

 **Review Article**

Tracing Virtual Reality Research: A 2009–2024 Bibliometric Analysis

Desi Handayani ¹ ¹Department of Chemistry Education, Universitas Negeri Jakarta, Jakarta, Indonesia**Abstract**

This study provides a comprehensive bibliometric analysis of virtual reality (VR) research in education from 2009 to 2024, with data sourced from the Scopus database. Out of 1,749 initial publications, a refined selection of 735 articles was analyzed using Bibliometrix software. Results reveal significant growth in VR research, particularly in K-12 and higher education, with peak citations observed in 2014. The United States and China emerged as leading contributors, producing the most impactful studies. Central research themes focus on VR's role in enhancing instructional design through games, simulations, and immersive environments. The analysis identifies influential authors and institutions, with Hwang G.J. as the top author and National Taiwan Normal University leading in institutional contributions. The most cited articles highlight VR's efficacy in improving student engagement, comprehension of abstract concepts, and overall learning outcomes. A notable finding is the application of VR in collaborative and experiential learning, as well as its potential to address educational needs for diverse learners, including those with disabilities. Key bibliometric indicators underscore a 20.68% annual growth rate in publications, with interdisciplinary collaboration playing a pivotal role. Visualization through citation and co-citation networks elucidates the intellectual structure of VR research, highlighting prominent studies and emerging trends. Keywords like “virtual reality,” “e-learning,” and “students” dominate, reflecting a focus on technology-driven educational methods. This research provides valuable insights into the evolving landscape of VR in education, emphasizing its transformative potential. It informs educators, policymakers, and researchers on the trends, challenges, and opportunities for integrating VR technologies into educational practices to enhance learning experiences and outcomes.

Keywords: Bibliometric Analysis, E-Learning, Educational Technology, K-12, Scopus, Virtual Reality

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1. INTRODUCTION

Technological advances in recent decades have caused substantial transformations in different areas of life, including in education. One technology that is increasingly gaining attention in improving the learning experience is Virtual Reality. A three-dimensional environment, generated by a computer, is allowed to be experienced and interacted with by users through VR technology. By using devices such as VR headsets, users can feel the sensation of being in a realistic virtual world (Flavián et al., 2019). The positive impacts of VR technology in education are extensive and diverse, including VR can increase student engagement and motivation. Engaging and interactive learning experiences can increase students' interest and enthusiasm for studying the subject matter, with VR allowing simulations and visualizations to be carried out in the real world, VR strongly supports collaborative learning, students can work together in a virtual environment to complete tasks or projects, which can improve their social and teamwork skills. At the K-12 level, the application of VR in learning has great potential to improve the quality of education. VR can be used to teach a variety of subjects, from science, mathematics, history, to art. In addition, VR can also help students with special needs to learn in a way that is more appropriate to their needs. Thus,

the integration of VR in the K-12 curriculum can provide a richer and more meaningful learning experience for students (Won et al., 2023).

Educational technology has advanced considerably over the past few decades, especially with the advent of Augmented Reality and Virtual Reality. Augmented Reality (AR) is a technology that enriches the real-world environment by adding visual and sound elements through sophisticated devices. On the other hand, Virtual Reality (VR) is a technology that allows users to interact with a computer-generated 3D environment, offering an immersive experience that is entirely distinct from the real world. In the context of K-12 education, AR and VR have great potential to improve the quality of learning. AR can be used to enrich learning materials with visual and interactive elements, such as adding additional information to textbooks or real objects. Learning with the use of VR allows students to explore environments which cannot be accessed in the real world, such as visiting historical sites, dangerous scientific experiments, or even outer space (Yuen et al., 2011).

Learning videos, while useful, are often passive and less interactive. Learners are simply recipients of information without any active involvement in the learning process. In contrast, VR allows learners to engage directly in a specially designed learning environment, allowing them to learn through exploration and hands-on learning experiences. This interaction can increase student motivation and engagement, which in turn can improve comprehension and retention of the subject matter (Damaševičius & Sidekerskiene, 2024).

The importance of using VR compared to conventional methods such as video learning needs to be analyzed using a bibliometric approach. Bibliometrics is an analytical method that uses statistical data from scientific literature to identify patterns, trends, and relationships in research. The advantages of this method include its ability to provide a comprehensive picture of the distribution of publications, the main topics discussed, and collaborations between researchers. Bibliometric analysis can provide deep insights into the influence and effectiveness of VR in education compared to other learning methods (Rojas-Sánchez et al., 2023).

