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Past, Present, and Future of Virtual Reality in Healthcare Education and Training: Bibliometric Analysis

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Abstract

Background: As an important tool to help students and technicians learn from afar in the era of COVID-19, the literature on the application of VR technology in the field of education is increasing rapidly.

Objective: The aim of this analysis is to provide a dynamic and longitudinal bibliometric analysis of the application of VR technology to the educational field of publication.

Methods: Web of Science was searched for all existing and highly cited research papers on the application of English VR in education as of November 2022. Based on bibliometric indicators, a search strategy was developed to screen titles for eligibility, using abstracts and full texts when needed. Citespace software was used to calculate the growth rate of publications, characteristics of research activities, publication patterns and hot research trends.

Results: The search identified 28,817 hits, of which 795 publications were included in the analysis. The output of publications increased. Since 1995, the average annual growth rate has been 13.01%, but since 2015, the growth rate of research papers has increased significantly to 58.49%. By 2022. VR in the field of Education is mainly used in surgery, operating room, medical education, and learning curve. Virtual reality, Augmented reality, and Haptic feedback have the greatest impact on educational applications. Simulation training, augmented reality, and medical education will continue to be hot research topics until 2022.

Conclusion: This analysis provides a comprehensive overview of the research on the application of VR technology in the field of education, which will help researchers, educators, and students better understand the development of VR technology and its possible practical implications. In the future, VR technology research should be more applied to the field of education and explore the possibility of VR technology innovation in the field of education and teaching methods.

Key words: Virtual Reality; Education; Bibliometric Analysis; Augmented Reality

Introduction

Virtual reality (VR) has made significant strides in the medical and healthcare professions, transforming the way practitioners are trained and educated [1,2]. Particularly, the outbreak of COVID-19 has provided an impetus for the broader and more diverse application of VR technology in healthcare training [3,4]. As traditional face-to-face training became limited due to social distancing measures and the need to minimize potential virus exposure, VR emerged as a viable alternative. This technology enabled healthcare professionals and students to continue their education and skill development remotely, ensuring uninterrupted progress and maintaining the quality of healthcare services during the pandemic [5–7].

In medical training, VR plays a crucial role in the simulation of surgeries and medical procedures. Medical students can practice complex operations in a controlled, risk-free environment without causing harm to real patients [10-12]. They can repeat procedures as often as needed to hone their skills, thereby increasing their proficiency and confidence. The use of VR has also expanded to areas such as anesthesia, emergency medicine, and diagnostics, providing a wide range of training opportunities for medical professionals [12–16]. Furthermore, VR has been instrumental in fostering patient communication and empathy. By simulating realistic patient interactions, healthcare providers can practice their bedside manner and learn to navigate difficult conversations, such as delivering bad news or discussing sensitive topics [17–19]. This type of training is essential for enhancing interpersonal skills, which are critical in building trust and rapport with patients. Moreover, VR has been employed in the rehabilitation and mental health sectors. Therapists use VR simulations to treat patients with conditions such as PTSD, anxiety, and phobias, providing exposure therapy in a controlled and safe setting [20]. Similarly, physical therapists can utilize VR to create customized rehabilitation programs that cater to individual patients' needs, making recovery more engaging and motivating [20, 21].

VR offers numerous benefits for education and training, including immersive learning experiences, safe and controlled environments

for practice, customizable and adaptive content, and increased accessibility for remote learners [1, 2, 8, 9]. However, concerns persist, such as high costs, technical limitations, motion sickness, equity and accessibility issues, and potential distractions [8]. To fully harness VR's potential, it is essential to address these challenges, ensuring that its advantages are realized while minimizing drawbacks and making it accessible to a diverse range of learners. As a result, there is a growing body of research interest surrounding VR in healthcare education, reflecting its importance and potential impact on the future of learning.

A bibliometric analysis is needed to provide a comprehensive understanding of the emerging trends, the knowledge structure, and the key research areas within this domain, to guide future studies and facilitate interdisciplinary collaboration. The purpose of this bibliometric analysis is to examine the studies of VR in healthcare education and training by investigating the growth rate of publications, characteristics of research activities, publication patterns, and research hotspot tendencies. This analysis aims to provide insights into the development and progression of VR applications in healthcare education and training, as well as identifying emerging trends and potential areas for future research. In this study, healthcare-related VR education and training refer to the use of VR technology to enhance the acquisition of knowledge, skills, and competencies in healthcare among professionals, students, and patients. This study provided an overall view of VR research on healthcare related education and training to help researchers, patients and providers to identify knowledge gaps, potential collaborations, and future research directions, fostering informed decision-making and resource allocation.

