Research and Application of Virtual Reality Techniques in the Field of Education: A Bibliometric Analysis Based on Web of Science via VOSviewer

Long Liang [1], Zhirong Yang [2, *]

[1] Research Management and Social Services Office of Zhuhai Campus, Jinan University, Zhuhai, Guangdong, 519070, China
[2] Library of Zhuhai Campus, Jinan University, Zhuhai, Guangdong, 519070, China
*Corresponding author.

E-mail: lianglong@jnu.edu.cn (Long Liang);
yangzhirong@jnu.edu.cn (Zhirong Yang)

Abstract. Virtual reality technology in education is a vibrant research field. This study employs VOSviewer software to conduct a bibliometric analysis of 1595 relevant publications in the Web of Science database. By analyzing the existing literature, this study examines the quantity of publications, research countries, significant institutions, and primary authors. The bibliometric analysis reveals that *Computers & Education* is the most influential source of literature, with influential publications primarily focusing on computer education, educational technology, as well as learning and educational psychology. The research highlights encompass simulation, interactive learning environments, augmented reality, and medical education. Finally, this paper presents pertinent recommendations for further research on virtual reality technology in education.

Keywords: Virtual Reality; Augmented Reality; Simulation; Interactive Learning Environment; Medical Education

1 Introduction

Virtual reality technology is a computer generated technology that simulates the real environment. Users are placed in the virtual world through perceptual devices (such as Head-mounted display and handles) and computer graphics technology. In the field of education, it can create interactive virtual environments that provide learners with multiple sensory inputs, including visual, sound, and tactile feedback [1-3]. Therefore, this technology achieves an immersive and authentic learning experience, which has significant advantages compared to traditional classroom environments. Virtual reality has a profound impact on the field of education, as it can significantly improve learning outcomes, promote practical participation, improve the overall educational experience, and promote cross-cultural communication. At present, virtual reality technology has been

G. Guan et al. (eds.), *Proceedings of the 2023 3rd International Conference on Education, Information Management and Service Science (EIMSS 2023)*, Atlantis Highlights in Computer Sciences 16,
https://doi.org/10.2991/978-94-6463-264-4_75

widely used in many educational fields, including medical education, pharmaceutical education, Chemistry education and engineering education.

Amidst the dynamic and thriving research landscape of virtual reality technology in education, a comprehensive and objective understanding of research progress and development directions is paramount. Although the field has seen remarkable growth, there remains a critical need for an objective evaluation and visual representation of the collective scientific knowledge through bibliometric analysis. Presently, a lack of such evaluation poses challenges in effectively gauging the field's advancements and identifying potential research gaps.

To address this issue, the present paper utilizes VOSviewer software and draws data from Web of Science to perform an extensive bibliometric analysis of research literature pertaining to virtual reality technology in education. By employing this rigorous methodology, our analysis seeks to shed light on the research trends, influential sources, and key contributors within this dynamic domain. Moreover, it aims to provide valuable insights into the significance and potential applications of virtual reality technology in enhancing teaching quality and student learning experiences.

2 Methodology

In order to ensure the authority of the research data, this study utilized the Web of Science Core Collection as the data source, extracting data from three databases: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI). The indexing date range was from January 1, 2000, to June 11, 2023. Additionally, to ensure the relevance of the retrieved literature to this study, the search query was set as "TS= ("virtual reality") AND WC=(education)". Ultimately, a total of 1595 relevant publications were retrieved as the data source for this study.

Bibliometric analysis is a quantitative method that utilizes statistical and metrological techniques to analyze scientific literature. In this study, VOSviewer_1.6.19 was selected as the bibliometric analysis tool to analyze publication characteristics, co-citation patterns, and keyword characteristics of the full records and referenced literature data from 1595 relevant publications. This analysis aims to assess the quality, impact, and research trends of scientific literature and provide insights for future research on virtual reality technology in education.

3 Results

3.1 Publications analysis

Publication distribution analysis.

