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Research on the Current Situation and Future Development Trend of Immersive Virtual Reality in the Field of Education

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Abstract: In recent years, emerging technologies such as immersive virtual reality (IVR) and Metaverse are pointing to new directions for the future of education. To summarise the current research status and development trend of immersive virtual reality in the field of education, this paper used the CiteSpace tool to search the SSCI literature included in the Web of Science under the theme of "Immersive virtual reality" or "Educational technology". The results show a total of 1293 SSCI publications between 1996 and 2022, with the number of studies in this area increasing year on year. Current research hot spots focus on the application of IVR technology, evaluation and effectiveness research, and curriculum design and teaching. Analysis of node network diagrams and knowledge graphs suggest that future trends in the field will be to deepen immersive experiences, increase interactivity, and continue to explore more pedagogical value and application scenarios. In addition, there are increasingly close partnerships between research institutions and large-scale collaborative research is taking place internationally. In future research, researchers can explore scenarios for the application of Metaverse and the design of assessment systems that can facilitate the development of immersive education.

Keywords: immersive virtual reality; educational technology; Metaverse; CiteSpace

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1. Introduction

The year 2021 ushered in the "Meta-universe year" and with it the "Internet+" model was further developed into "Meta-universe+". The Metaverse is a big concept that incorporates network and arithmetic technologies, Artificial Intelligence technologies, Internet of Things technologies, interaction technologies, Blockchain technologies, and digital twin technologies. The Metaverse has become the focus of the world's technological advancement, and major technology companies have joined the Metaverse industry, as evidenced by the establishment of Metaverse research and development departments and investments in Metaverse-related enterprises. At the same time, it has also set off a wave of academic research on theories related to the Metaverse. Among them, one of the core technologies of the Metaverse is virtual reality. It is a science and technology that integrates the results of multiple fields of human-computer interface technology, computer graphics, sensor technology, and Artificial Intelligence, and is divided into non-immersive and immersive virtual reality technologies. Non-immersive virtual reality allows users to watch or operate in a virtual world while still being able to perceive and communicate with their surroundings and people through the use of screen devices such as head-mounted displays or TV screens. However, the scenes are more singleness and barely reflect the environment and depth of the three-dimensional space, making it difficult to provide a more realistic experience. Immersive virtual reality is more engaging, with immersion, imagination, and interaction (3I). The immersive nature means that the user is immersed in the virtual environment and has a sense of immersion; the interactive nature means that the user interacts with the virtual object and achieves the corresponding actions and functions; the imaginative nature means that the user plays with the imagination and makes creative simulations in the virtual world, expanding the mind and the imaginable space. Immersive virtual reality blurs the boundaries between the real and digital worlds, creating highly immersive scenarios for learners, stimulating students' interest and enthusiasm in learning, and breaking through the difficulties and bottlenecks of traditional teaching. Back in 1993, Pauline A. Smith [1] published the first article on virtual reality technology in Online, entitled Navigation in hypertext through virtual environment, describing the substantial usability advantages that VR technology offers to hypertext databases. Since 2010, all-in-one VR glasses have been in the public eye, allowing users to experience virtual worlds in an immersive way using head-mounted display devices, and it has directly brought humans closer to the virtual world. With the advancement of technology, a variety of software based on VR devices have been created, allowing users to download their favorite applications from shops and experience them directly [2]. In 2005, Michael Zyda [3] suggested that virtual reality researchers should focus on games research and development, and that research in the area of games affects both the entertainment industry, government, and business. An article entitled: From visual simulation to virtual reality to games was published. In 2021, Alec Bodzin developed an IVR game for high school students, it was a study of economically disadvantaged students, which showed that almost all of them had a positive attitude towards the game. IVR technology can turn abstraction into concrete, enriching the form of science teaching resources, helping students to observe and analyze things from multiple perspectives, giving them a comprehensive understanding of knowledge and hands-on solutions to difficult problems. The game is a great way to teach science to all students so they can enjoy an equal education.

The single teaching method and outdated curriculum is a major shortcoming of traditional education. In traditional teaching and learning, teachers generally impart knowledge through oral or PPT forms, with less interaction and stereotypical content. Comparatively, immersive virtual reality technology is able to create rich contexts, reproducing boring text in the textbook with realistic and dynamic virtual images, and adding interest as students explore and interact in the virtual world. In 2014, Zahira Merchant [4] found that virtual reality-based game-based learning was more effective in learning. Compared to traditional teaching, game-based learning greatly enhances the sense of presence and motivates students to learn. In November 2019, the Ministry of Education issued the Opinions on Strengthening and Improving Experimental Teaching in Primary and Secondary Schools [5] which for experiments that cannot be completed due to the limitations of time and space, and for experiments that are dangerous and destructive, augmented reality, virtual reality, and other technological means can be used to present them. It can be seen that the state actively promotes IVR technology teaching. During the COVID-19 pandemic, our government called for "Suspension of classes without suspension of classes", and online learning became the best program to implement educational goals under many unfavorable conditions. Despite the popularity of online education courses during the epidemic, there are some drawbacks: students with low self-control can become addicted to games and lose their concentration in learning; online teaching is much less interactive, with teachers and students at both ends of the screen, students can only face a single screen to receive education, resulting in a decline in learning efficiency and self-efficacy. In 2020, Cathi L. Dunnagan [6] and his team developed the virtual reality organic chemistry lab, which provided VR browsers and WIFI support for all students. Virtual reality technology can simulate real experimental scenes, greatly reduce the dangers and accidents in practice, and the virtual environment can be reused to achieve resource saving and efficient use [7]. The intelligence education supported by IVR technology has more abundant situation presentation effect and interactive perception mode, which overturns the traditional education idea and teaching method. In the future, immersive virtual reality will be extensively used in the school virtual classroom and lead the way in education.

The coming of the Metaverse era has brought many opportunities for modern education, which not only enriches the learning resources, but also breaks the regional limit of learning. In 2004, Ramesh Sharda [8] first proposed computer-supported collaborative learning (CSCLIP) based on immersive presence, it integrates collaborative learning systems, immersive technology, computer-supported collaborative learning (CSCCL), and human-machine interface (HCI) principles. Tassos A. Mikropoulos [9] reviewed a critical review of ten years of experiential research on the use of virtual reality in Education at Computers & Education in 2011. Microsoft released a white paper called "Immersive Experiences in Education" at ISTE 2019, highlighting the increasingly wide range of scenarios in which virtual reality was being used in education. It can give a positive impact on teachers and students and improve the learning efficiency and quality of teaching. In the intelligent learning, students use the Metaverse service according to their own idea to find the suitable learning mode and realize the personalized learning, which not only improves the learning efficiency but also finds the fun in the learning. The integration of modern education with the Metaverse also faces some problems. The shortage of teaching resources is a difficult problem. Under the present condition of IVR technology, it is very difficult for teachers to carry out formative assessment, and there is a lack of systematic theoretical guidance for virtual teaching. The integration of immersive virtual reality technology with other educational technologies to achieve a seamless integration of real and virtual environment and to construct an optimal intelligent learning environment is something to think about.