Method

Search Strategy

Utilizing the Web of Science (WoS) Core Collection by Clarivate PLC, a comprehensive search of current and influential publications in the field of education-focused VR technology was performed. The selected databases within Web of Science for this search were the Science Citation Index (SCI) and the Social Science Citation (SSCI). Following this, we carried out a series of analyses including chronological and geographical assessments, word co-occurrence evaluations, investigations into co-authorship patterns, and cross-national collaboration examinations. Search keywords related to (1) training programs applied virtual reality technologies and (2) health care and medicine were identified from a preliminary literature review and consultation with a librarian.

We entered the retrieval search string by combing keywords with Boolean operators: ((TI=(virtual reality)) OR TI=(virtual reality intervention)) OR TI=(virtual reality simulation)) OR TI=(virtual reality game)) OR (TI=(virtual reality video))AND ((TS=(health) OR TS=(healthcare) OR TS=(medicine) OR TS=(mental health) OR TS=(behavior health)) AND ((TS=(coaching)) OR TS=(training)) OR TS=(education)) OR TS=(teaching)), Indexes=SCI-EXPANDED, SSCI Timespan=All years. The final search was conducted on November 15, 2022, in the WoS. A total of 28,817 papers that were registered between January 1995 and November 2022 in the SCI Expanded and the SSCI Index databases from the Web of Science. This process was illustrated in graph 1.