Table 1. Statistic of publication year

Year	Count	Percentage	Year	Count	Percentage
2000	11	0.69	2012	43	2.696

2001	8	0.502	2013	50	3.135
2002	9	0.564	2014	50	3.135
2003	13	0.815	2015	62	3.887
2004	7	0.439	2016	67	4.201
2005	12	0.752	2017	66	4.138
2006	14	0.878	2018	86	5.392
2007	17	1.066	2019	125	7.837
2008	32	2.006	2020	228	14.295
2009	33	2.069	2021	240	15.047
2010	38	2.382	2022	228	14.295
2011	49	3.072	2023	107	6.708

Table 1 lists the publication year data of 1595 research articles retrieved in this article. Between 2000 and 2008, the number of literature per year was relatively small, with an average of less than 50 articles per year. With the passage of time, the number of research literature has been increasing year by year since 2009, especially rapidly after 2010. In the decade after 2010, the number of research literature showed a significant growth trend. Especially in 2020, 2021, and 2022, the number of literature reached 228, 240, and 228, more than twice the number of previous years. The data from 2023 shows that as of now, 107 articles have been published, indicating that research in this field is still ongoing. In summary, the research on virtual reality technology in the field of education has shown a rapid growth trend in the past twenty years, reflecting the importance of the application and research of virtual reality technology in the field of education for the academic community and educational practice.

National analysis.

Since 2000, a total of 77 countries/regions worldwide have been engaged in research on virtual reality technology in the field of education. Fig. 1 illustrates the collaboration network of countries/regions created using VOSviewer. In terms of publication output, the United States, China, and the United Kingdom have shown higher research productivity in this field. In terms of collaboration relationships, the United States has close ties with countries such as the United Kingdom and Canada, indicating frequent collaborations in research projects, knowledge exchange, and scientific publications.

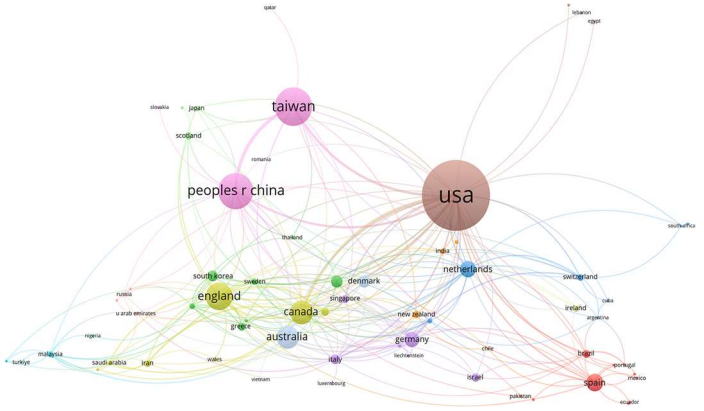

Fig. 1. Cooperation network relationship among countries/regions

Most productive institutions analysis.

Since 2000, a total of 1617 institutions worldwide have been involved in research on virtual reality technology in the field of education. Table 2 presents the research output of the top 8 institutions based on the Total Publications indicator and the top 8 institutions based on the Total Citations indicator. Among the highly productive institutions, "natl taiwan normal univ" ranks first with the highest number of publications (TP=45), while "florida state univ" ranks first in terms of the highest number of citations (TC=1943). When the TC/TP ratio is used as an indicator to measure research quality, "florida state univ," "texas a&m univ," and "natl changhua univ educ" have ratios as high as 114.29, 108.58, and 99, respectively, reflecting the high quality and global impact of the research work conducted by these three institutions.

Table 2. Most productive institutions

According to TP				**According to TC**			
Name	TP	TC	TC/TP	Name	TP	TC	TC/TP
natl taiwan normal univ	45	1822	40.48	florida state univ	17	1943	114.29
natl taiwan univ sci & technol	31	1711	55.19	natl taiwan normal univ	45	1822	40.48
univ copenhagen	30	1797	59.9	univ copenhagen	30	1797	59.9
mcgill univ	19	661	34.78	natl taiwan univ sci & technol	31	1711	55.19
chinese univ hong kong	18	556	30.88	texas a&m univ	12	1303	108.58
univ toronto	18	874	48.55	natl changhua univ educ	11	1089	99
florida state univ	17	1943	114.29	univ toronto	18	874	48.55
mcmaster univ	15	706	47.06	univ british columbia	11	782	71.09

Leading authors analysis.