CiteSpace is an information visualization tool dedicated to the analysis of academic literature, suitable for multivariate, time-phased, dynamic, and complex network analysis that can detect hot topics and their evolution in a particular discipline or field. No analysis of learning research in immersive virtual reality environment in the WOS database has yet been conducted using the CiteSpace software. This paper therefore presents a visual analysis of the main function buttons of the CiteSpace software, keyword, cited author, cited journal, and cited reference, and draws relevant maps. The software has been widely used to detect and analyze the changing trends of disciplinary research frontiers and the interrelationships between research frontiers and the knowledge base, and between different research frontiers, which is intuitive, scientific, and objective, and helps to gain a comprehensive understanding of research frontiers and future development trends. Inspire the education industry by analyzing the research frontiers of IVR technology in education to address the challenges and opportunities of the future education sector. Future educators should master the technologies related to virtual reality to provide immersive learning environments for students and tap more educational value.

2. Data Sources and Research Methods

2.1. Data Sources

To improve the guidance of IVR research in the field of education, the study used the Web of Science Core Collection of SSCI literature as the search database. The search topic was set to topic = "Immersive Learning" or "Virtual Reality Learning Environment". The language set to "English" and the document types to "Article" were browsed on Web of Science and 1293 documents were retrieved (search date: 10 February 2023). At last, we exported the data to Refworks format with the contents of the "Full Record and Cited References" record. According to the available SSCI literature, research related to learning in immersive virtual reality environments began in 1996 (Pauline A. Smith, 1996), so the years 1996–2022 were selected for this study, and each article contained information such as author, institutional keywords, abstract, and publication date.

2.2. Research Pathways

This study uses CiteSpace software, an information visualization tool specifically designed for the analysis of academic literature, to visually analyze research on the application of immersive virtual reality in the field of education as a way to analyze the current status and trends in the field. CiteSpace [10] is a Java-based information visualization tool developed by Professor Chao-Mei Chen of Drexel University, USA, specifically for the analysis of academic literature. In CiteSpace, a word or term related to new trends and sudden changes in time t is called a research frontier term. $\Omega(t)$ contains multiple sets of papers cited by papers where research frontier terms can be found. For example, Stitle means the set of headline terms, IsHotTopic ($term$, t) means a Boolean function, and $article_0 \rightarrow article$ means that $article_0$ cites an $article$. Especially, we use two examples to illustrate the use of the new approach, one showing the influence of internal events and the other showing the influence of external events. In particular, we use two examples to illustrate the use of the new approach, one showing the influence of internal events and the other showing the influence of external events.

$$\Phi(t)\colon \Psi(t) \rightarrow \Omega(t)$$

$$\Psi(t) = \{term \mid term \in S_{title} \cup S_{abstract} \cup S_{descriptor} \cup S_{descriptor} \wedge IsHotTopic\ (term,t)\}$$

$$\Omega(t) = \{article \mid term \in \Psi(t) \wedge term \in article_0 \wedge article_0 \rightarrow article\}$$

3. Analysis of Study Conclusions

3.1. Temporal Analysis of the Volume of Articles Issued

The temporal analysis of the volume of articles published enables reflection on the current state of application and overall trends in the field [11]. The search data show that the number of posts on learning in immersive virtual reality environments is increasing year on year (Figure 1). This indicates that the research direction is attracting widespread interest in the academic community. Research on learning in immersive virtual reality environments can be divided into the following three stages.

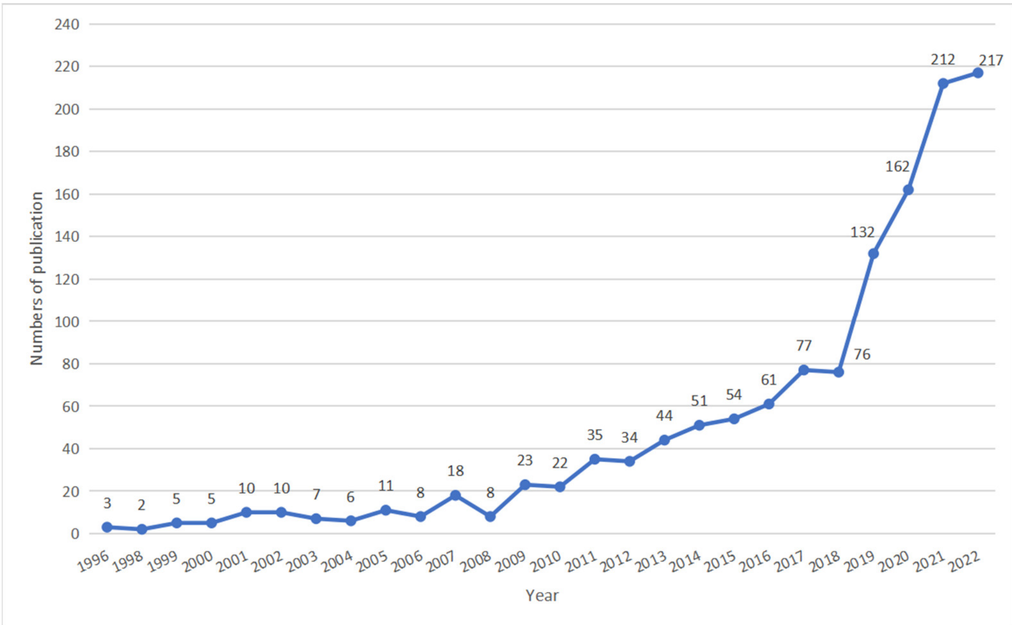

Figure 1. A temporal analysis of the volume of posts for learning in an immersive virtual reality environment from 1996 to 2022.

Stage 1 (1996–2008): As you can see from the graph, before 2008, there were relatively few research articles published each year, only 7.75. The first was published in 1996 by John Wann, the title was [1] What does virtual reality NEED?: human factors issues in the design of three-dimensional computer environment. In an early phase, D. Jack [12] (2001) developed a personal computer-based desktop virtual reality system for the rehabilitation of stroke patients with hand function, with objective measurements showing improvement in each patient; the subjective evaluation was also positive. This is a milestone in the early days of VR. Albert Rizzo [13] (2004) discusses the use of VR in neuropsychology such as learning disabilities and neurological disorder. It also shows that VR technology can improve the speed of cognitive and functional behaviors assessment and rehabilitation.