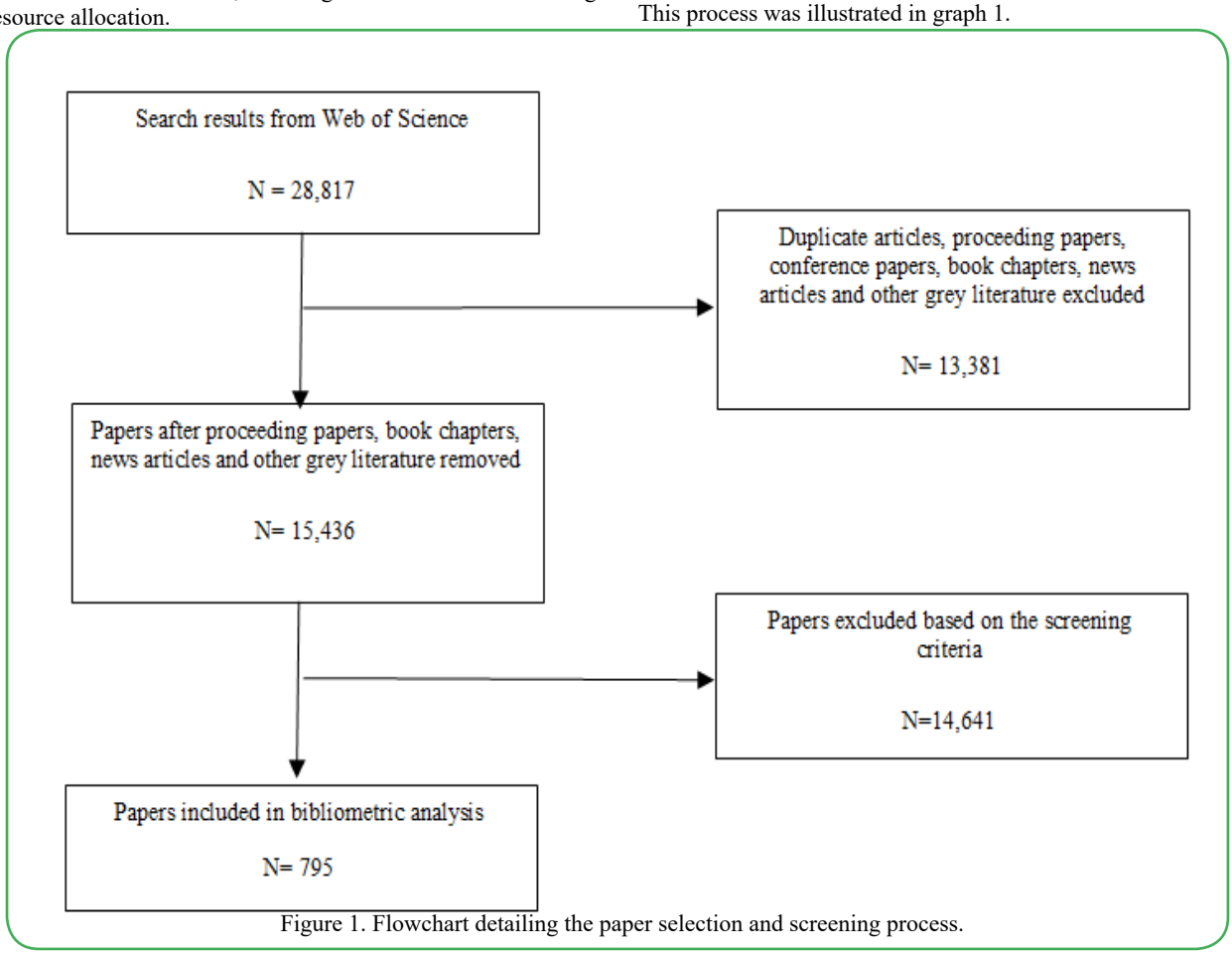

Figure 1. Flowchart detailing the paper selection and screening process.

Alt of figure 1: This picture is a flow chart of our literature screening process, showing the amount of literature screened at each step and the number of documents retained at the end.

Screening Strategy

All journal articles that employed VR technologies for training and educational purposes were included for screening. The articles selected for examination were limited to those that (1) were authored in English, (2) concentrated on educational or training purposes, and (3) incorporated VR technologies. Given the fast-paced and cutting-edge nature of VR technology research, the analysis included papers published in peer-reviewed journals and early access articles. The selection criteria did not limit articles solely to those aimed at medical or healthcare professionals but also encompassed those pertaining to

patient education. To ensure research quality, grey literature was excluded from the analysis, thus omitting conference papers, book chapters, and poster presentations. The screening based on the selection criteria resulted in 795 articles using VR technology for training that were included in this analysis.

Bibliometric analysis

Bibliometric analysis is a quantitative research method used to evaluate and assess the impact, trends, and patterns within a specific field of scientific publications. In this analysis, we computed the growth rate of publications, characteristics of research activities (topics and keywords), publication patterns (countries and journals), and research hotspot tendencies (citation bursts and cluster analysis) with using. Citation bursting and clustering analysis was developed by HistCite, a software package for bibliometric analysis and information visualization, which measures the representativeness of selected words to the text content by based on intersectionality, closeness, degree, eigenvectors, PageRank (Google LLC), eccentricity, coreness, clustering coefficients and term frequency scores [22].

Result

Growth Rate of Publications

The annual growth of the publish trend of VR applications in education was plotted in figure 2. The average growth rate of the publishing volume of articles related to VR applications in education was 13.01% (Number of publications issued in that year/Number of publications issued in last year*100%) from 1994 to 2022, 6.4% from 1995 to 2010, and 16.08% from 2011 to 2015. From 2015 to 2021, the growth rate was 51.90%. The number of publications increased steeply after 2015, accounting for 58.49% of all included papers.