Since 2000, a total of 5430 authors worldwide have conducted research on virtual reality technology in the field of education. Table 3 presents the research output of the top 10 authors based on the avg. norm. citations indicator. In terms of average normalized citation count, "Mayer, Richard E." stands out as the most prominent scholar. With a total of 6 publications, their citations amount to 694, resulting in an average citation count of 115.67 per publication. This indicates that their research output holds significant influence within the field.

Table 3. Most productive institutions

Author	**No.of documents**	**Total citations**	**Norm. citations**	**Avg. pub. year**	**Avg. citations**
mayer, richard e.	6	694	26.47	2019.83	115.67
makransky, guido	20	1205	51.10	2020.7	60.25
baceviciute, sarune	3	51	6.40	2021.66	17
jong, morris siu-yung	12	403	20.64	2020.75	33.58

hwang, gwo-jen	19	424	29.35	2021.63	22.31
tsai, chin-chung	9	403	13.46	2019.55	44.77
cheng, kun-hung	8	212	10.90	2020.62	26.5
klingenberg, sara	6	126	5.91	2021.33	21
wilson, timothy d.	10	342	8.64	2015	34.2
ke, fengfeng	14	274	10.57	2018.28	19.57

3.2 Co-citation analysis

Cited sources co-citation analysis.

Fig. 2 presents the co-citation analysis mapping of cited sources, created using VOSviewer. Among the 19,797 cited sources in the dataset, this study focuses on the 30 sources that have been cited more than 240 times. The Fig. 2 illustrates that the most influential sources are primarily concentrated within three clusters.

Fig. 2 depicts the clustering of cited sources co-citation analysis, created using VOSviewer. The red region represents the first cluster, which focuses on the application of virtual reality technology in education and research related to human-computer interaction. Among these sources, "Computers & Education" has the highest citation frequency and total citation strength among all the cited sources in this study. Additionally, "*Learning and Instruction*" and "*Journal of Chemical Education*" also exhibit high citation frequency and total citation strength.

The blue region in Fig. 2 represents the second cluster, which emphasizes the application of virtual reality technology in interactive learning and language learning within educational environments. This cluster includes journals such as "*Journal of Computer Assisted Learning*," and "*Computer Assisted Language Learning*."

The green region in Fig. 2 represents the third cluster, which focuses on the application of virtual reality technology in medical education and surgical fields. Journals such as "*Anatomical Sciences Education*," "*Surgical Endoscopy*," and "*Academic Medicine*" are included in this cluster.

In summary, the most influential cited sources primarily originate from journals in the fields of education, language learning, and medicine. These sources have made valuable contributions to the research and application of virtual reality technology and are widely cited within the academic community.

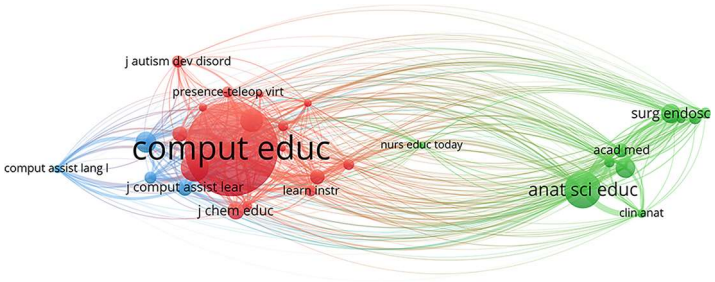

Fig. 2. The mapping of cited sources co-citation analysis

Cited references co-citation analysis.

Fig. 3 presents the mapping of cited references co-citation analysis, created using VOSviewer software. Among the 52,131 references in the dataset, 15 references meet the criterion of having a citation frequency exceeding 60. The Fig. 3 demonstrates that the most influential references are concentrated within two clusters.

Cluster 1, represented by the red region in Fig. 3, consists of highly cited references. "Merchant, Z. (2014) in Computers & Education" and "Jensen, L. (2018) in Educational Information Technology" are the most frequently cited and have the highest total link strength. These references primarily focus on the applications and research of virtual reality in computer education and educational technology, highlighting the significance of virtual reality in educational technology research.