Teresa Monahan [14] (2008) proposed the application of virtual reality technology in online learning to enhance learning interactivity and experience and enriching the monolithic nature of traditional online learning.

Stage 2 (2009–2016): The number of studies has grown steadily, the average number of publications per year during these eight years was 40.50, mainly concentrated in the United States. According to Hsiu-Mei Huang [15], animation and multimedia in learning has been extended to applications in virtual reality learning environments. This is from the traditional single-style multimedia teaching to a more immersive and interesting virtual reality learning environment. Veljko Potkonjak [16] (2016) first proposed the creation of virtual laboratories for science, technology, and engineering education, especially for application in online distance learning. This stage of rapid development is pivotal in the application of immersive virtual reality in education and laid the foundation for future wisdom teaching.

Stage 3 (2017–2022): The literature on immersive virtual reality in education has grown rapidly in the last six years, with 146 papers published annually, which is 2.6 times more volume per year than the previous period, and the application of virtual reality technology to immersive learning is in the ascendant. Scholar Cathi L. Dunnagan [17] designed a VR laboratory to teach students how to use infrared spectrometers, which students operated in the first person, making it more immersive. Experimental results show similar learning efficiency to traditional laboratory operations. This shows that the virtual reality learning environment can be widely used in online learning platforms, so more learners are not limited by time and space experience. In 2022, the education Metaverse starts getting a lot of attention [18]. The Metaverse merges physical and virtual reality and provides channels for multi-sensory interaction and immersion in a variety of environments. Chinese scholar Minjuan Wang [19] has developed a new theoretical framework for innovation by exploring the Metaverse, including research and technology hub and knowledge hub, etc. In a word, immersive virtual reality learning has become the trend of future education. As the literature continues to grow, the research on immersive virtual reality learning is more and more diversified.

3.2. Analysis of Published Journals

According to statistics, the literature on the application of immersive virtual reality in education were published in 200 journals. Of all the journals published by the SSCI, the top 10 were Computers Education, Sustainability, Clinical Simulation in Nursing, Virtual Reality, Applied Sciences Basel, IEEE Transactions on Learning Technologies, BMC Medical Education, Journal of Science Education and Technology, Nurse Education Today, and International Journal of Human Computer Interaction (Table 1). Of these, 152 articles were published in Computers Education with an impact factor of 11 or more. It is evident that there is a boom in academic research into immersive virtual reality in education.

Table 1. Top ten journals on immersive virtual reality in education research from 1996 to 2022.

Journal Title	Impact Factor	Article Number	Percentage
Computers Education	11.182	152	12.50%
Sustainability	3.889	44	3.60%
Clinical Simulation in Nursing	2.856	36	3.00%
Virtual Reality	4.697	35	2.90%
Applied Sciences Basel	2.838	28	2.30%
IEEE Transactions on Learning Technologies	4.433	27	2.20%
BMC Medical Education	3.263	24	2.00%
Journal Of Science Education and Technology	3.419	24	2.00%
Nurse Education Today	3.906	23	1.90%
International Journal of Human Computer Interaction	4.92	19	1.60%

3.3. Country and Institution Analysis

3.3.1. Analysis of Issuing Countries

Based on the data analysis function of WOS, we filtered out the top eight countries with the highest number of publications (Table 2). The United States has the highest number of articles, with 347. Other countries with more than 100 articles include the UK, China, and Australia, accounting for 51.9% of the total, but China still has a certain gap compared to the US. Germany and Taiwan are relatively few in number, with Taiwan at the bottom of the list with only 69 articles. Overall, learning in immersive virtual reality environments has been most enthusiastically researched in the United States. As early as 1968, Ivan Sutherland, the father of computer graphics and virtual reality in the United States, invented a fully functional set of VR equipment, which opened the way for subsequent research in the United States. Our country did not become relatively mature in VR technology until 2016, and with relentless efforts and strong support from the state, we have also achieved excellent results at this stage. The 2021 World VR Industry Conference Cloud Summit opened in Nanchang, Jiangxi, with the conference site releasing breakthroughs made by China's virtual reality industry in many key technologies, for instance, virtual simulation technology, multi-sensory collaboration technology, and content processing technology.

Table 2. Top eight research countries statistics.

Serial Number	Countries	Article Number	Percentage
1	USA	347	26.83%
2	England	118	9.13%
3	China	106	8.20%
4	Australia	100	7.73%
5	Spain	98	75.80%
6	Canada	82	6.34%
7	Germany	79	6.11%
8	Taiwan	69	5.34%

To explore inter-country collaboration, CiteSpace was used to analyze countries with published papers, with a time slice of three, as shown in Figure 2. Nodes (n = 78) correspond to institutions, and node size is related to the author's volume of publications and the author's relevance to other authors. Connections between nodes (e = 298) represents the state of the relationship. As we can see from the graph, the three countries with the highest number of publications are USA (347), UK (118), and China (106). The four countries with the highest bursts are the UK (10.94), China (9.56), Spain (5.2), and France (3.57), it shows that they have provided a clear direction for immersive virtual reality research in the field of education.

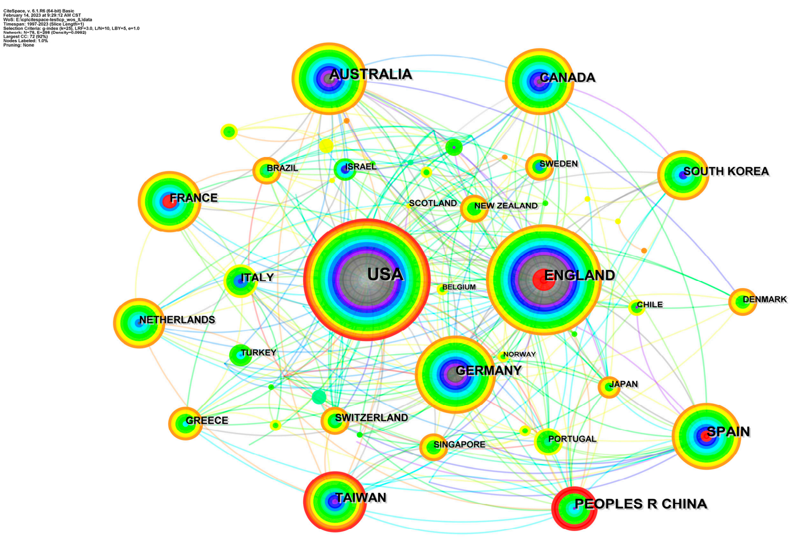

Figure 2. Country cooperation mapping from 1996 to 2022.