The influence of VR in education has been widely discussed in previous studies. Several studies have shown that Virtual Reality can increase student engagement and motivation, enhance comprehension of abstract ideas, and provide a more meaningful learning experience. However, a comprehensive bibliometric analysis is still needed to identify trends and contributions of VR in education more broadly (Lin et al., 2024).

The objective of this study is to thoroughly explore the conceptual, intellectual, and social evolution of virtual reality, with the goal of enhancing empirical evidence and understanding of its application in learning from 2009 to 2024.

This study provides benefits to various stakeholders. For education providers and policy makers, the results of the study can be used to develop more effective technology implementation strategies. For teachers, this study can help in designing innovative learning methods. For learners, this study is expected to enhance more interactive and immersive learning experiences. The following are the research questions:

1. What are the main information and literature developments on virtual reality?
2. What are the backgrounds of scholars and the titles of literary references related to virtual reality?
3. An overview of which articles are most cited in virtual reality?
4. Which countries and affiliations of virtual reality literature are most productive?
5. What are the trends in keywords and their visual mapping in virtual reality?
6. What is the structure of virtual reality knowledge?
7. How does the development of publications on the application of VR in education compare to that of video-based learning in recent years?

2. DATA AND METHODS

This study utilizes a bibliometric method to analyze and visualize research advancements in the field of virtual reality (VR). This research development can be understood as a collective tendency of scientists to focus on certain topics (Mohakud et al., 2024). Furthermore, the relationship between ideas in the ever-

evolving scientific knowledge system can be revealed through bibliometric mapping. This mapping will help academics design future research directions (Amiruddin et al., 2025).

For bibliometric analysis, a comprehensive bibliographic database is required, providing complete information on scientific publications. Scopus, being one of the largest databases for citations and abstracts is well suited for this purpose. Scopus's broad coverage, from scientific journals to conference proceedings, as well as its rigorous selection process, guarantee the quality of the indexed data (Baas et al., 2020). In addition, Scopus also accommodates multiple formats and data analysis tools.

2.1. Article Selection Proses and Method

Bibliographic data collection through Scopus was conducted on September 12, 2024, resulting in 1,749 documents related to virtual reality. The search keywords used were TITLE (virtual reality and K-12). Referring to Chen et al. (2023), the filtering stage was carried out by limiting the range of publication years (2009-2024), types of publications in articles, conference papers, and language in English. This limitation aims to obtain relevant and consistent data. After eliminating duplicates and irrelevant articles, 735 articles were selected for further analysis (Georgiou et al., 2024). The complete selection process is illustrated in Figure 1.