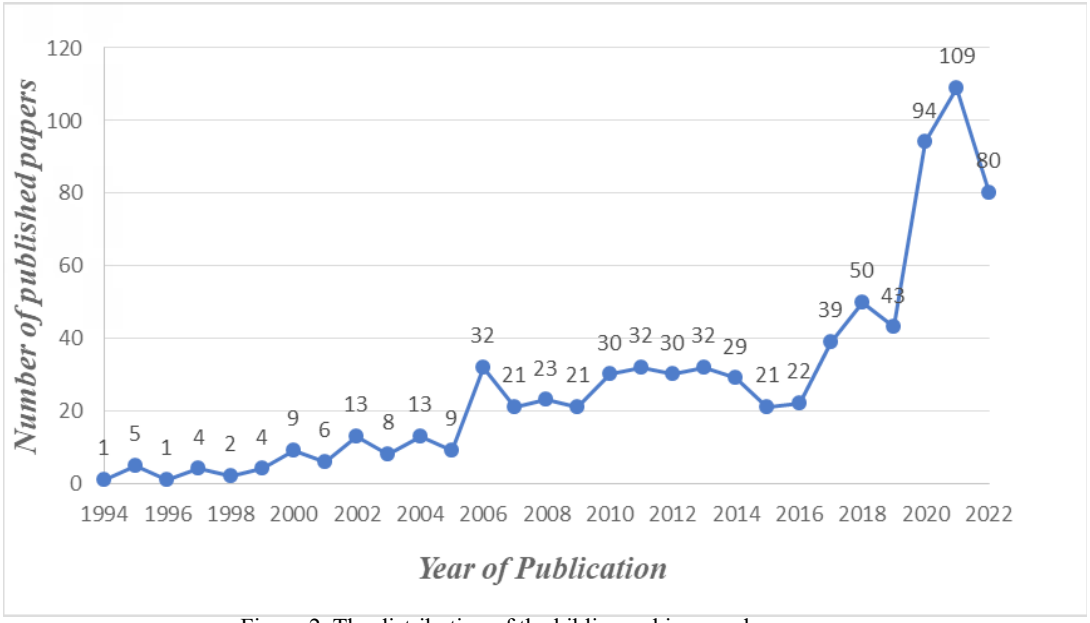

Figure 2. The distribution of the bibliographic records per year.

Alt of Figure 2: This is a line chart showing the change in the number of articles published each year. According to the trend of the line, we can see that the number of articles published on the application of VR in the field of education has increased year by year.

Publication Patterns

Overall, 83.91% (657/783) of the total articles came from 10 countries, as shown in Table 1. The United States contributed 30.52% of the publication. UK was the next leading country, followed by Germany (7.92%). These studies have been published in 464 different journals. As demonstrated in Table 2, Medical Education Online published the most articles, accounting for 22.35%; Surgical Endoscopy and other Interventional Techniques accounted for 7.15%, and Journal of Surgical Education accounted for 2.68% (21/783).

Countries	Ranking based on total output	Output[a],(n%)	Ranking based on citations	Citations[b],(n%)
USA	1	239(36.40)	1	8963(40.95)
England	2	97(14.80)	2	3788(17.31)
Germany	3	62(9.44)	5	1189(5.43)
Canada	4	58(8.83)	4	2080(9.50)
China	5	49(7.46)	7	733(3.35)
Australia	6	41(6.24)	6	1095(5.03)
Denmark	7	38(5.78)	3	2762(12.62)
France	8	25(3.81)	8	507(2.32)
Japan	9	25(3.81)	10	348(1.59)
Italy	10	23(3.51)	9	422(1.93)

[a]N=657
[b]n=21,887

Table 1. The distribution of the bibliographic records by top 10 (by quantity) countries.

Alt of Table 1: This table shows the top 10 countries that have published articles on the use of VR in education, and we can see which countries have done the most research in this field.

Journals	Ranking based on total output	Output[a],(n%)	Ranking based on citations	Citations[b],(n%)
Medical Education Online	1	175(57.00)	7	104(6.38)
Surgical Endoscopy and other Interventional Techniques	2	56(18.24)	1	325(19.93)
Journal of Surgical Education	3	21(6.84)	4	157(9.63)
Journal of Endourology	4	14(4.56)	8	98(6.01)
Journal of Urology	5	12(3.91)	10	40(2.45)
American Journal of Surgery	6	11(3.58)	3	277(16.98)
Annals of Surgery	7	8(2.61)	2	290(17.78)
Journal of The American College of Surgeons	8	4(1.30)	5	143(8.77)
World Journal of Surgery	9	3(0.98)	6	110(6.74)
Medical Teacher	10	3(0.98)	9	87(5.33)
[a]N=307 [b]N=1631				

Table 2. The distribution of the bibliographic records by top 10 (by quantity) journals.

Alt of Table 2: This table shows the top 10 journals that have published articles on the application of VR in the field of education. By using this table, we can see which journals have focused on this field and summarize the current research.

Characteristics of Research Activities

WOS subject categories were employed to indicate the research domains of included papers, as demonstrated in Table 3. Health science service, Computer Science Artificial Intelligence, and Public Environmental Occupational Health accounted for the top three domains and were the main subjects to study the application of VR in education, accounting for 8.56%, 7.54%, and 7.02%, respectively.