3.3.2. Analysis of Issuing Institutions

The distribution of institutional research was analyzed through CiteSpace. Table 3 shows the top seven research institutions for the application of immersive virtual reality in education from 1996 to 2022. Harvard University in the USA is the most published institution with 13 articles. London's Global University in England and Universitat de València in Spain both published 12 articles. Among the top seven institutions are two from Canada, the University of Alberta, and the University of Toronto, and two from China, the National Taiwan Normal University, and the National University of Singapore. The volume of articles from each institution is relatively spread out, with many countries participating, suggesting that the application of immersive virtual reality in education is the future.

Table 3. Statistics on the top seven research institutions.

Serial Number	Institutions	Countries	Number of Articles
1	Harvard University	USA	13
2	London's Global University	England	12
3	Universitat de València	Spain	12
4	National Taiwan Normal University	China	11
5	University of Alberta	Canada	11
6	University of Toronto	Canada	10
7	National University of Singapore	Singapore	10

The CiteSpace software was used to map and analyze the volume of articles published by each institution, as shown in Figure 3. The results show that N (the number of nodes) = 481, E (the number of connections) = 375, and Density = 0.0032. National Taiwan Normal University is the largest node with 11 publications, but has fewer network connections to other institutions, with University of Illinois, Beijing Normal University, and National Changhua University of Education to form a collaborative subgroup.

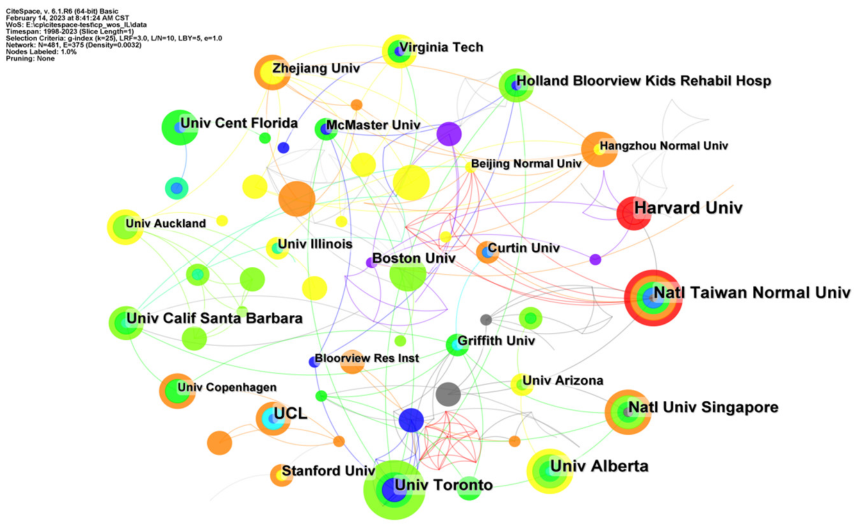

Figure 3. Cooperation map of immersive virtual reality technology in education from 1996 to 2022.

3.4. *Keyword Co-Occurrence Analysis*

Keywords are an important part of and essence of academic papers; the keyword co-occurrences can reflect the hot spots and frontiers of research in a certain field in a sharp and direct way. We conducted a keyword co-occurrence analysis of immersive virtual reality learning (Figure 4). There is a positive correlation between circle size and frequency of keyword occurrence, thus reflecting the hot research and future trends. The keywords with a frequency of more than 100 times in the research on IVR technology in education are: virtual reality, environment, education, augmented reality, and performance, representing popular research themes in the field. In terms of keyword centrality, those above 0.1 are memory, environment, virtual reality, model, and information, indicating that they are key nodes connecting different research themes and clusters in the field of IVR technology in education.

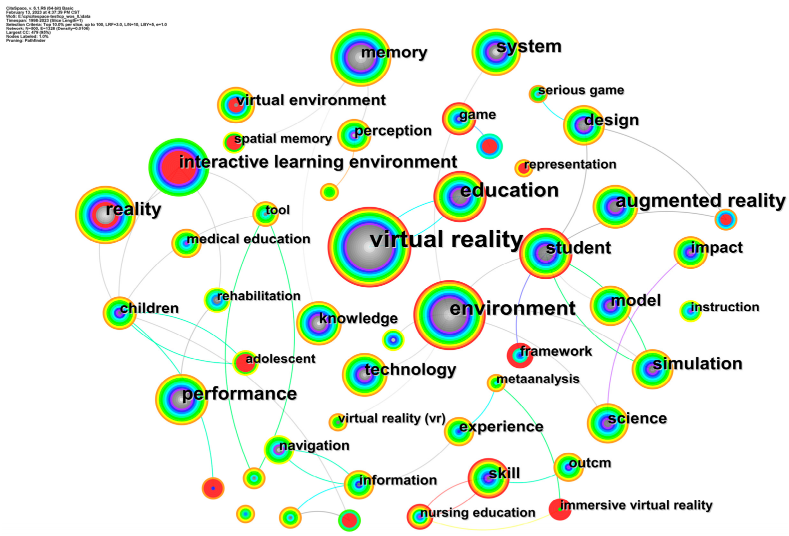

Figure 4. Learning in an immersive virtual reality environment studies keyword co-occurrence network graph.

Through the study of keyword co-occurrence, virtual reality (John Wann, D. Strickland et al., 1996) [1] and interactive learning environments (Alma S. Merians, 2002) [20] emerged early, with 1996 to 2002 being the nascent period for the application of immersive virtual reality in education. The initial period of development in the field of learning in immersive virtual reality environment was from 1996 to 2002. Research in this period initially applied virtual reality to teaching and learning and was an initial exploration of moving from single traditional teaching and learning to intelligent teaching and learning. From 2009 to 2016, game (Bokyeong Kim, 2009) [21], cognitive load (Eric Fassbender, 2012) [22], health (Lori I Kidd, 2012) [23], virtual world (Feasel J., 2011) [24], and other research topics have emerged, suggesting that the range of application areas for virtual reality technology is gradually expanding as research continues to delve into cognitive load in educational applications. In recent years, keywords such as immersive learning, immersive virtual reality, immersive environment, higher education, and computer-based learning have come together, indicating that IVR technology is beginning to be widely used in education research and is a major trend in the future development of education.

3.5. Analysis of the Authorship of the Literature

Statistical analysis of the authors of published articles in the WOS database was carried out using CiteSpace software to analyze and filter the top nine authors who published more papers (Table 4). The results show that there is little difference in the number of articles published by different authors, involving more authors (689). Mou, Weimin is the most published scholar with nine articles, while the rest of the authors published between six and seven articles, generally less.

Additionally, to accurately study author collaborations, we used CiteSpace software to analyze author collaboration networks. The analysis was conducted from 1996 to 2022, with a time slice of 1 year, and ran CiteSpace software to obtain a knowledge map of the application of immersive virtual reality in education, with the number of nodes $N = 684$, the number of connections $E = 703$, and density $D = 0.003$ (Figure 5). The network graph is relatively fragmented, with fewer connections between class clusters. This suggests that the core team for research on IVR technology in education has not yet been established and that the major teams need to strengthen their collaboration and work together.