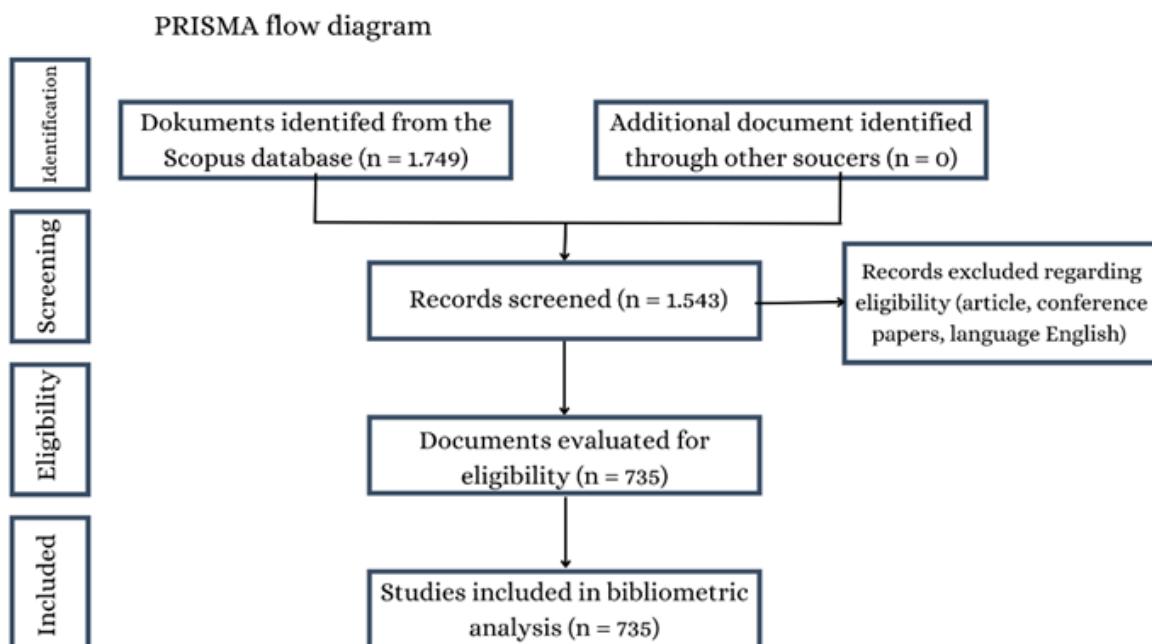


Figure 1. Process and Methods for Selecting Articles

2.2. Data Analysis

This study aims to map the current research landscape in the field of virtual reality through bibliometric analysis. Using Bibliometrix software, we have processed and analyzed data obtained from various scientific databases. The data analyzed includes information on publications, authors, affiliations, keywords, and journals (Rojas-Sánchez et al., 2023).

The study began with data collection from sources like Scopus. The gathered data was cleaned and converted into CSV format to streamline analysis in Bibliometrix. The analyzed variables included publication details (year, title, journal name, and source), author-related information (names, institutional affiliations, and countries), and keywords for indexing. Once the data was prepared, Bibliometrix was used to carry out the bibliometric analysis. A descriptive approach highlighted the total publication count, identified the most productive years, and assessed publication distributions by country and institution (Baarimah et al., 2024).

Co-authorship patterns were also explored using citation analysis. Co-occurrence knowledge mapping was employed as a method to understand the progression of research areas, describe, keywords frequently appearing together in publications can reveal research trends, popular topics, and connections

among concepts (Guo, 2022). A higher frequency of co-occurrence between keywords indicates a stronger conceptual link. These maps are particularly beneficial for developing targeted and relevant research agendas (Narong & Hallinger, 2023).

3. RESULTS AND DISCUSSION

3.1 Main Information

3.1.1 Publication Trends

Table 1 highlights a notable growth in the number of scientific publications on virtual reality, as reflected in Scopus data. The substantial average number of citations per document suggests that these studies have a considerable impact. Collaborative authorship patterns, observed at both national and international levels, underscore the strong collaborative nature of this field. Virtual reality research, characterized by its wide-ranging and interdisciplinary focus, consistently contributes meaningfully to diverse scientific domains, driving advancements in innovation and creativity among researchers.

Table 1. Key Details of Bibliometric Data

Description	Result
MAIN INFORMATION ABOUT DATA	
Timespan	2009 : 2024
Sources (Journals, Books, etc)	623
Documents	1300
Annual Growth Rate %	20.68
Document Average Age	4.6
Average citations per doc	14.58
References	40098
DOCUMENT CONTENTS	
Keywords Plus (ID)	5398
Author's Keywords (DE)	3009
AUTHORS	
Authors	4067
Authors of single-authored docs	95
AUTHORS COLLABORATION	
Single-authored docs	104
Co-Authors per Doc	3.8
International co-authorships %	13.54
DOCUMENT TYPES	
Article	631
Conference paper	669

The yearly scientific production in the field of virtual reality, illustrated in Figure 2, reflects the annual count of published articles from 2009 to 2024. The data reveals a notable upward trend, despite some fluctuations between 2009 and 2014. A significant rise in publication output became apparent starting in 2017, leading to a steady climb that peaked in 2023. While the number of articles reached its highest level in 2023, a moderate drop was observed in 2024. Overall, Figure 2 demonstrates a consistent increase in research productivity over the years, with a slight dip in the most recent year.

Figure 3 depicts the annual average of citations from 2009 to 2024, with the x-axis showing the years and the y-axis representing the average number of citations per year. The data indicates notable fluctuations in citation trends over the years. Initially, between 2009 and 2010, the citation numbers were minimal, followed by a sharp increase in 2010 and a significant decline in 2011. The period from 2014 to 2016 saw a peak in average citations, reaching nearly 4.5. After this peak, a downward trend emerged, which was briefly interrupted by a rise during 2018–2020. Post-2020, citation numbers experienced a steep drop, falling to nearly zero by 2024. In general, while the yearly citation averages show considerable variability, the trendline

reveals a modest upward trajectory. This suggests a gradual long-term growth in citations, despite occasional years marked by significant decreases.