Cluster 2, represented by the green region in Fig. 3, comprises highly cited references. "Makransky, G. (2019) in Learning and Instruction" and "Parong, J. (2018) in Journal of Educational Psychology" are the most frequently cited and have the highest total link strength. These references primarily explore the applications of virtual reality in learning and educational psychology, covering research on cognitive processes, learning outcomes, and motivation. This underscores the importance of Virtual Reality in computer-assisted learning.

In summary, the analysis of these highly cited references and the total link strength data reveals that the most influential literature revolves around computer education, educational technology, learning, and educational psychology. These references have played a significant role in the development and application of virtual reality, providing theoretical and practical guidance for researchers.

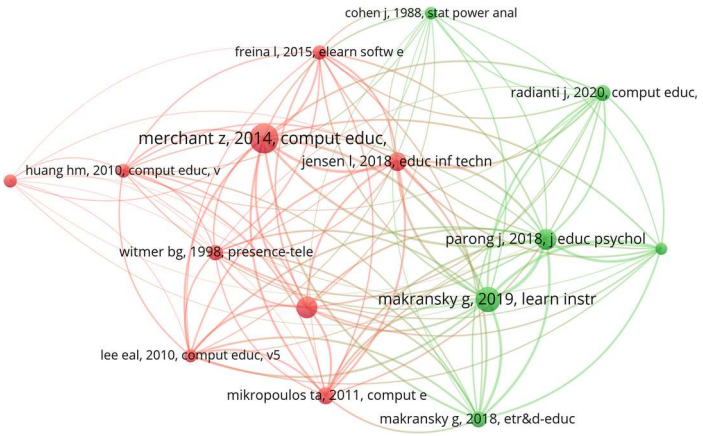

Fig. 3. The mapping of cited references co-citation analysis

3.3 Most common keywords analysis

In this study, author keywords were subjected to co-occurrence analysis using VOSviewer. Prior to the analysis, term merging was performed in VOSviewer to consolidate similar expressions. For example, terms such as "vr," "virtual-reality," and

"virtual reality (vr)" were unified as "virtual reality." Subsequently, from a total of 3069 keywords in the dataset, 228 author keywords met the criterion of having a co-occurrence frequency exceeding 5. A keyword co-occurrence analysis diagram, as depicted in Fig. 4, was then generated.

Based on Fig. 4, the top 5 most common keywords were selected and ranked according to the "Total link strength" metric in VOSviewer, as presented in Table 4.

Fig. 4 and Table 4 indicate the results of the high-frequency author keyword co-occurrence analysis based on VOSviewer. Excluding "virtual reality" itself, the research hotspots in virtual reality technology in education are primarily focused on "simulation," "interactive learning environment," "augmented reality," and "medical education."

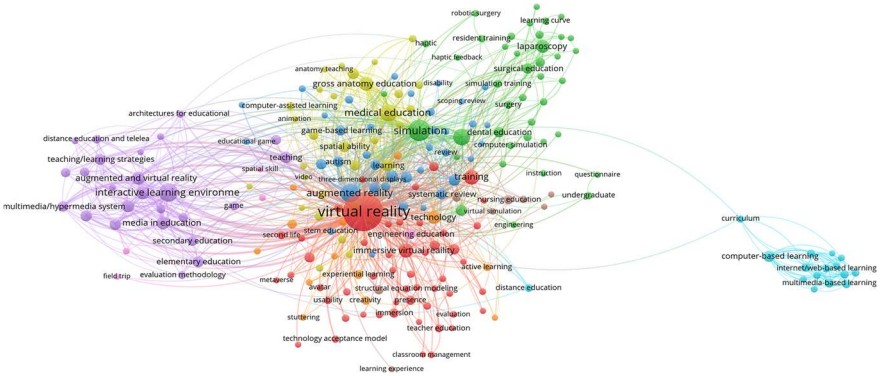

Fig. 4. The mapping of cited references co-citation analysis

Table 4. Most productive institutions

Rank	Keyword	Occurrences	Total link strength
1	virtual reality	780	1474
2	simulation	153	382
3	interactive learning environment	100	311
4	augmented reality	104	281
5	medical education	80	243

Research related to simulation.