Table 4. Top seven authors by volume.

Authors	Number of Articles
Mou, Weimin	9
Andersen, Patrea	7
Munoz-cristobal, Juan A	7
Slater, Mel	7
Martinez-mones, Alejandra	7
Asensio-perez, Juan I	6
King, Gillian	6
Makransky, Guido	6

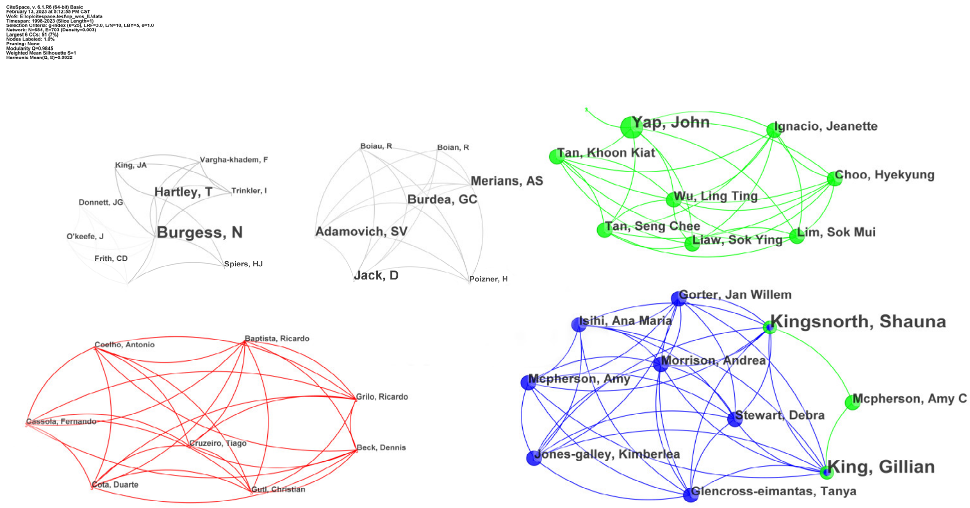

Figure 5. Author collaboration chart.

3.6. Analysis of Highly Cited Literature

Highly cited literature has high academic value and professional influence. Therefore, the publication of highly cited literature has become the goal of many researchers. We selected the 30 most frequently cited literature for our study, as shown in Table 5. Since 2018, there has been a decrease in the number of highly cited articles. This literature focuses on interactive learning environment, validation, spatial memory, motivation, and representation. They focus on the process of learning.

Table 5. Top 30 highly cited literature.

Authors/Year	Title	Citation Frequency
Wu, HK./2013	Current status, opportunities and challenges of augmented reality in education [25]	889
Ressler, KJ./2004	Cognitive enhancers as adjuncts to psychotherapy—Use of D-cycloserine in phobic individuals to facilitate extinction of fear [26]	787
Hanus, MD./2015	Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance [27]	722
Merchant, Z./2014	Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis [4]	627
Hartley, T./2003	The well-worn route and the path less traveled: Distinct neural bases of route following and wayfinding in humans [28]	579
Dunleavy, M./2009	Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning [29]	574
Scaife, M./1996	External cognition: How do graphical representations work? [30]	481
Jack, D./2001	Virtual reality-enhanced stroke rehabilitation [12]	425

Table 5. *Cont.*

Authors/Year	Title	Citation Frequency
Annetta, LA./2009	Investigating the impact of video games on high school students' engagement and learning about genetics [31]	340
Potkonjak, V./2016	Virtual laboratories for education in science, technology, and engineering: A review [16]	334
Huang, HM./2010	Investigating learners' attitudes toward virtual reality learning environment: Based on a constructivist approach [15]	323
Merians, AS./2002	Virtual reality-augmented rehabilitation for patients following stroke [20]	319
Hill, NTM./2017	Computerized Cognitive Training in Older Adults with Mild Cognitive Impairment or Dementia: A Systematic Review and Meta-Analysis [32]	303
Moro, C./2017	The Effectiveness of Virtual and Augmented Reality in Health Sciences and Medical Anatomy [33]	298
Caplan, JB./2003	Human theta oscillations related to sensorimotor integration and spatial learning [34]	288
Tuzun, H./2009	The effects of computer games on primary school students' achievement and motivation in geography learning [35]	284
Ben-Zeev, D./2014	Feasibility, Acceptability, and Preliminary Efficacy of a Smartphone Intervention for Schizophrenia [36]	278
Maguire, EA./1998	Knowing where things are: Parahippocampal involvement in encoding object locations in virtual large-scale space [37]	274
Wojciechowski, R./2013	Evaluation of learners' attitude toward learning in ARIES augmented reality environment [38]	261
Rizzo, AA./2004	Analysis of assets for virtual reality applications in neuropsychology [13]	252
Ibanez, MB./2014	Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness [39]	249
Jarmon, L./2009	Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life [40]	249
Lee, EAL./2010	How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach [41]	243
Wolbers, T./2005	Dissociable retrosplenial and hippocampal contributions to successful formation of survey representations [42]	238
Kim, B./2009	Not just fun, but serious strategies: Using meta-cognitive strategies in game-based learning [21]	233
Mirelman, A./2011	Virtual Reality for Gait Training: Can It Induce Motor Learning to Enhance Complex Walking and Reduce Fall Risk in Patients with Parkinson's Disease? [43]	232
Kamarainen, AM./2013	EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips [44]	228
Martin, S./2011	New technology trends in education: Seven years of forecasts and convergence [45]	228
Moffat, SD./2001	Age differences in spatial memory in a virtual environment navigation task [46]	226
Bujak, KR./2013	A psychological perspective on augmented reality in the mathematics classroom [47]	222

3.7. Co-Citation Analysis of Authors

Two (or more) authors who are simultaneously cited in one or more subsequent papers are said to constitute a co-citation relationship. We analyzed the top ten first authors of IVR technology in education by CiteSpace (Table 6), with the year in which the authors published their first article in the field. Anonymous is the most cited author, with 237 citations, but its centrality is only 0.03. Witmer BG has the highest centrality (0.09) and is cited 106 times. A high frequency of citations does not necessarily mean a high degree of centrality, but their articles have contributed greatly to subsequent research.

Table 6. Top 10 authors cited analysis from 1996 to 2022.