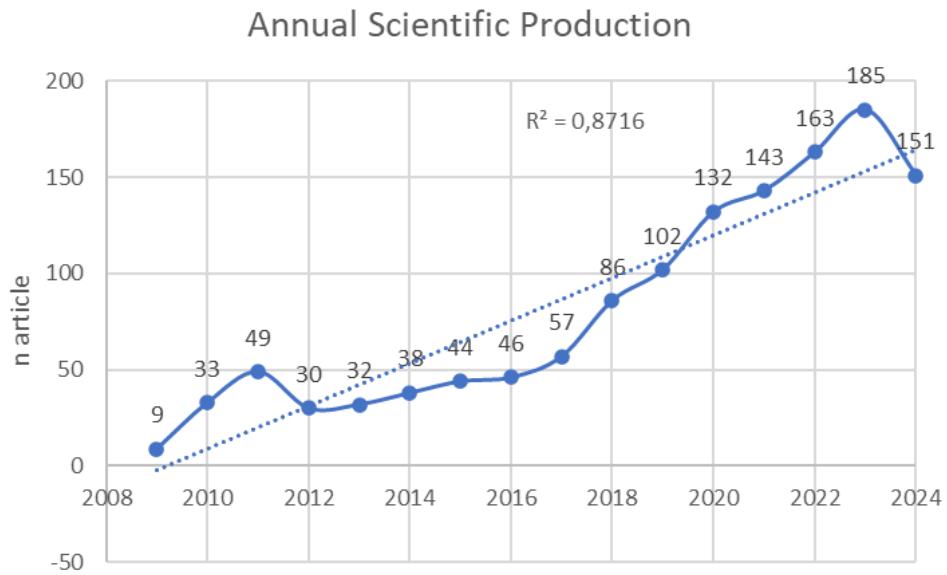


Figure 2. Yearly Scientific Output on Virtual Reality

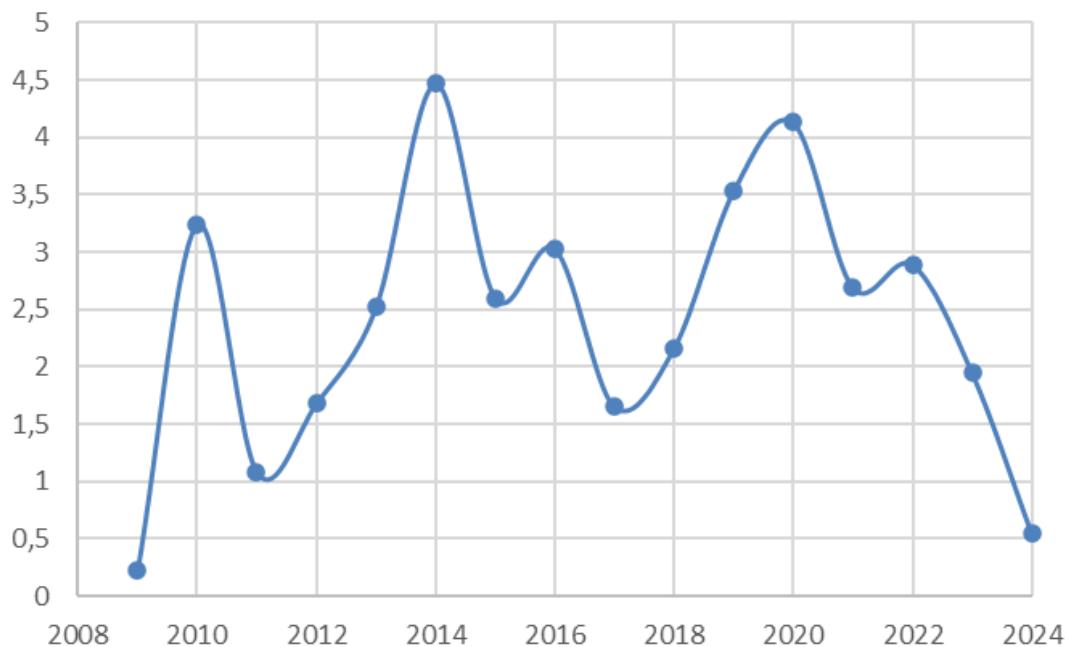


Figure 3. Average Number of Citations Per Year in the Virtual Reality (2009 – 2024)

3.1.2 Thematic Development

Figure 4 showcases a Sankey diagram that visualizes the relationships among key research components, focusing on scholarly literature about virtual reality in education. The diagram connects three primary categories: Citation Reference (CR), Author (AU), and Domain/Field (DE).

The left section (CR) highlights frequently cited studies, including notable works by Makransky G. and collaborators who have a significant impact on the field of virtual reality research. Makransky G. has made significant contributions to the use of virtual reality in education, emphasizing its influence on students' learning experiences and cognitive growth.

The center section (AU) highlights key authors in the field, with Makransky G. standing out as a prominent contributor frequently linked to numerous studies on virtual reality. Thick lines connecting Makransky to references on the left and research domains on the right illustrate his central role in bridging related works. Other influential authors, including Southgate, Hwang, and Alan, also significantly shape this area of research.

