Gesundheitswes 2021;164:23-34.
34. Indriani M, Anggraeni LB. What augmented reality would face today? The legal challenges to the protection of intellectual property in virtual space. Media Iuris 2022;5. doi: 10.20473/mi.v5i2.29339.
35. Lee J, Kim D, Kim H. Smart wearables for sports training and rehabilitation: A systematic review. J Healthc Eng 2020;2020:1-15.
36. Zendejas B, Brydges R, Hamstra SJ, Cook DA. State of the evidence on simulation-based training for laparoscopic surgery: A systematic review. Ann Surg 2013;257:586-93.
37. Torda A. CLASSIE teaching – using virtual reality to incorporate medical ethics into clinical decision making. BMC Med Educ 2020;20:326. doi: 10.1186/s12909-020-02217-y.
38. Rogers SL, Broadbent R, Brown J, Fraser A, Speelman CP. Realistic motion avatars are the future for social interaction in virtual reality. Front Virtual Real 2022;2:750729. doi: 10.3389/frvir.2021.750729.
39. Mazzone E, Puliatti S, Amato M, Bunting B, Rocco B, Montorsi F, *et al*. A systematic review and meta-analysis on the impact of proficiency-based progression simulation training on performance outcomes. Ann Surg 2021;274:281-9.
40. Skulmowski, A. (2023). Ethical issues of educational virtual reality. *Computers* & *Education: X Reality*, *2*, 100023.
41. Kenwright B. Virtual reality: Ethical challenges and dangers [opinion]. IEEE Technol Soc Magazine 2018;37:20-5.