



VIRTUAL REALITY AND HEALTH SCIENCE EDUCATION: A SCIENTIFIC MAPPING WITH IMPLICATIONS FOR PUBLIC HEALTH AND DIGITAL THERAPEUTICS

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Abstract. *Virtual Reality (VR) is transforming health science education by enabling immersive, interactive learning environments. As global health challenges rise and digital tools proliferate, it is critical to map the evolution of VR's application in health science education, particularly its effects on health outcomes. A bibliometric analysis was conducted using the Web of Science Core Collection from 2004–2024. We applied VOSviewer, CiteSpace, and Excel to analyze publication trends, research collaborations, thematic developments, and keyword co-occurrence. From 4,369 articles analyzed, VR-related health education publications have grown exponentially, especially after 2020. The United States, England, and Canada led in publication volume and collaboration. Keyword clustering identified five major themes: surgical simulation, immersive patient education, digital health promotion, AI-enhanced learning, and telemedicine training. Recent trends reflect a shift from technical skills training toward AI integration and personalized VR systems. VR improves learner engagement, enhances long-term health literacy, and supports behavioral change. Its integration with AI and remote delivery models facilitates scalable interventions, bridging healthcare and health science education in underserved regions. Future research should assess VR's direct impact on clinical and public health outcomes, explore ethical and regulatory safeguards, and foster global equity in digital health science education.*

Keywords: *virtual reality, health science education, educational technology, scientific mapping, systematic literature review*

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Introduction

Information and communication technology (ICT) continues to exert a transformative influence on education by promoting equity, enhancing instructional quality, and improving the efficiency of teaching and learning processes (Lim et al., 2019). Its integration has led to significant modifications in teaching strategies, moving away from traditional didactic methods towards more interactive, student-centered learning environments (Agnelli, 2020). The utilization of ICT tools has been shown to increase student engagement, foster a deeper understanding, and provide more inclusive access to educational resources, thereby improving overall learning outcomes across various disciplines.

Virtual reality (VR) is a standout among new ICT innovations due to its capacity to transform educational methods. VR utilizes sophisticated computer-generated settings to create immersive, three-dimensional environments that facilitate experiential learning and active engagement (Groysman et al., 2025; Miltykh et al., 2023; Song et al., 2025). By allowing learners to participate in realistic scenarios, VR improves their understanding, critical thinking, and retention of complex ideas, especially in disciplines that demand spatial awareness and procedural knowledge, such as science, engineering, and medicine (Akman & Çakır, 2023; Shu & Huang, 2021; Soliman et al., 2021). Furthermore, the educational benefits of VR are heightened when integrated with constructivist, experiential, and collaborative learning theories, as it encourages meaningful knowledge building through interaction, exploration, and reflection (Mallek et al., 2024).

In the realm of health education, VR has become a significant asset in overcoming obstacles related to training and enhancing public health literacy. It allows both learners and professionals to delve into complex medical ideas, replicate clinical procedures, and hone decision-making skills within a secure, standardized, and cost-efficient setting (Huang et al., 2025; Mardon et al., 2025). By offering an immersive experience that engages multiple senses—



such as visual, auditory, and occasionally tactile feedback—VR enhances motivation, cognitive engagement, and learner involvement (Lie et al., 2023; Ryan et al., 2022). This technological capability is especially advantageous for building clinical skills, encouraging changes in health behaviors, and providing scalable health education solutions, irrespective of geographical or resource limitations (Elliott & McErlain, 2022; Pottle, 2019; Sattar et al., 2019).

Recent research has shown encouraging results for the application of VR in health science education, emphasizing its role in enhancing learner engagement, knowledge retention, and the development of clinical skills. For instance, a systematic review and meta-analysis by (Kyaw et al., 2019) indicated that VR-based training significantly boosted knowledge and skills among healthcare professionals compared to traditional educational methods. Likewise, a randomized controlled trial demonstrated that medical students who learned through VR simulations of surgical procedures surpassed those who received conventional lecture-based training in both theoretical understanding and procedural precision (Talks et al., 2023). In the realm of nursing education (Foronda et al., 2020) found that VR simulations improved students' clinical reasoning, confidence, and readiness for real-world situations. Additionally, a study by Guitierrez et al highlighted the immersive quality of VR as crucial in cultivating empathy among medical trainees during patient interaction modules (Gutiérrez et al., 2007). These findings are consistent with earlier research by (Cook et al., 2011), which concluded that technology-enhanced simulations, including VR, had moderate to large impacts on learning outcomes in healthcare education. Overall, this collection of evidence supports the growing agreement that VR is an effective educational tool for providing impactful, scalable, and experiential health education across various fields.

To systematically investigate the application and evolution of VR in health science education, bibliometric analysis offers a valuable research approach. As a scientific method grounded in quantitative analysis of academic metadata—such as authorship, publication venues, citations, and keywords—bibliometric analysis provides a macro-level overview of research trends, scholarly impact, and knowledge gaps across disciplines and regions (Blakeman, 2018; Lim & Kumar, 2024; Lyu et al., 2023). It enables researchers, educators, and policymakers to map the intellectual structure of a research field, assess its growth trajectory, and identify emerging topics and underexplored areas requiring further inquiry (Aria & Cuccurullo, 2017; Li, 2024). Within the domain of VR-based health science education, such an approach can guide evidence-informed decision-making, foster international collaboration, and support the strategic advancement of educational technologies in health sciences.

Despite the rapid expansion and increasing integration of VR technologies into health science education, several critical issues remain inadequately addressed. Notably, the actual impact of VR interventions on clinical and public health outcomes requires comprehensive mapping and systematic evaluation to better understand their effectiveness. Additionally, there is limited clarity regarding the depth and effectiveness of interdisciplinary collaborations, ethical compliance, and the potential barriers to VR adoption, such as cost, accessibility, and data security. To address these gaps, this bibliometric study aims to systematically investigate the evolution, application trends, and scholarly landscape of VR in health science education over the past two decades. Specifically, the research seeks to answer the following questions: (1) How has scholarly research in VR-based health science education evolved from 2004 to 2024? (2) What are the prevailing themes and emerging research trends in VR applications within health science education? (3) Which countries, institutions, and authors dominate this research domain, and how have their collaborations evolved over time? (4) What critical gaps exist in current research, and what areas require further investigation to optimize VR's potential in improving health education and outcomes?

Research Methodology

Design

This study employed a systematic bibliometric analysis to examine the application of virtual reality (VR) in health education. Data were retrieved from the Web of Science (WoS) Core Collection on 15 February 2025. WoS was selected as the data source due to its comprehensive indexing of high-impact, peer-reviewed journals and its widespread use in bibliometric research (Aria & Cuccurullo, 2017; Donthu et al., 2021). We clarify that WoS is not a research-producing entity but rather a curated indexing platform that enables access to scholarly publications. Its



structured metadata supports reproducible bibliometric analyses across various disciplines. Bibliometric analysis identifies emerging trends, research collaborations, and critical knowledge gaps by synthesizing large datasets and generating temporal trend charts (Hassan & Duarte, 2024). The analysis included citation mapping, co-authorship networks, keyword co-occurrence, and thematic evolution.

Procedure

A systematic search was conducted using the “Advanced Search” function in the WoS Core Collection. The dataset comprises articles and reviews published between 1 January 2004 and 15 February 2025 on the application of virtual reality in health education. The retrieval formula used was: TS = (“virtual reality” OR “immersive technology” OR “simulated environment” OR “computer-simulated reality” OR “digital simulation” OR “artificial reality”) AND TS = (“health education” OR “wellness instruction” OR “medical education” OR “public health training” OR “health care teaching”) OR **TS = (“virtual reality **” OR VR) AND (“health education **” OR “medical education **” OR “patient education” OR “health promotion” OR “public health education”) OR **TS = (“virtual reality **” OR VR OR “augmented reality” OR AR) AND (“health education **” OR “medical education **” OR “health promotion” OR “patient care training”) AND (“application” OR “intervention” OR “adoption”) AND SU = (“Education” OR “Public Health”) AND PY = (2004-2024).