Count	Centrality	Year	Cited Authors
237	0.03	1999	Anonymous
106	0.09	2000	Witmer BG
97	0.06	2003	Slater M
72	0.03	2014	Merchant Z
69	0.06	2019	Makransky G
69	0.06	2009	Dede C
69	0.08	2009	Dalgarno B
62	0.04	2006	Mayer RE
57	0.04	2012	LEE EAL
51	0.06	2011	Mikropoulos TA

A network graph of author co-citations was plotted using CiteSpace (Figure 6). *N* (number of nodes) = 978, *E* (number of lines) = 2247, and Density = 0.0047. Larger circles in the graph represent more author co-citations.

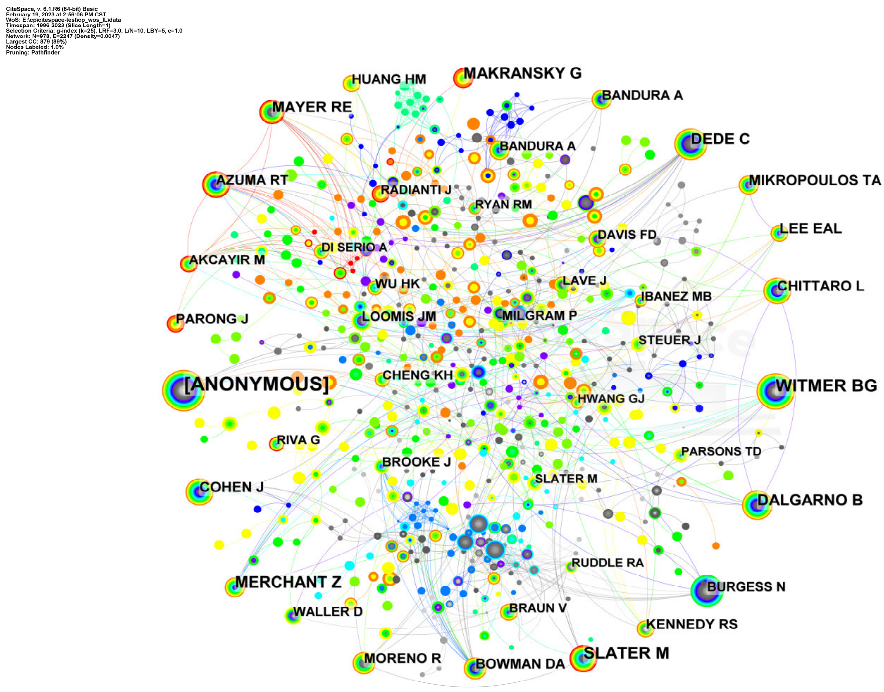

Figure 6. Author citation chart from 1996 to 2022.

3.8. Analysis of Keywords Clustering

CiteSpace's keyword clustering function can clarify hot spots and trends in a research area. We used CiteSpace to conduct cluster analysis of keywords, in the selection criteria dialog box, Top *N* = 10%. In Pruning, select Pruning the merged network, Pruning sliced networks, and Pathfinder to obtain the results shown in Figure 7. After the slicing process, the clustering graph retained 474 lines and 276 nodes. Network density is 0.0125 and the degree of modularity *Q* is 0.8074 > 0.5, which indicates that the keyword clustering results are very promising. Ten clusters were derived by the log-likelihood LSI algorithm, as shown in Figure 7. Cluster size and number of mentions in the study are positively correlated. Good clusters with small numbers and many members. *S* = 0.9173, indicating a more favorable clustering result.

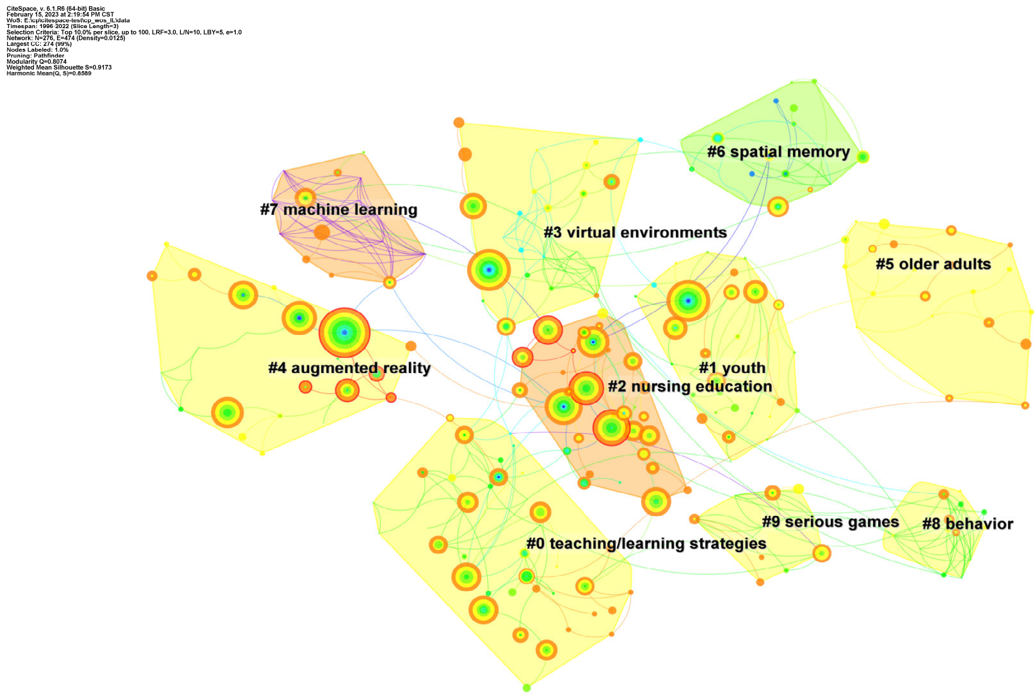

Figure 7. Map of keyword clustering.