Research Domain	Ranking based on total output	Output[a],(n%)	Ranking based on citations	Citations[b],(n%)
Health Care Science Service	1	93(12.41)	1	1293(21.66)
Computer Science Artificial Intelligence	2	91(12.15)	6	517(8.66)
Public Environmental Occupational Health	3	78(10.41)	2	1007(16.87)
Computer Science Interdisciplinary Applications	4	77(10.28)	4	707(11.84)
Engineering Electrical Electronic	4	77(10.28)	8	351(5.88)
Education Educational Research	6	75(10.01)	5	545(9.13)
Computer Science Cybernetics	7	66(8.81)	9	344(5.76)
Computer				
Science Information Systems	7	66(8.81)	7	404(6.77)
Computer Science Theory Methods	9	64(8.54)	10	194(3.25)
Medical Informatics	10	62(8.28)	3	951(15.93)
[a]N=749 [b]N=5969				

Table 3. The distribution of the bibliographic records by top 10 (by quantity) research domains.

Alt of Table 3: This table is the top ten research categories on the application of VR in the field of education. Through this table, we can understand the main application aspects of VR in the field of education at present, and help us understand the development direction of the future research field.

Keywords were the core word extractions provided by researchers in the studies. Table 4 showed information about the frequency and centrality of keywords. The top five VR-related technologies used in education were virtual reality, augmented reality, computer simulation, haptic feedback, and virtual reality simulation. The top5 applications of VR in education were surgery, operating room, medical education, learning curve, and surgical simulation.

Category	Frequency (as identified by title, keywords, or manuscript)	Centrality
Technology		
Virtual reality*	446	0.22
Augmented reality	37	0.05
Haptic feedback	21	0.03
Application of VR In Education		
Surgery*	198	0.09
Operating room	74	0.10
Medical Education	70	0.10
Learning curve	52	0.06
Virtual reality includes computer simulation and virtual reality simulation.* Surgery includes surgical simulation and robotic surgery.*		

Table 4. The top keywords of virtual reality in education publications.

Alt of Table 4: This table is the key word for the application of VR in the field of education at present. Through the table, we can understand the current research focus in this field and provide the direction for follow-up research.

Research Hotspot Tendencies

The software Citespace was used to analyze the keyword clustering. As shown in the Figure 3, the selected studies were clustered into 14 clusters, and the Q value after clustering was 0.5476, greater than 0.3, indicating significant clustering results. Cluster 0(Environment) is the largest cluster and cluster13 (Tactile device) is the smallest cluster. Each cluster is generated based on the number of keywords under the study domain, not the frequency of keywords.

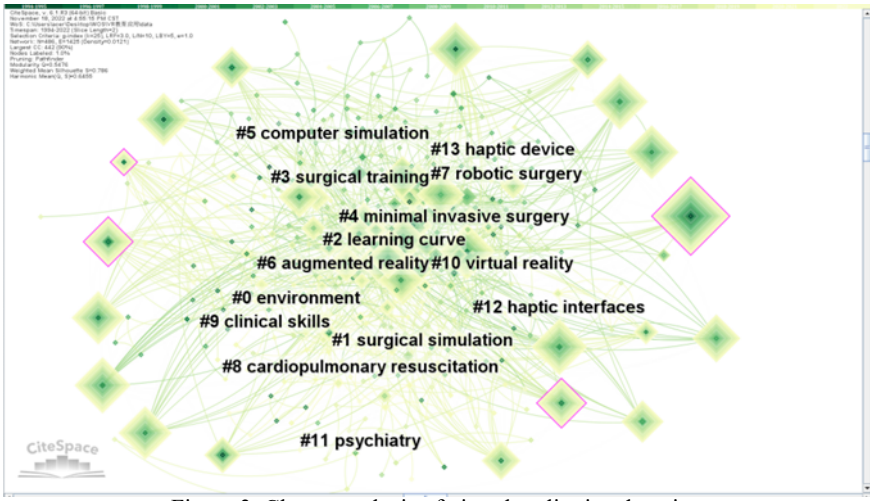

Figure 3. Cluster analysis of virtual reality in education

Alt of Figure 3: This is a cluster graph showing the research distribution of the current research field. Through the picture, we can know the current research focus and direction of the field, which can help us quickly understand the research status and find the next research direction.