To ensure the relevance and quality of the selected publications, explicit inclusion and exclusion criteria were used. The inclusion criteria were articles published between 1 January 2004 and 15 February 2025, written in English, and classified as research articles or reviews. The exclusion criteria were publications categorized as conference proceedings, reports, or letters, as well as studies that did not explicitly focus on VR or health education. Due to the limited language skills of the researcher, only articles written in English were used in the screening process. Applying these criteria refined the dataset to include only peer-reviewed studies, thereby enhancing the validity of bibliometric analysis.

Data Analysis and Visualization

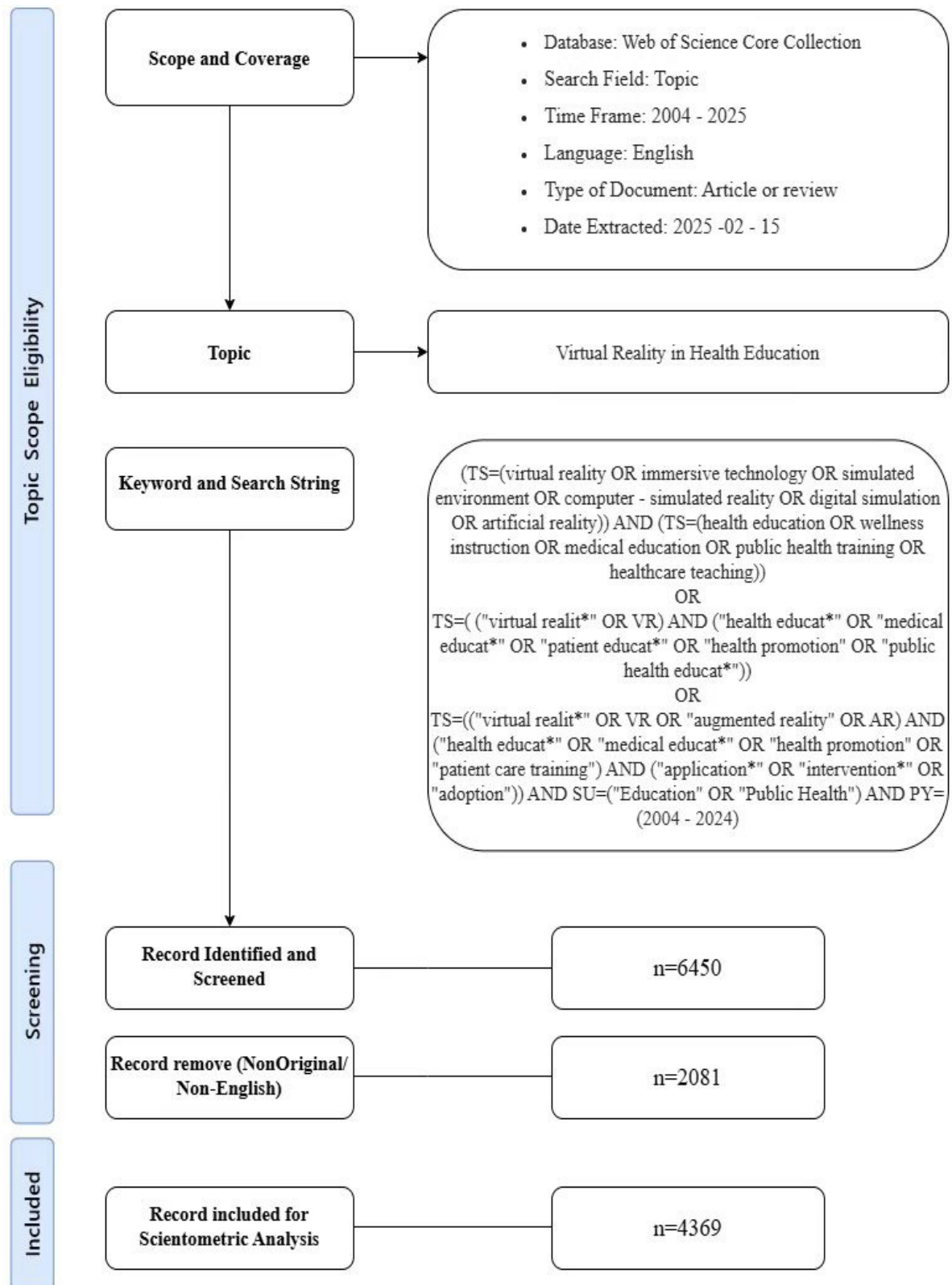
This study utilized VOSviewer, CiteSpace, and Excel for bibliometric analysis. VOSviewer is widely employed for its advanced visualization and network mapping capabilities, facilitating cluster analysis of authors, institutions, and keyword co-occurrence. CiteSpace enables the identification of emerging trends, co-citation networks, influential journals, authors, and publications. Excel was used for data cleaning, tabulation, and statistical analysis. Co-authorship and institutional networks were analyzed using total link strength, reflecting the number and intensity of collaborations. Keyword co-occurrence was assessed based on fractional counting, clustering strength, and modularity to identify research themes. Citation bursts were computed via Kleinberg’s burst detection algorithm in CiteSpace, which identifies significant changes in citation frequency over time.

Research Results

Overview of Selected Literature

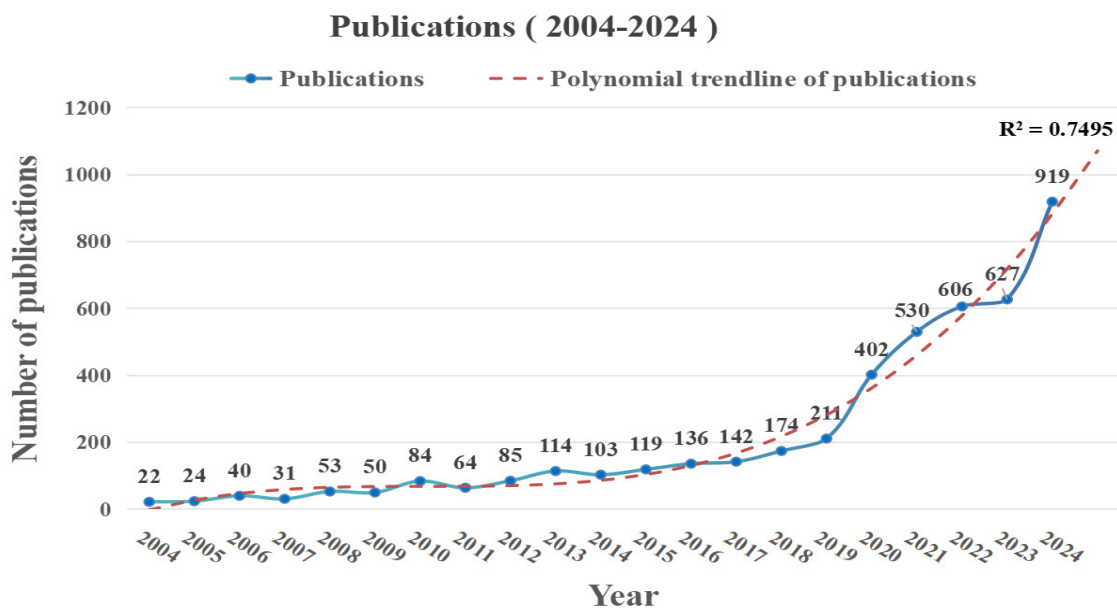
A total of 4,369 relevant publications were selected for further examination. The findings of this bibliometric analysis provide a comprehensive overview of existing research trends and identify future directions for the application of VR in health education. Figure 1 illustrates the research workflow structured according to the PRISMA-P framework.