Cluster #0-teaching/learning strategies: This set of keywords includes design, science, and impact. Gonzalo Lorenzo (2013) [48] studied the use of immersive virtual reality as a tool and learning strategies in educational interventions for students, and the results showed that students' social competence and executive function were improved. In addition, companies are given the opportunity to develop immersive and virtual professional training practices through powerful 3D virtual technology [49]. To improve students' sense of self-efficacy, teaching strategies should be designed properly, and virtual stimulation should be used effectively. A recent study published in Computers & Education, integration of the peer assessment approach with a virtual reality design system for learning Earth science, shows that teaching with a combination of peer assessment and VR design can improve students' learning efficiency, at the same time improve the sense of thinking ability [50]. Cluster #1-youth: These keywords in this group are memory, perception, and children. Immersive virtual reality technology, as an advanced interactive experience, can be very helpful for children's development and learning. However, children need adequate attention and guidance from parents and educators when accessing IVR technology to ensure they have a positive, healthy, and growing experience in the process. As technology continues to evolve, many K12 schools have begun to introduce IVR technology to improve teaching and learning. It can provide an immersive learning experience for students, helping them to better understand abstract knowledge and stimulate their interest in learning. Cluster #2-nursing education: This group of keywords contains education, student, and simulation. Grace V. Ryan (2022) [51] evaluated the learning outcomes of students in the medical field with immersive technologies and traditional learning. In contrast, virtual reality, the most important form of immersive technology, received widespread attention among students. Cluster #3-virtual environment: This group of keywords contains reality, virtual environment, and rehabilitation. Cluster #4-augmented reality: This group of keywords contains environment, augmented reality, and performance. AR is an extension of VR technology used to simulate objects, allowing learners to see virtually generated simulated objects in the context of a realistic environment and to quickly generate, manipulate, and rotate them. Cluster #5-older adults: This group of keywords includes feedback, older adult, and adult. Cluster #6-spatial memory: This group of keywords contains navigation, spatial memory, and path integration. Cluster #7-machine learning: The keywords for this set of clusters are information, task, and medicine learning. Cluster #8-behavior: This group of keywords contains behavior, anxiety, and exposure therapy. Cluster #9-serious game: This group of keywords contains instruction, serious game, and engagement. In recent years, a clever combination of immersive virtual reality and serious games has become a popular tool for earthquake emergency training [27], where learners simulate the escape process through specific virtual environment and teaching methods. In our opinion, this study should be extended to primary and secondary schools and be practiced more often (Table 7).

Table 7. Analysis of keyword clustering.

Cluster ID	Clustering	Cluster Size	Silhouette	Identifying Words (Top 3)
0	teaching/learning strategies	41	0.845	Design; Science; Impact
1	youth	31	0.958	Memory; Perception; Children
2	nursing education	31	0.788	Education; Student; Simulation
3	virtual environment	25	0.869	Reality; Virtual Environment; Rehabilitation
4	augmented reality	24	1	Environment; Augmented Reality; Performance
5	older adults	21	0.941	Feedback; Older Adult; Adult
6	spatial memory	19	0.98	Navigation; Spatial Memory; Path Integration
7	machine learning	15	0.986	Information; Task; Medicine Learning
8	behavior	14	0.962	Behavior; Anxiety; Exposure Therapy
9	serious game	13	0.934	Instruction; Serious Game; Engagement

3.9. Timeline Analysis

The timeline view, in which the keywords are spread out in the clusters to which they belong according to the year in which they themselves appear, is essentially a cluster diagram. According to the timeline diagram generated by the CiteSpace software for the cluster analysis of immersive virtual reality in education, the common literature on the clustering of virtual reality environment, human-computer interaction, user-centered design, and engagement citations are relatively dense (Figure 8). Virtual reality, science, and interactive learning environment were initially cited a lot, suggesting that they laid the foundation for immersive virtual reality in education. Recent research has focused on immersive virtual reality, immersive learning, deep learning, and machine learning, and the number continues to rise. Therefore, learning in an immersive virtual reality environment will be an important research topic in the future. At the same time, virtual reality technology applied to machine learning, deep learning, medicine, and other fields are also a future development trend.

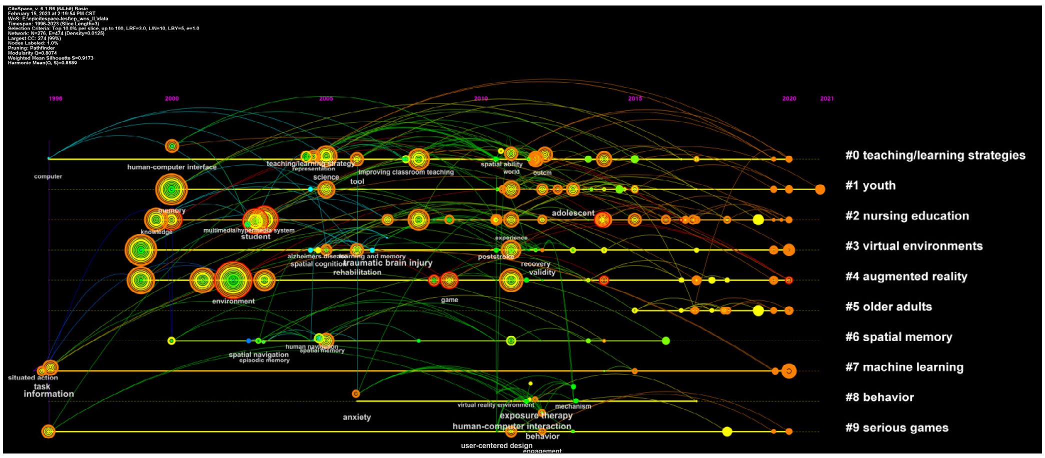

Figure 8. Timeline of immersive virtual reality applications in education from 1996 to 2022.

Through a study of learning timeline mapping through immersive virtual reality environment, we have identified the following three key research pathways for research on immersive virtual reality in education.

3.9.1. Multi-Disciplinary Integration Research

Today in the information age, multi-domain integration research has become a research priority in many disciplines. Some researchers have applied virtual reality technologies to immersive learning, healthcare, machine learning, meta-universe fields, and more [52–55]. For example, learning in an immersive virtual reality environment has resulted in far more effective learning than traditional teaching. In the field of healthcare, VR technology provides medical students with a realistic clinical learning environment that prepares them for clinical practice and saves educational resources, putting theory into practice. In the field of machine learning, the authors have extended causal convolutional neural networks to predict railway traffic congestion. In the Metaverse field, where virtual reality technology is a central part of the technologies, some researchers have developed a learning VoRtex platform that supports collaboration in virtual environment in the Metaverse platform, and a comparative analysis of these virtual world platforms using the Mannien matrix shows that the VoRtex platform dominates in online teaching and learning. As a result, research on virtual reality technologies is no longer one-sided.

3.9.2. Optimization of the Student Learning Environment

With advances in educational technology, learners can find vast amounts of learning resources on the Internet. In 2022, the Ministry of National Education introduced the National Public Service Platform for Smart Education, which provided free learning resources for students of all ages. Students no longer have a single source of access to knowledge, and teachers' teaching methods are following in the footsteps of the times. During the COVID-19 pandemic, our government called for "Suspension of classes without suspension of classes", and for all teaching to be online. Early online education was single and boring, and students and teachers lacked interaction. Applying virtual reality to online learning provides students with more motivation and enjoyment and improves the learning experience [55]. Virtual reality technology can provide students with rich perceptual cues and multi-channel feedback, enabling situational learning.