Simulation refers to the method of using computer-based models to mimic and replicate real-world scenarios and processes. It involves creating virtual environments and objects that allow users to interact and experience them in an immersive manner. From medical training [4] to aviation maintenance training [5] and even psychological diagnosis and therapy [6], virtual reality simulation technology plays a crucial role across various fields. It provides practical experiences, enhances learning outcomes, and improves skill levels.

Research related to interactive learning environment.

Interactive learning environments refer to learning environments where learners actively participate, interact, and engage in real-time communication with the learning content using computer technology and interactive tools [7]. These environments utilize technologies such as virtual reality, augmented reality, and gamification to provide learners with opportunities for interactive engagement with real-life contexts, thereby enhancing learning outcomes, developing practical skills, and stimulating learning interest [8].

Research related to augmented reality.

Augmented reality is a technology that enhances user experiences by overlaying virtual elements onto the real world [1]. While virtual reality provides a fully immersive virtual environment, augmented reality combines virtual and real-world elements [9]. In the field of education, augmented reality is used to provide immersive learning experiences, enhance learning outcomes, and promote student engagement and understanding of the learning content.

Research related to medical education.

In recent years, there have been changes in medical education, with related technologies such as virtual reality, augmented reality, computer animation, and Web3D being recognized for their positive impact on medical education [10]. The application of virtual reality technology in medical education helps provide practical experiences, enhance learning experiences, improve students' skills and knowledge, and has the potential to adapt to the learning needs of different students [11].

4 Discussion

In the field of education, virtual reality has the potential to provide immersive learning experiences, create personalized learning environments, offer safe learning environments, facilitate cross-cultural learning and distance education, and enhance learning motivation and interest. Therefore, research and application of virtual reality technology in the educational domain hold significant value. Future research should focus on the following aspects:

First, educational goals and needs analysis. Research on virtual reality technology typically begins with identifying educational goals and needs. Therefore, researchers in the educational field should explore how to utilize virtual reality technology to improve learning outcomes, stimulate student interest, facilitate information transmission, and promote knowledge acquisition.

Second, technological applications and tool development. Researchers need to explore specific applications and tools of virtual reality technology in education, including the development and design of virtual reality-based instructional software, virtual laboratories, simulated scenarios, etc., to provide more immersive learning experiences.

Third, analysis of learning processes and cognitive effects. The impact of virtual reality technology on learning processes and cognitive effects is an important research direction. Researchers should investigate how virtual reality technology influences learners' attention, memory, comprehension, and knowledge transfer, and explore how to maximize the use of virtual reality technology to improve learning outcomes.

Fourth, analysis of learning environments and social interactions. Virtual reality technology can provide simulated learning environments where students can engage in practical activities and interactions. Researchers should focus on the design and organization of learning environments, as well as social interactions, collaborative learning, and feedback mechanisms within virtual reality environments.

Fifth, analysis of the role of teachers and support. The role and support of teachers in virtual reality technology research are also crucial aspects. Researchers should explore how teachers can effectively utilize virtual reality technology for instruction and how they can guide students in learning and exploration within virtual reality environments.

5 Conclusions

Based on the bibliometric analysis conducted in this study, we can conclude that virtual reality technology in education is a vibrant research field that has exhibited rapid growth over the past two decades. Our bibliometric analysis revealed that *Computers & Education* is the most influential source of literature, and the most influential articles primarily focus on computer education, educational technology, and learning and educational psychology. The research hotspots identified include simulation, interactive learning environment, augmented reality, and medical education. Based on these findings, we have provided relevant recommendations for research on virtual reality technology in education, encompassing aspects such as educational goals and needs analysis, technological applications and tool development, analysis of learning processes and cognitive effects, analysis of learning environments and social interactions, and analysis of the role of teachers and support.

Acknowledgment

This research is supported by the Philosophy and Social Sciences Foundation of Guangdong Province of China (GD20CTS04).

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