Figure 1
PRISMA 2020 Flow Diagram for Systematic Reviews

Annual Trend of Published Papers

As depicted in Figure 2, the number of publications related to VR in health education exhibited a steady upward trend. This study analyzed publication data from 2004 to 2024, revealing a polynomial trend line value of 0.7495, indicating a strong fit for the observed trend. The overall trajectory suggests a significant increase in scholarly interest in this field, with expected future growth. Distinct publication trends were observed across different periods. Between 2004 and 2010, the number of publications increased gradually, with fluctuations in growth. For example, the number of articles increased from 22 in 2004 to 40 in 2005 but then declined to 31 in 2006, reflecting the nascent stage of VR research in health education, limited researcher engagement, and lower academic interest.

Figure 2*Annual Trend of Papers Related to Virtual Reality in the Field of Health Education From 2004 to 2024*

Publication output increased steadily between 2010 and 2020. The number of articles has increased from 84 in 2010 to 136 in 2015, reaching 402 in 2020. This period marked an expansion in scholarly attention toward VR applications in health education, with more researchers contributing to the field.

From 2020 to 2024, the number of publications surged significantly. Projections estimate that the number of articles will rise from 402 in 2020 to approximately 1,100 in 2024, likely driven by advancements in VR technology and the growing societal demand for innovative health education methods. These findings suggest that the application of VR in health education is a rapidly evolving research domain with a significant growth potential. The steady increase in publications underscores its academic and practical relevance, indicating that research interests in this field will continue to expand in the coming years.

Countries or Regions Analysis of Publications

Figure 3 illustrates the countries or regions' cooperation co-occurrence network diagram, indicating that the United States, China, Germany, Canada, England, Australia, and other countries or regions have established substantial and effective collaboration networks in the application of VR technology in health education. Table 1 presents the ten leading countries or regions in this domain. A significant number of publications originated from the United States, followed by England and Canada, with the respective publication counts being USA (1439), England (468), and Canada (413). Among the top 10 countries or regions in terms of publication volume, the USA (0.25), England (0.2), India (0.14), and Canada (0.12) exhibit an intermediary centrality exceeding 0.1, indicating



their core position in this domain and suggesting that their research outcomes may significantly impact the field. Nonetheless, several countries or regions exhibit high output and low centrality, as exemplified by Germany.

Figure 3
Co-occurrence Network Diagram of Cooperation Between Countries or Regions

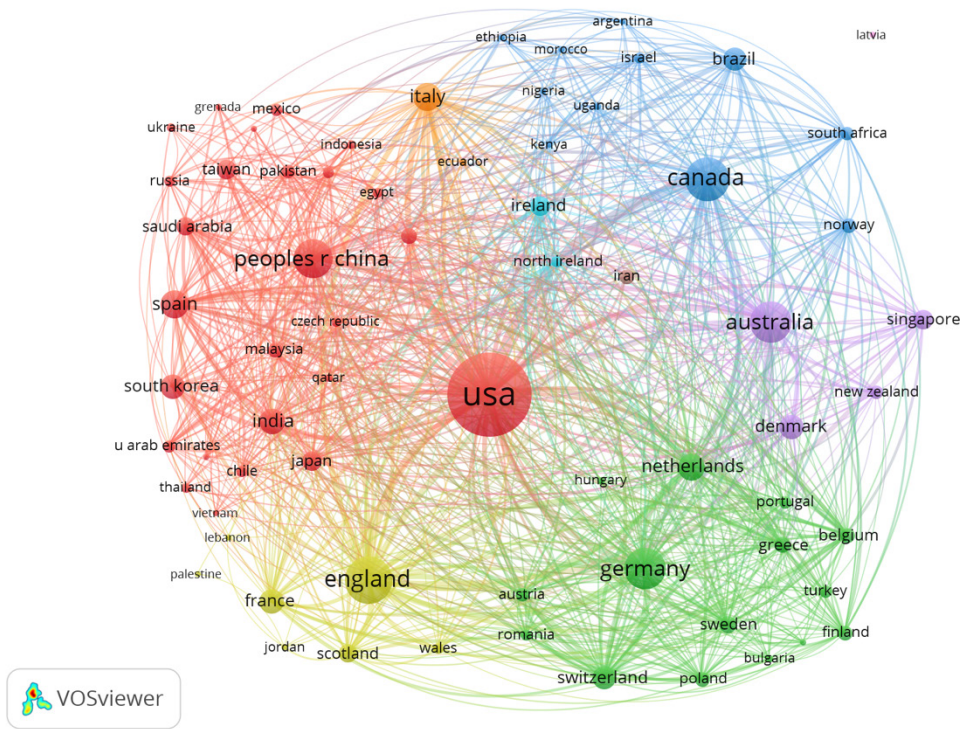


Table 1
Top 10 Countries or Regions in the Field

Rank	Count	Centrality	Year	Countries or Regions
1	1439	0.25	2004	USA
2	468	0.20	2004	England
3	413	0.12	2005	Canada
4	364	0.08	2006	Australia
5	350	0.03	2004	Germany
6	328	0.08	2005	China
7	169	0.08	2006	Spain
8	160	0.08	2004	Italy
9	148	0.06	2004	Netherlands
10	143	0.14	2009	India

Cooperation among several countries or regions in this domain illustrates the trend of globalization and the necessity for interdisciplinary interaction.



Table 2*The Top 10 Institutions in This Field*

Rank	Count	Citations	Total link strength	Institutions
1	118	6334	237	University of Toronto
2	70	1607	111	Stanford University
3	64	2571	105	University of Copenhagen
4	54	1522	72	Monash University
5	53	1374	76	McGill University
6	48	967	105	Harvard Medical School
7	48	1905	81	Imperial College London
8	46	2564	88	Mayo Clinic
9	44	1349	81	University of Washington
10	41	1174	45	National University of Singapore

To enhance the comprehension of the impact of institutional research, the researcher examined the ten institutions exhibiting the greatest citation outbreak rate in this domain (Table 3). The data suggest that Columbia University achieved a citation intensity of 9.63 in 2006, which persisted for nine years (2006-2015), signifying that the research output of this institution garnered extensive recognition and sustained attention throughout that period. Moreover, Northwestern University and the Feinberg School of Medicine emerged in 2005, exhibiting high citation intensity (8.74 and 7.82%, respectively), signifying that the research outputs of these institutions were extensively referenced in their initial years.

Table 3*Top 10 Institutions with the Strongest Citation Bursts*

Institutions	Year	Strength	Begin	End
Northwestern University	2005	8.74	2005	2016
Feinberg School of Medicine	2005	7.82	2005	2016
University of Toronto	2006	9.63	2006	2015
Mayo Clinic	2006	8.55	2006	2014
Saint Michaels Hospital Toronto	2009	6.74	2009	2019
University of Western Ontario	2007	7.01	2011	2017
University of Copenhagen	2012	9.38	2013	2017
Rigs Hospitalet	2013	9.21	2014	2017
Nanyang Technological University	2018	7.96	2018	2019
University of California San Francisco	2011	6.47	2019	2020

In terms of time distribution, early research institutions (such as Northwest University and Columbia University) contributed high-impact research results from 2005 to 2015. In recent years (2018-2025), the research results of academic institutions such as Nanyang Technological University and the University of California San Francisco have also begun to receive extensive attention, indicating that these institutions have become important emerging research forces in this field.