3.9.3. Change in Approach to Learning

Innovation in learning methods brings about improved learning outcomes. With the advent of the information age, it is no longer easy to learn the essence of knowledge in the traditional indoctrination and lecture style of teaching, etc. Immersive learning is gradually becoming mainstream. Some scholars have compared the concept of students learning relative motion using computer simulations under immersive virtual environment (IVE) and non-immersive desktop virtual environment (DVE) conditions, and the findings show that IVE can facilitate understanding of abstract scientific phenomena [56]. Today in the age of information, smart education is leading the way to change and innovation in educational informatics.

3.10. Analysis of Prominent Citation

Burst words are used to monitor words with a high rate of frequency change over a certain period of time. It identifies research frontiers and trends. We analyzed the emergent words for IVR applications in the education field by CiteSpace and the results are shown in Figure 9. The article written by Merchant Z. (2014) [4] was found to be the most emergent, ranking first with a burst intensity of 12.42. It suggests that this article has guided the direction of research in the field. The article has driven the development of immersive virtual reality in education. Makransky G.'s (2019) [57] article ranked second in terms of burst intensity. Radianti J.'s (2020) [58] article ranked third in terms of burst intensity. The burst intensity also increased from 2009 to 2019 per Jarmon L. (2009) [40], Dalgarno B. (2010), Di Serio A. (2013), Cummings J.J. (2016), Parong J. (2018) and Pottle Jack (2019) [59–63]. Their research has been progressively refined and progressed from virtual reality technology to its application in teaching and learning to immersive learning, completing the exploration with the support of numerous experiments. The emergence of emergent terms in 2023, which has just begun, suggests that immersive virtual reality in education is a hot topic for future research.

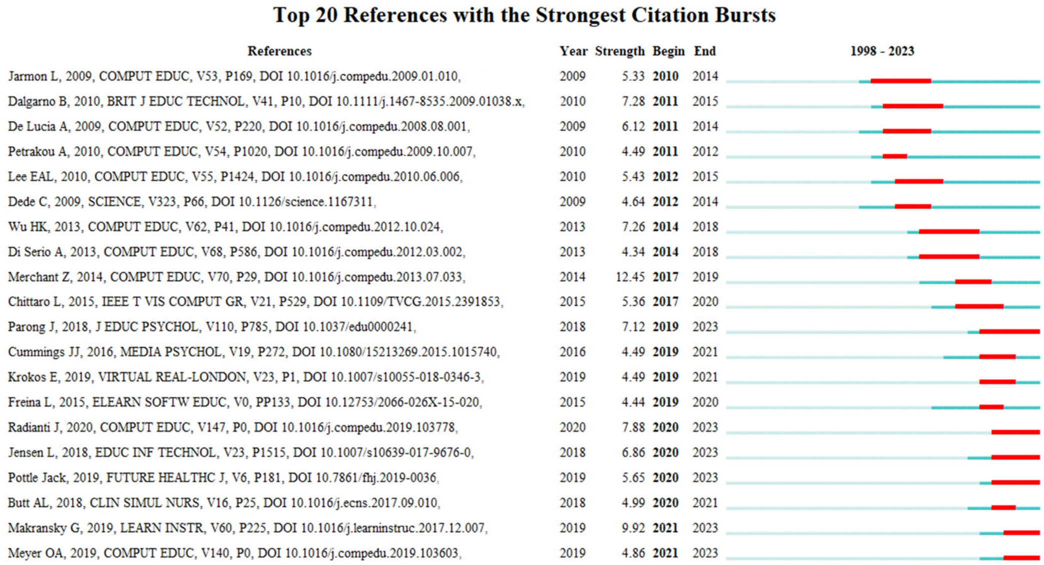

Figure 9. Citation of immersive virtual reality in education studies outbursts from 1996 to 2023 [4,40,57–63].

4. Discussion

This article uses CiteSpace, an information visualization tool dedicated to academic literature analysis, to retrieve and analyze the application of IVR in education, with the aim of clarifying the research landscape and current hot spots.

IVR technology can be integrated with learning theory of constructivism, contextual learning theories, and other educational theories to create rich and realistic teaching and learning situations, providing learners with a variety of perception and interaction methods to achieve an immersive and intelligent educational environment.

The number of studies is on the rise, with North America and Europe leading the way in research on the application of IVR in education. China contributes greatly to research in this area. The US, UK, China, and Australia are active in research related to learning in IVR environments. Research teams are more concentrated, with various countries involved, mainly in the USA. There is less communication and collaboration among core authors, and cross-team research leads to better benefits. In addition, when analyzing the cited literature and author co-citations, 26 papers had more than 230 times, with the most cited being Hsin-Kai Wu et al. Current status, opportunities, and challenges of augmented reality in education, with a cumulative total of 889 citations, is published in Computers & Education with an impact factor of 11.182. The most influential co-cited authors are Anonymous and Witmer BG, with over 100 cumulative citations, contributing significantly to the study of immersive virtual reality in education. Currently, Sungjin Park and Sangkyun Kim are applying Metaverse to education, innovating educational environment in virtual worlds and providing equal educational opportunities for learners. Finally, virtual reality technology has ventured into many fields such as immersive learning, medicine, machine learning, Metaverse, etc.

In summary, a bibliometric knowledge mapping tool allows visual analysis of the current state of research and future trends in immersive virtual reality in education, and virtual reality technology is found to be widely used in various fields. Research hot spots in this field focus on virtual reality, technology, education, interactive learning environment, and science. Research topics focus on the educational Metaverse and the benefits and effectiveness of immersive learning in virtual environments, immersive learning versus traditional learning, and the integration of virtual reality technology with machine learning. The Metaverse should be considered as a key concept and emerging theory in the construction of future intelligent domains [64]. However, this study has limitations in that the research literature was only retrieved in Web of Science for English papers on learning in immersive virtual reality environments in SSCI, ignoring data from other languages and databases to some extent.

A more comprehensive bibliometric study of the global application of immersive virtual reality in education has not been found in the context of a learning environment with constantly updated technology. Therefore, this study analyzes the history and research hot spots in the field and predicts that the combination of immersive virtual reality technology and educational Metaverse will be a major trend in the future development of modern education. An engaging and highly personalised learning environment can be created, providing students with a richer, livelier, and interactive learning experience. In the education Metaverse, students can engage in diverse activities, build their own digital identity, show off their interests, skills, etc., interact with students from different regions and cultures, and develop communication, teamwork, and leadership skills as they engage in collaborative processes. In addition, IVR technology can be combined with artificial intelligence, IoT technology, 5G, and more.

5. Future Work

In summary, this study is relatively limited in that the research literature was only retrieved in Web of Science for English papers on learning in Immersive Virtual Reality environment in SSCI, ignoring data from other languages and databases to a certain extent. Therefore, in the age of information technology, we should expand the scope of the search to make the study comprehensive. Learning in immersive virtual reality environments is not isolated but should also be studied in conjunction with gamified learning and Metaverse.

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