On the right side (DE), research domains are represented, showing virtual reality, secondary education, and learning as the primary areas of focus. This suggests that studies on virtual reality in the educational context, especially in secondary education, dominate the field.

In summary, the diagram offers a detailed depiction of the development of virtual reality research in education. It underscores the contributions of key authors, the prominence of topics like virtual reality-enhanced learning experiences, and the interconnectedness of cited literature with specific research domains, providing valuable insights into trends and priorities in this area.

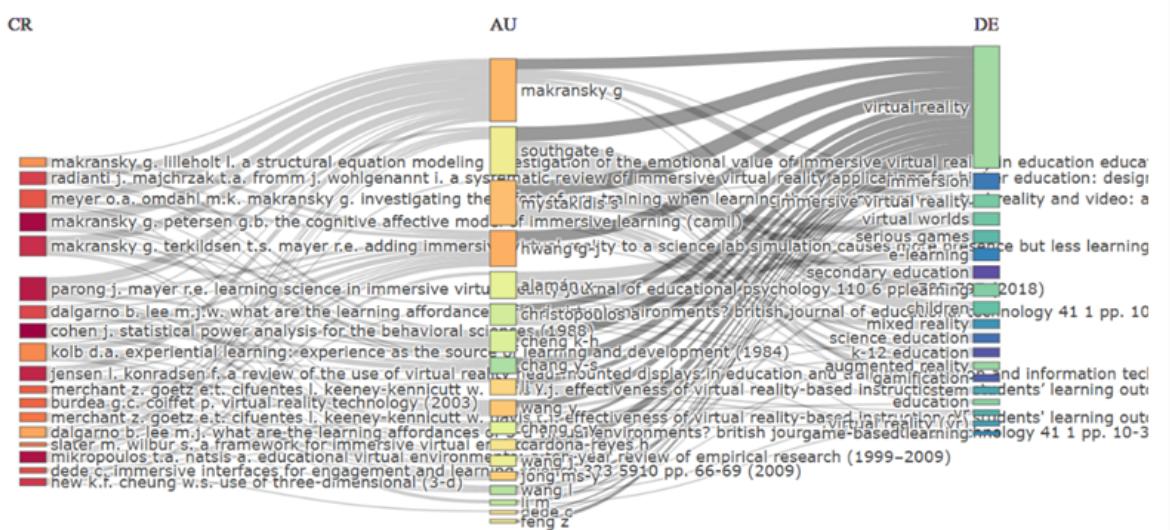


Figure 4. Thematic Evolution of Virtual Reality Research Presented Through a Sankey Diagram

3.2 Researchers' profile and source titles

3.2.1 Top Author

Highly productive authors offer important perspectives on the growth of virtual reality research, covering aspects such as output, collaboration trends, and the influence of their studies. Table 2 highlights the top 10 contributors to virtual reality literature, with Hwang GJ emerging as the leading author, having published 14 articles and demonstrating considerable impact based on the h-index and overall citations. Following him is Makransky G, who has authored 12 articles. The concept of fractionalized articles suggests that their work is spread across multiple publications, likely in partnership with other researchers.

Table 2. List of Leading Authors and Their Contributions to Virtual Reality Research

No.	Authors	Article	Articles Fractionalised	h - index	Total Citation
1	Hwang GJ	14	3,57	9	506
2	Makransky G	12	3,65	9	535
3	Mystakidis S	11	3,59	8	355
4	Wang Y	11	2,59	5	357
5	Jong MS Y	10	2,45	4	365
6	Li Y	9	1,78	4	85
7	Rusyati L	9	3	3	19
8	Dede C	8	2,17	4	236
9	Cardona-Reyes H	7	1,62	2	13
10	Feng Z	7	1,73	2	42

Figure 5 titled Authors' Production over Time, illustrates the number of articles published by various authors over several years, as well as the annual citation count (TC per Year). Hwang GJ (College of Management, Yuan Ze University, Taoyuan City, Taiwan) appears highly productive in recent years (2019 to 2023), as indicated by the large, darker circles, signifying both a high volume of publications and a significant number of citations. Mystakidis S (School of Natural Sciences, University of Patras, Patras, Greece) is also productive, with numerous large circles in recent years, reflecting a substantial number of articles and high citation counts. Other authors such as Li Y, Wang Y, and Jong MS-Y also show productivity, but with more varied citation levels.