We presented the major milestones in the development of VR applications in education by analyzing the list of keywords that had strong citation bursts between 1994 and 2022, as seen in Figure 4. The first milestone word was the environment, which first appeared in 1998 and continued to be studied until 2003. The next words to pop out were fog virtual reality, computer simulation, learning curve has been hot research from 2000 to 2013; The operating room milestone keyword first appeared in 2004, introducing VR technology in education into the medical field. The most recent milestone was pharmaceutical education, which first appeared in 2020 and continued to be a hot topic of research.

Discussion

By using bibliometric data, this study analyzed scientific publications of VR technologies employed in health care–related training and education. Growth rate of publications, characteristics of research activities, publication patterns, and research hotspot tendencies were analyzed and discussed below.

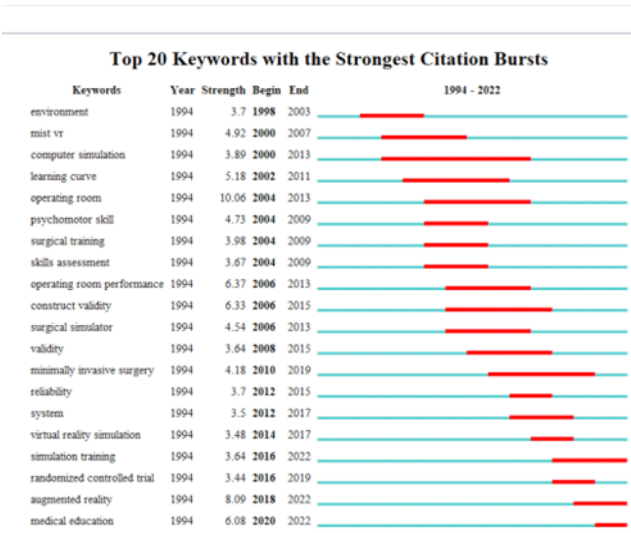

Figure 4. Top 20 keywords with the strongest citation bursts.

Alt of Figure 4: This is a picture showing the top 20 breakout words, through which we can see how the focus of research in this field has changed since then, as well as the ongoing research hot spots.

Growth Rate of Publications

There is a significant increase in the publication of articles related to VR applications in education over the years, particularly after 2015. The early years, between 1994 and 2010, show a modest growth rate of 6.4%, indicating that VR applications in education were still in their infancy and had not yet gained widespread recognition. However, from 2011 to 2015, the growth rate increased to 16.08%, suggesting that the potential of VR in educational settings started to gain traction among researchers and practitioners. The average growth rate of publishing volume has seen a consistent rise, with the most significant growth occurring between 2019 and 2021 at 51.90%. This increase highlights the growing importance and relevance of VR applications within the educational sphere. Increased awareness of the benefits of VR in enhancing learning experiences, such as increased engagement, better retention, and immersive learning environments, has contributed to a surge in interest and research in the field.

The substantial growth after 2019 to date other than attributed to advancements in VR technology in education, the breakout of COVID-19 is a key. The global crisis caused by the pandemic has necessitated a shift towards remote learning and working, prompting an urgent need for alternative and innovative methods to facilitate education and training 3. This has led to an accelerated development and adoption of VR technologies, particularly in healthcare education and training. The need for effective, engaging, and immersive training environments that could be accessed remotely became crucial to maintain the quality of education and ensure the development of essential skills [4, 7]. VR technology has proven to be a valuable tool in this regard, allowing for safe, efficient, and realistic training experiences without the constraints of physical location [5]. Our analysis suggested that the increase in publications on the use of VR in education since 2020 coincided with the explosion of COVID-19 and the resulting shift to distance learning and training. This pandemic may have accelerated the development and adoption of VR technologies, particularly in healthcare education and training.

Characteristics of Research Activities

Our analysis provided valuable insights into the research domains where VR applications in education have been most extensively studied. The results suggested that the application of VR in education is particularly relevant and beneficial in surgery training and surgical simulations, likely due to the unique requirements and challenges that they present. From surgical simulations to patient communication and continuing education, VR provides immersive and interactive experiences that enhance learning, skill development, and patient care [11, 15]. This further emphasizes the significant role of VR in medical students training, with a particular focus on surgical procedures and medical practice. The widespread use of VR in this context highlights its potential to revolutionize traditional teaching methods, enhance skill acquisition, and ultimately improve patient outcomes.