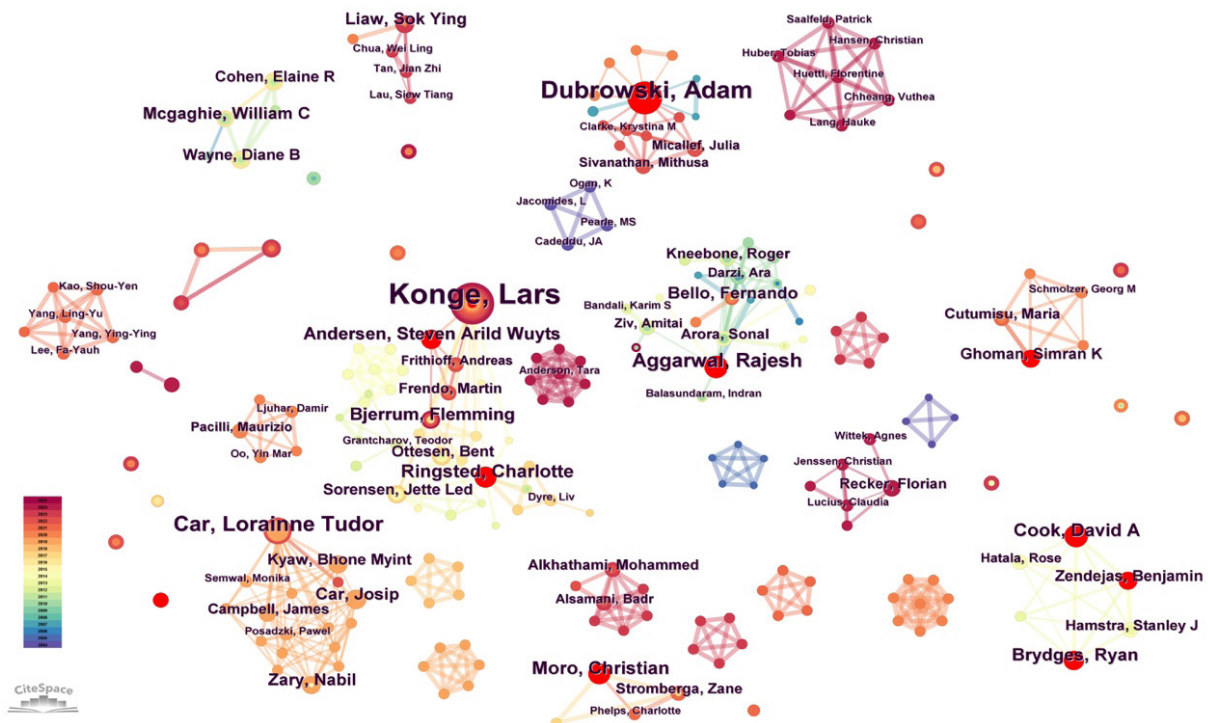
This study conducted a thorough analysis of the co-occurrence network of institutions in the domain of VR health education. The findings indicate that academic institutions such as the University of Toronto, Stanford University, and Copenhagen University play a central role in research within this domain, and these institutions continue to advance the area through broad international collaboration. Inter-agency collaboration is crucial in advancing research and development in this domain, and future cooperative trends are expected to be more integrated and varied.

Author Co-occurrence Analysis

In the scientific research network, the cooperative network among authors not only reflects the research activity in this field but also reveals the main scholars and their academic influence. To analyze the research pattern of VR technology in the field of health education, this study used the author co-occurrence analysis method to construct and visualize the author cooperation network in this field.

As shown in Figure 5, the author co-occurrence network includes several closely cooperating research groups. The data shows that Konge and Lars are the most published scholars in this field, and their research focuses on the application of VR technology in medical education, and they have formed the largest core cooperation network with scholars such as Dubrowski, Adam, Car, Lorainne Tudor, Aggarwal, Rajesh. In addition, there are several relatively independent research networks, indicating that the research directions in this field are diverse. Table 4 shows the top ten authors in this field, among which Konge and Lars ranked first with 42 academic papers, followed by Dubrowski and Adam (22 papers), and Car and Lora Inn Tudor (14 papers).

Figure 5
Author's Cooperative Co-occurrence Network Diagram



From the analysis of regional and time dimensions, the core researchers in this field mainly come from North America and Europe, and some scholars have been active in this field since 2007, such as Dubrowski, Adam, Aggarwal, Rajesh. At the same time, in recent years, emerging researchers such as Car, Lorainne Tudor, Andersen, Steven Arild Wuyts have also begun to contribute high-impact research, indicating that this field is attracting more and more scholars to join.

Table 4
Top 10 Authors in Terms of the Number of Articles Published

Rank	Count	Year	Author
1	42	2014	Konge, Lars
2	22	2007	Dubrowski, Adam
3	14	2019	Car, Lorainne Tudor
4	11	2007	Aggarwal, Rajesh
5	9	2017	Moro, Christian
6	9	2012	Ringsted, Charlotte
7	9	2013	Cook, David A
8	8	2020	Andersen, Steven Arild Wuyts
9	8	2013	Brydges, Ryan
10	8	2016	Bjerrum, Flemming