In general, numerous authors have demonstrated growth in both article output and citation counts from 2018 to 2023. Certain authors, like Dede C (Graduate School of Education, Harvard University, USA) and Feng Z (Department of Information Science and Engineering, University of Jinan, China), published fewer articles in the earlier years but have been more prolific in recent years. Figure 5 provides insights into the trends in the productivity and scholarly impact of these authors over the past few years, as reflected by their publication and citation counts.

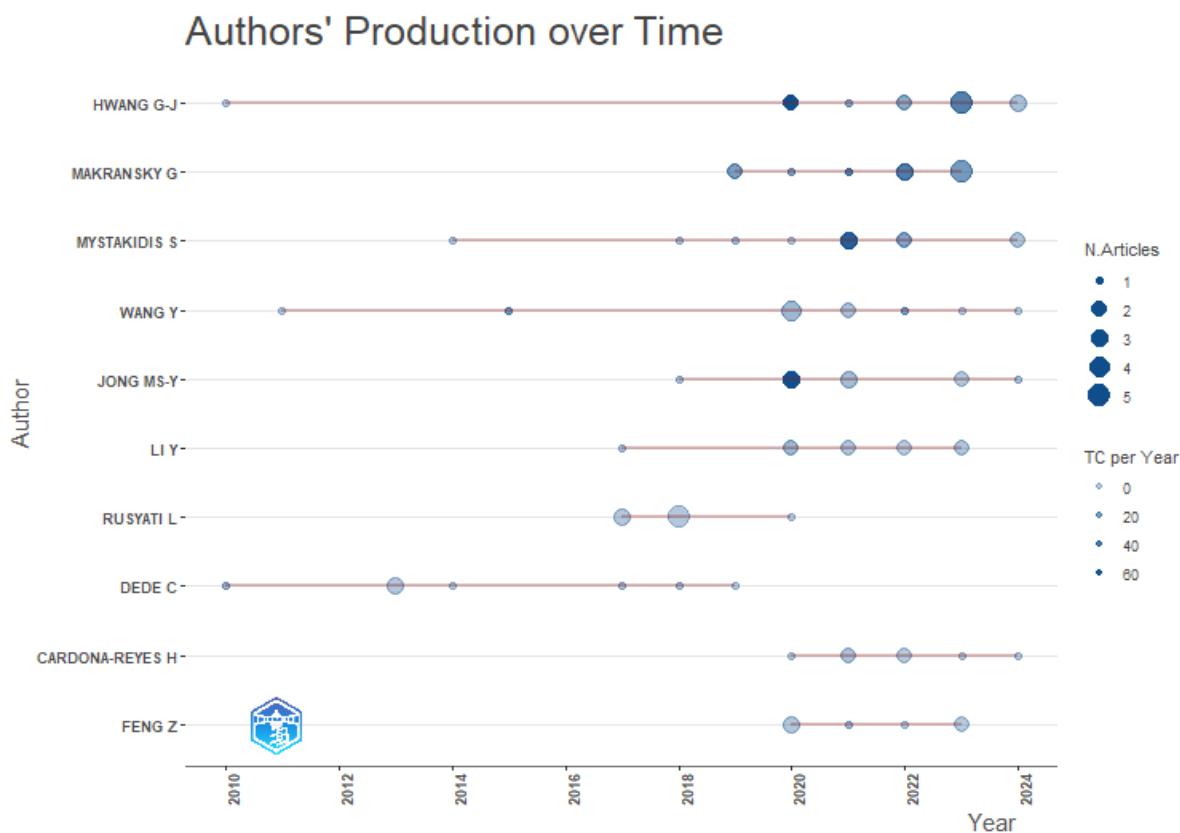


Figure 5. Output of Top Authors Over Time

Figure 6 illustrates the distribution of author productivity, focusing on the number of documents authored by each individual and how this distribution conforms to Lotka's Law (Lotka, 1926). Lotka's Law is frequently used in bibliometric studies to depict the distribution of author productivity, suggesting that the quantity of authors with significant productivity is significantly smaller than those who publish fewer works.

Lotka's Law, also known as the inverse-square law, suggests that the productivity of authors within a particular field follows a disproportionate pattern, where a small number of authors produce the majority of the work, while most authors contribute far less. In other words, the majority of authors will publish only one or two works, while a small group remains highly prolific. The curve supports this concept, demonstrating that most authors (around 75% or more) contribute just a few documents. The number of highly productive authors decreases significantly, with very few producing more than 10 documents.

The solid and dashed lines illustrate the comparison between two distributions. Generally, the dashed line represents empirical data or real observations, while the solid line depicts a theoretical distribution according to Lotka's Law. When the dashed line closely follows the solid line, it indicates that the empirical data conform to the theoretical expectations of Lotka's Law.