Gratifyingly, we found that the technology of augmented reality (AR) is starting to emerge in applications related to healthcare training and education. The integration of AR in healthcare education has facilitated the expansion and development of VR applications in this field. VR focuses on creating fully immersive virtual environments, while AR overlays digital information onto the physical world to enhance the user's perception of their surroundings. The combination of these technologies allows for a more comprehensive and versatile learning experience that meets a variety of educational needs and goals [23].

Publication Patterns

The distribution of research on VR applications in healthcare education indicated that majority of VR-related medical education studies were from developed countries, with the United States as the leading contributor accounting for 30.52% of the publications. This geographical distribution suggests that these countries have been at the forefront of research and development in VR applications for education, likely due to their advanced technological infrastructure, access to funding, and a supportive research environment.

A total of 464 different journals have published studies on VR related healthcare training and education, reflecting the widespread interest and diverse perspectives on this topic. A large number of peer-review journals that published VR-related education articles further emphasizes the importance of VR technology in healthcare education and training, with a focus on surgical procedures and medical practice. The publication interest in these prominent journals will undoubtedly further promote the exploration and application of

VR technology in the field of education and training, fostering interdisciplinary collaboration and innovation.

Research Hotspot Tendencies

The analysis of keyword clustering and citation bursts provides valuable insights into the key themes and areas may be focused in the future in the development of VR applications in healthcare related education. The keyword clustering map demonstrate the diverse range of topics and technologies being explored in this field. This diversity suggests that VR technology has the potential to impact a wide variety of educational topics in healthcare and create innovative solutions tailored to specific learning needs.

By analyzing the list of keywords with strong citation bursts between 1994 and 2022, we can identify major milestones in the development of VR applications in healthcare education. The first milestone word, "environment," which emerged in 1998 and continued to be studied until 2003, highlights the initial focus on creating immersive virtual environments for educational purposes. From 2000 to 2013, there is a growing research interest in understanding the effectiveness and potential of VR technology to enhance learning experiences. The appearance of the milestone keyword "operating room" in 2004 signals a shift towards incorporating VR technology in medical education, particularly in the context of surgical training. This trend aligns with the previously discussed prominence of healthcare-focused journals in publishing VR-related research, underscoring the significant potential of VR technology to transform medical education and improve patient outcomes. The most recent milestone, "simulation training" and "augmented reality," which emerged in 2020 and continues to be a hot topic of research, highlights the ongoing expansion of new VR technologies applied in healthcare education and training. Researchers and practitioners are increasingly recognizing the value of VR technology and continue exploring more advanced VR technologies in paving the way for further challenges and requirements of various healthcare educational needs.

Limitations

It is important to acknowledge the limitations of this review. Firstly, while we are confident that the WoS database offers a comprehensive range of VR publications for this bibliometric analysis, it is advisable for future studies to consider including other databases such as PubMed to discover additional relevant papers. Secondly, the search terms employed in relation to VR-based healthcare education may have been broad (ex., medical education), possibly leading to an incomplete representation of studies covering all specific subjects or pedagogical approaches involving VR applications across various educational fields, such as VR-based training in dementia care. Last but not the least, our study excluded gray literature (e.g., books) and non-English publications, potentially excluded studies conducted in different formats, languages, and regions. Future research can expand the search parameters to delve deeper into relevant literature and further enrich the understanding of VR-based healthcare training and education.

Conclusion

In conclusion, the continuous and rapid growth trend of publications related to VR-based healthcare training and education demonstrates a strong interest in this field and an acknowledgment of its potential to transform the educational landscape. The emergence of new technologies, such as Augmented Reality, indicates that VR has the potential to continue changing traditional teaching methods, enhancing learning experiences, and promoting interdisciplinary collaboration in the healthcare field, especially in areas like surgical training and scenario simulations. With the rapid development of VR technology and the increasing demand for personalized, immersive learning experiences, the growth of VR applications in education is expected to continue rising, further expanding the possibilities for innovative teaching and learning methods.

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