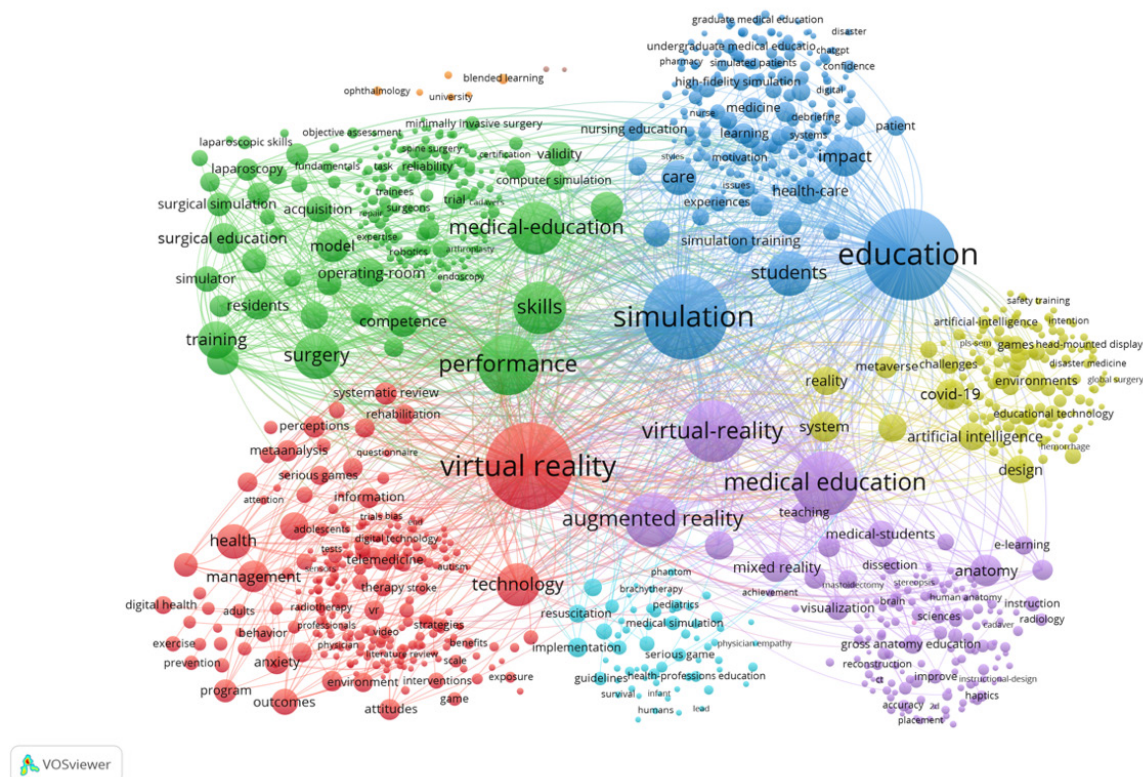
Keyword Analysis

1) Keyword Co-occurrence Analysis

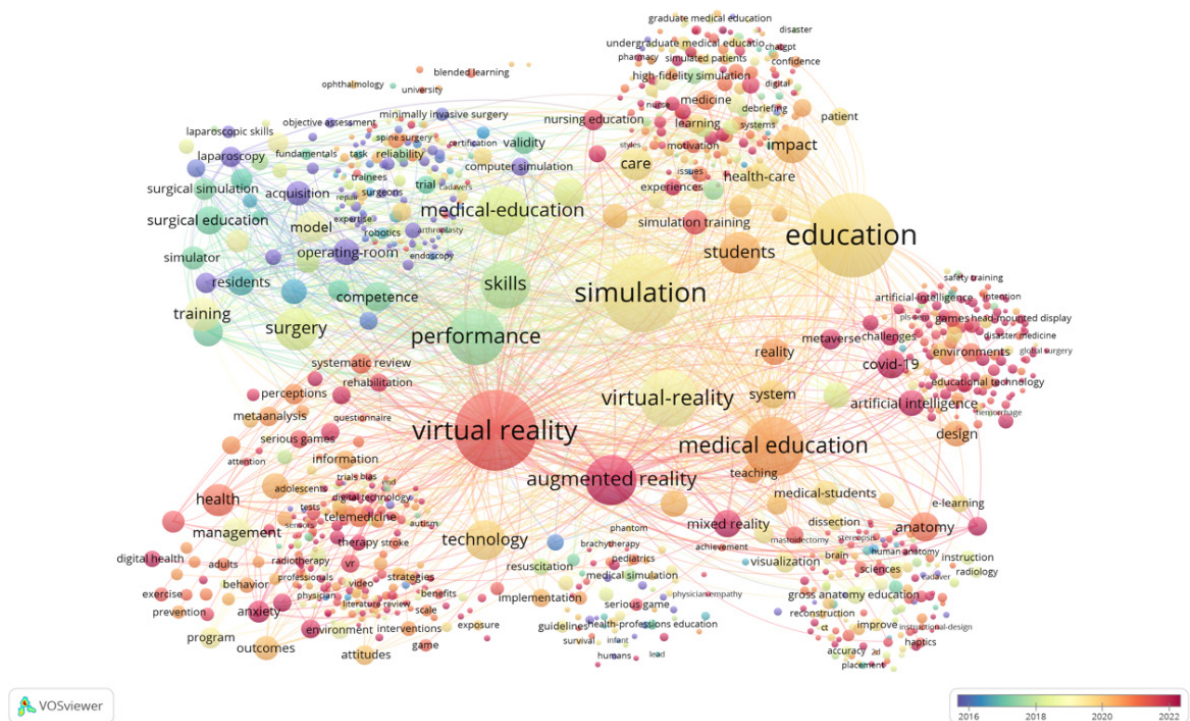
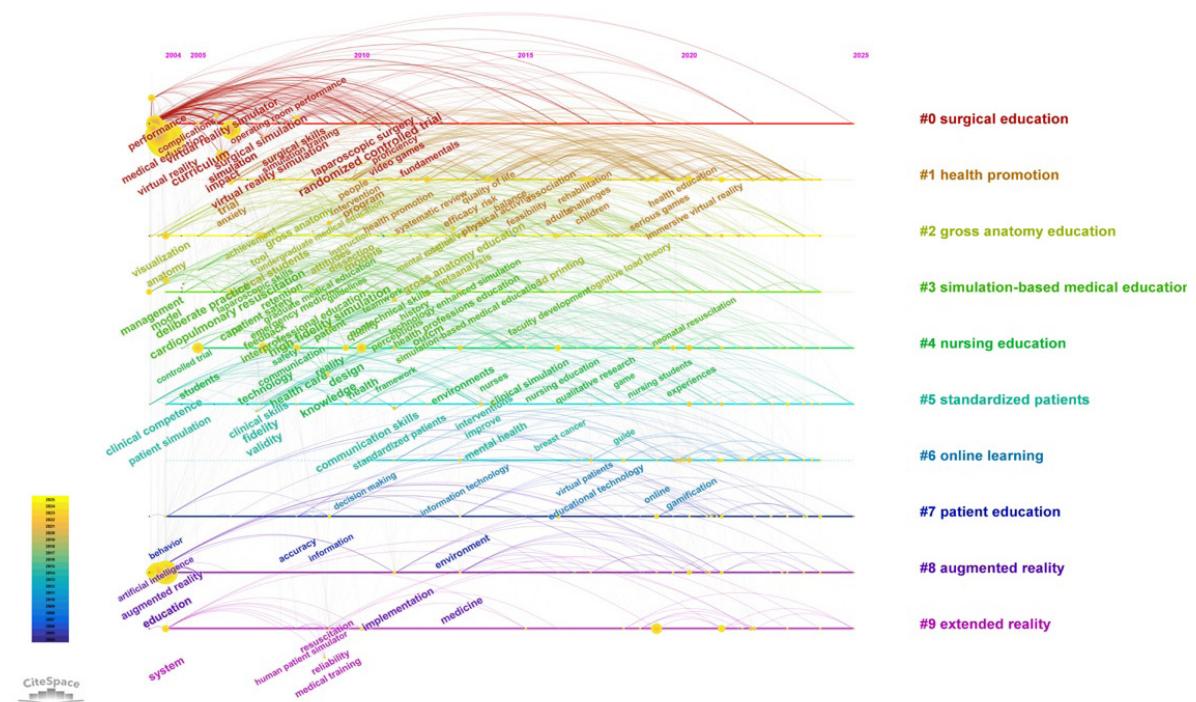
In academic research, keyword co-occurrence analysis can reveal the core theme and its development trends in the research field (Huang et al., 2020). Based on the Web of Science database, researchers used VOSviewer software to analyze the scientific knowledge map. During this analysis, researchers extracted and visualized high-frequency keywords and their clustering patterns to identify research hotspots and research development paths.

As shown in Figure 6, the keyword co-occurrence network presents several closely related research topics that constitute the core framework of VR health education research. In the keyword co-occurrence network, “virtual reality”, “simulation” and “education” are the core keywords, which not only occupy the core position in the co-occurrence network but also form close ties with keywords in many research fields. In addition, “virtual reality” is closely related to keywords such as “medical education” and “augmented reality”, which reflect the wide application of VR technology in the field of health education. “simulation” relates to keywords such as “students”, “performance” and “skills”, which reflects the key role of virtual simulation operation based on VR technology in improving students’ learning experience, skill training and academic evaluation.



Figure 6*Keyword Co-occurrence Clustering Diagram*

From the science mapping of the keyword co-occurrence time in Figure 7, it can be seen that the research trend of VR in the field of health education is gradually developing from early basic research to clinical practice, simulated scenes, and professional training. The research trend is constantly deepening and refining, and the keywords are closely related, which reflects the coherence and systematic Ness of research in this field. The researchers analyzed the time distribution of key words (Figure 8), from which we can see that the research on VR health education has gone through three main research stages: (1) From 2004 to 2010, academic research focused more on the initial application of VR in skill training and surgical simulation, with key words such as “performance” and “technical skills” dominating; (2) From 2010 to 2020, the research gradually expanded to a wider field of medical education and patient training, and the frequency of keywords such as “virtual reality simulation” and “clinical competence” increased; (3) Since 2020, intelligence and tele-learning have become the focus of research in this field. For example, keywords such as “artificial intelligence” and “augmented reality” have increased rapidly, indicating the research potential of VR technology in intelligent medical education, personalized learning, and telemedicine.