In general, this graph demonstrates the typical trend in author productivity, showing that only a few authors are highly productive (with numerous publications), while the majority of authors produce relatively few works, aligning with Lotka's Law.

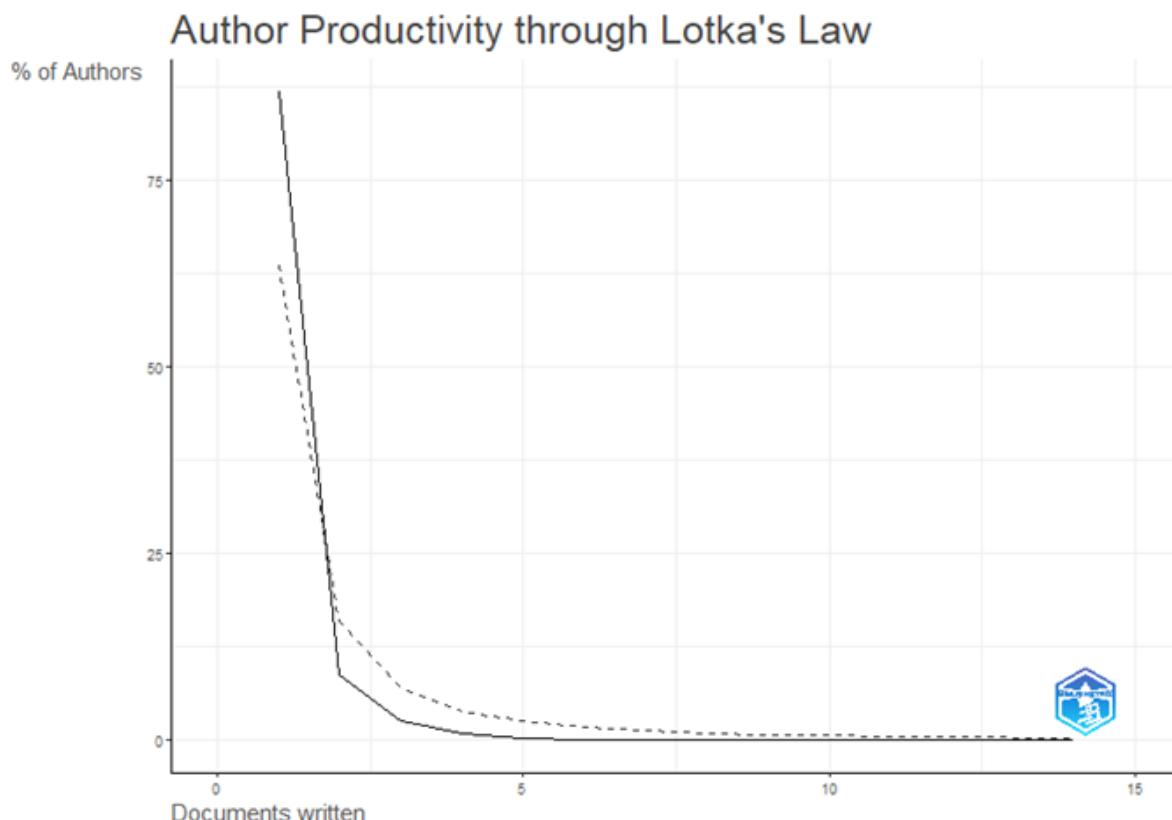


Figure 6. Author Output According to Lotka's Law

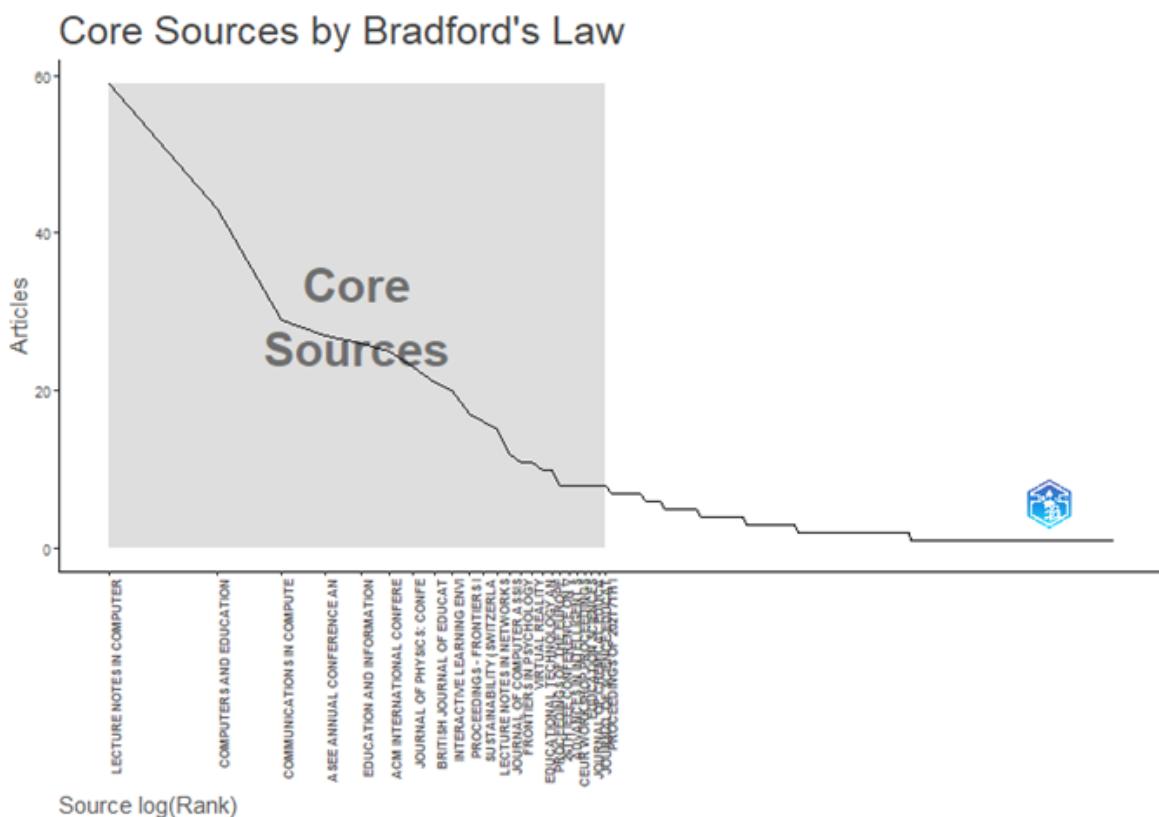
3.2.2. Leading Sources

The publications listed in Table 3 represent the most influential works, led by Lecture Notes in Computer Science (along with its subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), which features 59 articles on virtual reality. This journal has an h-index of 11 and a total of 421 citations, with its first publication dating back to 2009. Computers and Education also stands out, boasting a citation score of 15.6, 4,538 citations, and an h-index of 24, demonstrating its substantial impact in the academic field. This journal has been continuously contributing since 2010, underscoring its ongoing relevance. Meanwhile, Interactive Learning Environments began publishing on virtual reality in 2017, achieving a citation score of 12.1, an h-index of 13, and a g-index of 20, based on 6 scholarly articles. The g-index ranks articles according to their citation distribution, ordering them by the citation count (Egghe, 2006), while the h-index evaluates the number of an author's most cited works and the citations these receive (Hirsch, 2005).