Figure 7*Science Mapping of the Keywords Co-occurrence Time***Figure 8***Keywords Timeline Diagram*

Tables 5 and 6 provide high-frequency keywords and their citation outbreaks of VR technology in health education research, and these data can further verify the evolution trend of research hotspots. Table 5 lists the keywords with the highest frequency of co-occurrence, among which “virtual reality” appears the highest frequency, further indicating the dominant position of VR in this field, followed by “simulation” and “education”, indicating that the integration of virtual simulation technology and education content is still an important direction in this field. In addition, the frequency of “augmented reality” and “artificial intelligence” has increased significantly in recent years, reflecting the increasing importance of augmented reality and artificial intelligence technology in medical education.

Table 5*Top 10 Keywords with Frequency of Occurrence*

Rank	Occurrences	Total link strength	Keywords
1	1350	1831	Education
2	1225	1709	Virtual reality
3	1157	1906	Simulation
4	673	1061	Medical education
5	619	1033	Virtual reality
6	598	1115	Performance
7	477	931	Augmented reality
8	455	885	Skills
9	445	703	Medical education
10	347	724	Surgery

Table 6*Top 10 Keywords with the Strongest Citation Bursts*

Keywords	Year	Strength	Begin	End
Performance	2004	31.59	2004	2017
Operating room	2004	29.17	2004	2019
Acquisition	2004	23.95	2004	2018
Technical skills	2004	19.56	2004	2016
Residents	2004	17.6	2004	2017
Skills	2004	18.73	2005	2014
Virtual reality simulator	2006	15.43	2006	2018
Virtual reality simulation	2007	16.81	2007	2019
Validation	2004	16.58	2009	2019
Artificial intelligence	2004	17.29	2023	2025

The keyword citation burst analysis (Table 6) shows that research hotspots in this field are constantly evolving. For example, the citation intensity of “performance” was the highest during 2004–2017, which reflected that research on VR technology in skill evaluation and performance optimization was of great concern during this period. In addition, the outbreak intensity of “operating room” from 2004 to 2019 was 29.17, which reflected the high research interest in surgical related technology and education in this field. However, “artificial intelligence” has been paid attention to since 2004, and has become a high-explosive keyword in recent years (2023–2025),



indicating that the combination of a personalized learning system driven by artificial intelligence and VR medical training is becoming a new research frontier.

2) Keywords Clustering

To further reveal the research structure and hot spots of VR in the field of health education, this study used CiteSpace software for keyword clustering analysis and then formed a visual knowledge structure map (as shown in Figure 9). The color of keyword clustering represents different research topics, and the central word of each cluster marks the core content of this research direction.

As can be seen from Figure 9, education and learning research (blue) is centered on “education” and “simulation” and is associated with keywords such as “students”, “learning” and “assessment”, which shows that the learning form of virtual simulation through VR technology plays a key role in improving learners’ cognitive experience and mastering medical skills, especially in the fields of medical education and clinical training. VR medical training and surgical teaching (Tancredi et al.) revolves around “virtual reality”, “medical education” and “augmented reality”, highlighting the role of VR in surgical skill training, resident training and surgical simulation, and emphasizing the value of “experience” and “engagement” in enhancing learning immersion. Surgical skills and clinical training (green) focus on “surgery”, “skills” and “clinical training”, which shows the key position of VR technology in the process of surgical training and clinical ability training and further combines “happy feedback” and “virtual patients” to enhance the authenticity and interactivity of simulation training. It is worth noting that technology integration and intelligent development (purple) cover “artificial intelligence”, “machine learning”, and “big data”, indicating that VR technology and emerging intelligent technologies are being integrated and applied. At this stage, the AI-driven personalized learning path, its real-time feedback, and intelligent evaluation functions optimize the educational effects of VR technology. In addition, the emergence of keywords related to “remote education” and “telemedicine” indicates the broad application prospect of VR in medical education resource sharing and telemedicine training. Health promotion and patient education (yellow) involves “health promotion”, “patient education” and “digital health”, indicating the application potential of VR in chronic disease management, health behavior intervention and psychological rehabilitation, such as self-management training for patients, pain relief and psychological health intervention, to improve learners’ health literacy and the effect of educational intervention.

In this study, through the cluster analysis of keywords, the researchers found that the research focus in this field is mainly on the application of VR technology (including augmented reality, mixed reality, and augmented reality) in medical education, patient education, and health promotion (Table 7).

Figure 9
Keyword Clustering

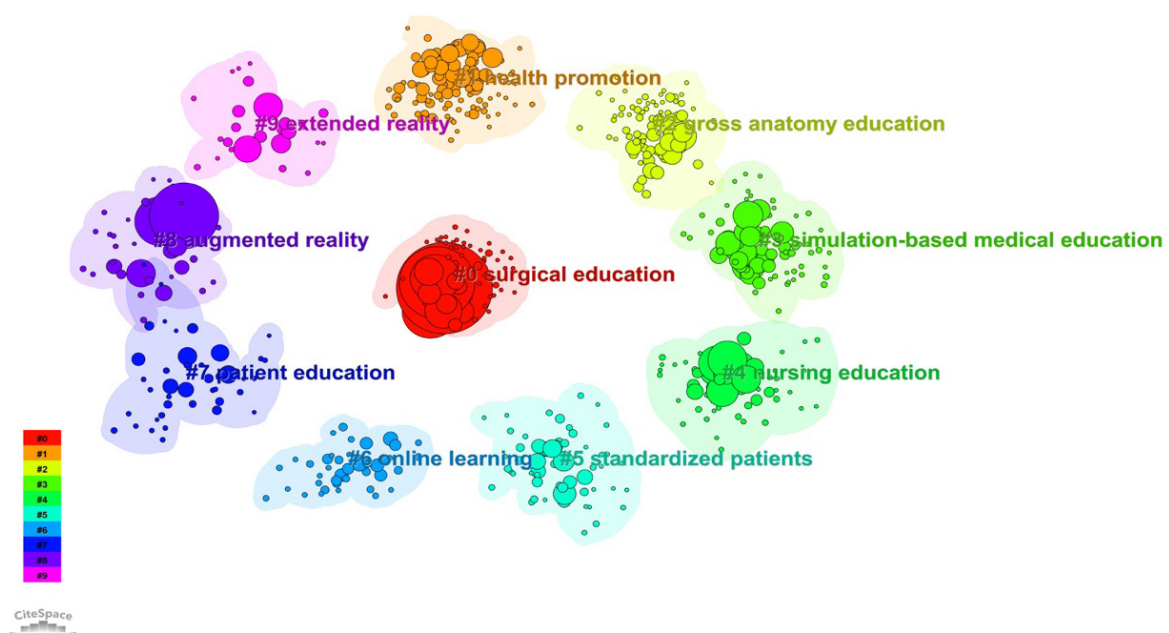


Table 7
Cluster Details

Cluster ID	Keywords
#0	surgical education; laparoscopy; surgical training; surgery; minimally invasive surgery
#1	health promotion; simulation; systematic review; physical activity; digital health
#2	gross anatomy education; undergraduate education; 3d printing; anatomy; medical education
#3	simulation-based medical education; interprofessional education; patient safety; emergency medicine; augmented reality
#4	nursing education; nursing students; virtual simulation; qualitative research; health care
#5	standardized patients; clinical competence; methods; patient simulation; mental health
#6	online learning; information technology; educational technology; simulation-based education; health professions
#7	patient education; information; informed consent; extended reality; medical education
#8	augmented reality; artificial intelligence; machine learning; mixed reality; deep learning
#9	extended reality; mixed reality; augmented reality; dental education; medical training

The data in this section indicate that the integration of technology, including AI and 3D printing, has improved educational outcomes, although multidisciplinary collaboration and patient safety are critical domains. Clusters #1 and #7 align with our study focus, wherein VR is utilized for health promotion and patient education, and augmented reality technology is integrated to increase the interactivity and intuitiveness of information dissemination. Second, clusters #0, #3, and #9 show that VR technology is widely used in surgical education (especially minimally invasive surgery and laparoscopic training), emergency medicine, and dental education, and can improve the accuracy and safety of medical operations through high-simulation virtual simulation. Clusters #2 and #4 focus on innovation in the field of education. For example, 3D printing technology and virtual simulation technology are gradually replacing traditional anatomy teaching, while nursing education trains students in clinical decision-making and operation ability through virtual simulation scenes. Second, Clusters #8 and #9 show the innovation and integration of technology, and the introduction of AI, mixed reality (MR), machine learning, and deep learning have enhanced the intelligent interactive ability of VR, such as analyzing simulated operation data through AI to optimize the training effect, which indicates that this technology will play a greater role in intelligent medical training in the future.

Discussion

This bibliometric analysis delves into the incorporation and development of VR technology within health education from 2004 to 2024. The results highlight not only a significant increase in the number of publications but also a fundamental change in educational philosophies—from traditional didactic methods to immersive, experiential learning environments—driven by cutting-edge digital tools such as VR, AR, and AI. This shift aligns with broader trends in educational innovation, where simulation-based learning has been shown to enhance learner engagement, cognitive retention, and the acquisition of clinical skills more effectively than conventional teaching methods.

This research identified a notable increase in scholarly work on VR technology in health education, especially post-2020. This trend is linked to rapid ICT progress, enhancing its use in medical training, patient education, and health interventions. Our support for VR’s leading role in medical education, clinical skills training, and patient education, as established by Pham Van et al. (2022). Recent research increasingly focuses on integrating disciplines, including VR and AI, as well as MR and AR, offering fresh perspectives for intelligent medical training and distance education (Oliveira et al., 2023). In international academic collaboration, institutions in the United States, Britain, and Canada significantly influence this domain, with the University of Toronto, Stanford University, and Copenhagen University establishing a robust cooperation network (Figure 3). This aligns with the academic collaboration paradigm (Cobo et al., 2012), where leading institutions advance research through international cooperation. The study data indicates burgeoning institutions like the National University of Singapore and Nanyang Technological University have enhanced their research impact in VR telemedicine training recently (Table 2). VR technology in health education is extending from Europe and America to a global context, particularly in the Asia-Pacific region,



where technological advancements and policy support have facilitated research in this domain (Docter et al., 2024; Penno & Gauld, 2017).

Originally applied in procedural skills and anatomical education, VR has transformed into a versatile educational tool that facilitates immersive learning, offers real-time feedback, and allows for personalized pacing—features that resonate with adult learning principles and constructivist learning theory (Mallek et al., 2024; Ryan et al., 2022). The initial emphasis on simulation for laparoscopic or basic procedural training is highlighted in research by Cook et al., which reported significant improvements in cognitive and psychomotor outcomes through simulation-enhanced learning (Cook et al., 2011). Likewise, Gutiérrez et al. underscored the role of immersion levels in boosting learner performance during medical simulations (Gutiérrez et al., 2007). With technological advancements, including haptic devices, VR gloves, and low-latency head-mounted displays, the realism and interactivity of simulations have greatly improved (Groysman et al.; Huang et al., 2025). These innovations not only enhance learners' situational awareness and procedural knowledge but also aid in error management and reflective learning (Dormegnny et al., 2024; Lie et al., 2023; Song & Ng, 2024).

In the beginning, VR applications were mainly focused on developing skills, assessing performance, and conducting surgical simulations (Foronda et al., 2020; Hassan & Duarte, 2024; Winkler-Schwartz et al., 2019). However, in the last decade, there has been a shift towards more sophisticated fields like nursing education, patient counseling, empathy training, and health promotion (Elliott & McErlain, 2022; Rafiq et al., 2024; Sattar et al., 2019). A notable emerging trend is the integration of VR with artificial intelligence (Fatima et al., 2024). This combination is transforming static simulations into dynamic, personalized experiences through intelligent tutoring systems, predictive learning analytics, and AI-driven decision-making within VR (Aldousari & Kithinji, 2024; Soliman et al., 2021). For example, current systems track biometric and behavioral data to modify difficulty levels in real-time, enhancing learner engagement and improving instructional design (Funk et al., 2018). Concurrently, VR-based telemedicine and remote training have attracted significant interest, particularly for communities in remote or underserved regions. This supports global health equity goals and enables broader access to standardized, high-quality education (Honey, 2018; Mardon et al., 2025).

Moreover, the extensive use of VR technology has increasingly highlighted concerns regarding data security and privacy protection (Giaretta, 2024a, 2024b). In the realm of medical training and patient education, which involves a vast amount of patient data and numerous medical scenarios, ensuring data security and personal privacy while upholding the quality of education is a crucial issue that must not be ignored in VR research (Lin & Latoschik, 2022). Future studies should explore more effective data security measures and incorporate blockchain and other technologies to enhance the security and privacy protection of VR technology in medical education systems (Kiyak, 2023). At the same time, in terms of ethical compliance, the future use of VR technology in medical training requires a clearer ethical framework to ensure its application in real medical environments aligns with ethical standards (Grebnyakova & Shilkina, 2023; Tusher et al., 2022).

This research presents several significant strengths that make valuable contributions to the domains of educational technology and health sciences. Notably, the extensive bibliometric analysis offers a macro-level overview of two decades of research, accurately identifying trends, key areas, and emerging themes. Utilizing powerful analytical tools like VOSviewer and CiteSpace, the study delineates intellectual frameworks and collaborative networks, which are crucial for comprehending the strategic evolution of VR in health education. Furthermore, the study's reliance on a substantial dataset ($n = 4,369$) from the Web of Science Core Collection ensures comprehensive coverage of high-quality peer-reviewed literature, thereby bolstering the credibility and reproducibility of the results. The inclusion of detailed visualizations—such as co-authorship networks, keyword clustering, and institutional mapping—not only provides interpretive clarity but also acts as a strategic guide for researchers navigating the field. From an educational perspective, the research demonstrates that VR significantly improves knowledge retention, technical skill development, learner motivation, and clinical decision-making through immersive and experiential learning environments.

Despite employing a comprehensive methodology and extensive scope, several limitations warrant consideration. Primarily, the study's reliance on a singular bibliographic source, the WoS, presents a potential limitation. Although WoS is a preeminent platform for citation analysis, its exclusion of non-indexed yet potentially significant regional literature, particularly from developing nations, may result in geographical and linguistic publication bias. Furthermore, the study's omission of gray literature, conference proceedings, and non-English publications could constrain the diversity of perspectives represented. Additionally, while bibliometric methods are proficient in identifying research trends and productivity, they do not assess the quality or depth of content within individual studies. This limitation complicates the evaluation of the effectiveness or contextual appropriateness of VR interventions.



discussed in the literature. Another concern is the technological heterogeneity in VR implementations; the term “VR” encompasses a broad spectrum of tools—from basic simulations to sophisticated, AI-enhanced platforms—yet many studies lack standardization or specification of the technological details employed. Lastly, ethical considerations related to VR in health education, such as learner psychological safety, data privacy, and equitable access, are insufficiently addressed in the analyzed literature, underscoring a critical area for further qualitative and empirical research.

This study provides a detailed bibliometric mapping of VR in health science education, elucidating the field’s rapid growth, evolving thematic landscape, and leading contributors over the past two decades. It reveals VR’s transition from procedural and simulation-based training to broader applications such as AI-driven personalized learning, telemedicine education, and patient engagement interventions. The value of this research lies not only in documenting scholarly output but in highlighting strategic areas for future innovation and interdisciplinary collaboration. However, while the potential of VR is vast, its real-world implementation faces critical ethical and practical challenges that remain underexplored. Key ethical concerns include data privacy, psychological safety, informed consent in virtual environments, and equitable inclusion of diverse populations, especially those with cognitive impairments or from low-resource settings. Practical barriers such as high development and deployment costs, limited infrastructure, digital literacy gaps, and the lack of standardized evaluation frameworks hinder broader adoption. These issues call for comprehensive frameworks that integrate ethical oversight, cost-benefit analysis, and context-specific adaptability into VR educational design. Future research should therefore move beyond trend analysis to assess the pedagogical effectiveness, accessibility, and ethical viability of VR tools in real-world settings. Ultimately, this study not only charts the academic trajectory of VR in health education but also underscores the urgent need for responsible, inclusive, and evidence-informed implementation to unlock its full potential in transforming global health education systems.

As VR tools increasingly incorporate sensitive personal data—particularly in the context of patient education and simulated clinical interactions, the necessity for robust data security frameworks becomes paramount. Future VR systems must incorporate privacy-by-design principles, encrypted data storage, and adherence to regulatory frameworks such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR). Ethical compliance should also encompass formal ethical review for VR-based interventions and the establishment of standardized protocols for informed digital consent, particularly in VR environments involving vulnerable populations such as minors or patients with cognitive impairments. Additional considerations include addressing risks of psychological discomfort, cybersickness, or overexposure in immersive environments. An interdisciplinary framework involving ethicists, clinicians, and technologists is essential for the ethical integration of VR into medical education and digital health.

The integration of VR into health education promises to enhance clinical outcomes and public health initiatives. VR-based interventions improve patient engagement, knowledge retention, and behavioral changes, aiding chronic disease management and treatment adherence. A systematic review showed VR applications in patient education significantly enhanced understanding of medical conditions and treatments, boosting compliance and health outcomes (van der Linde-van den Bor et al., 2022). VR also simulates real-life scenarios for healthcare professionals, improving clinical skills and decision-making. A *Journal of Medical Internet Research* study found VR training programs significantly improved health professionals’ knowledge and skills over traditional methods (Kyaw et al., 2019). In public health, VR designs immersive experiences promoting health literacy and preventive behaviors, potentially addressing health disparities. VR’s realistic simulations are valuable for emergency preparedness training and response planning, with VR simulations training emergency responders in disaster scenarios, enhancing preparedness and response efficiency.

Recent bibliometric insights reveal a growing scholarly interest in VR/AR applications across diverse domains, particularly from 2018 to 2022, with expanding research trajectories in education, medicine, engineering, and business (Zhao et al., 2023). However, limited synthesis exists regarding how leadership and technological integration influence the adoption of these tools in educational contexts. Our findings reinforce that VR and AR not only hold cross-disciplinary relevance but also demand critical evaluation of their viability, acceptance, and strategic implementation in educational environments, especially in light of accelerated digital adoption post-COVID-19.

Aligning VR applications within digital health frameworks enhances healthcare integration. The World Health Organization (WHO) defines digital health as using information and communication technologies to improve health (Mehl et al., 2021; Organization, 2019). The U.S. Food and Drug Administration (FDA) describes digital health technologies as systems using computing platforms, connectivity, software, and sensors for healthcare (Kadakia et al., 2020; Pavlovic, 2020). Incorporating VR into digital health recognizes its role in digital therapeutics, remote monitoring, and enhancing digital literacy. VR serves as a digital therapeutic tool by delivering immersive interventions for behav-



ioral modification and symptom management, like VR-based cognitive behavioral therapy for anxiety and chronic pain. For remote monitoring, VR facilitates virtual consultations and remote rehabilitation, increasing care access for patients in remote areas. Enhancing digital literacy through VR involves providing educational experiences that improve understanding of digital health resources. By embedding VR within these domains, healthcare providers can offer more personalized care. However, integration requires addressing interoperability, user accessibility, and the digital divide to ensure equitable access.

This study offers an extensive bibliometric analysis of VR in health science education, mapping its evolution over the last two decades and providing critical insights into research productivity, collaboration networks, thematic trends, and emerging areas of inquiry. The essence of this research lies in its ability to systematically organize and interpret a large body of literature, making sense of the rapid growth and diversification of VR applications in medical education, clinical training, public health promotion, and digital therapeutics. By identifying the most active institutions, countries or regions, and authors, and clustering keywords to reveal dominant and emerging themes, this study highlights the field's shift from procedural training toward intelligent, immersive, and patient-centered educational models. The value of this analysis is multifold: it not only informs future academic and policy directions but also serves as a strategic tool for stakeholders aiming to adopt VR technologies in educational and healthcare settings. Furthermore, this research exposes critical gaps, including the limited focus on long-term outcomes, data security, ethical governance, cost-effectiveness, and equitable access—issues that must be addressed to ensure sustainable and inclusive VR integration. These findings offer a launchpad for future research, including qualitative investigations into learner experience, comparative evaluations of VR platforms, and exploration of VR's role in underserved regions. In doing so, the study contributes to a deeper understanding of how immersive technologies can reshape health education and practice and underscores the importance of evidence-based implementation to fully harness VR's transformative potential for global health and education systems.

The potential of VR in health education is vast and spans multiple disciplines, offering numerous opportunities for exploration and innovation. As technology advances, the integration of artificial intelligence, machine learning, and natural language processing will enable VR systems to become more adaptive, providing real-time, personalized feedback and support that can intelligently react to learners' actions. Future studies should also focus on the long-term effects of VR on clinical skills, patient outcomes, and professional growth, as most existing research only assesses immediate learning improvements. Another promising direction is the extension of VR applications into interprofessional education and public health sectors. For example, virtual platforms could replicate multidisciplinary team-based care, emergency response coordination, or large-scale epidemiological interventions, which are often challenging to recreate in real-world training scenarios. From a global health standpoint, making VR more accessible through affordable hardware and open-source software could help close the educational gap between wealthy and resource-limited areas, allowing for scalable and standardized medical training worldwide. Crucially, future advancements must be accompanied by the development of comprehensive ethical and regulatory guidelines to steer implementation, ensure inclusivity, and protect user data. Collaborative efforts among academia, industry, and policy sectors will be crucial to fully realize VR's potential and integrate it sustainably into health education systems.

Conclusions and Implications

This comprehensive bibliometric analysis examined two decades of research on VR in health science education, revealing a significant increase in scholarly output and a shift from procedural simulation toward AI-integrated, immersive, and patient-centered applications. By mapping publication trends, identifying key contributors, and analyzing thematic evolution, the study provides a valuable macro-level overview of the field's development and highlights areas of scholarly influence and collaboration. The findings underscore VR's expanding role across domains such as surgical training, patient education, health promotion, and digital therapeutics, offering a strategic foundation for future academic inquiry and institutional investment. However, as a bibliometric study, it does not assess the methodological rigor or effectiveness of individual interventions—an important limitation acknowledged and suggested for future systematic reviews. Moreover, the study brings attention to critical yet underexplored issues, including ethical concerns related to data privacy, informed consent, and learner safety, as well as practical barriers such as high costs, technological infrastructure, and digital literacy disparities. Addressing these challenges is essential for equitable and responsible implementation. Moving forward, interdisciplinary research should assess long-term educational and clinical impacts of VR, develop ethical frameworks, and explore scalable solutions to bridge the digital divide. Ultimately, this study affirms VR's transformative potential in health education while emphasizing the need for thoughtful, inclusive, and evidence-informed integration to maximize its global benefit.



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