Figure 7 labeled Core Sources by Bradford's Law, depicts the distribution of articles among different sources in accordance with Bradford's Law. This law, commonly used in bibliometrics, explains how articles on a specific topic are distributed among different journals or sources. The graph features a steep decline from left to right, indicating that the majority of articles come from a small number of core sources on the left side, while the rest are scattered across numerous sources contributing fewer articles.

Table 3. Leading Sources and Their Influence Locally

No.	Sources Name	N	Cite Score (2023)	h_index	g_index	m_index	TC	PY_start
1	Lecture Notes In Computer Science (Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	59	2.6	11	19	0,69	421	2009
2	Computers And Education	43	27.1	24	43	1,6	4538	2010
3	Education And Information Technologies	26	10.0	8	17	1,6	302	2020
4	British Journal Of Educational Technology	21	15.6	13	21	0,87	1133	2010
5	Interactive Learning Environments	20	12.1	13	20	1,62	500	2017
6	Sustainability (Switzerland)	16	6.8	10	16	0,91	384	2014
7	Journal Of Computer Assisted Learning	12	9.7	8	10	1,33	291	2019
8	Educational Technology And Society	10	9.1	8	10	0,53	249	2010
9	Journal Of Science Education And Technology	8	9.4	8	8	0,67	230	2013
10	Journal Of Chemical Education	8	5.6	7	8	1,17	132	2019

**Figure 7.** Core Publications According to Bradford's Law

This pattern aligns with Bradford's Law, which asserts that a large proportion of articles on a particular topic originate from a limited number of core journals or sources. The gray-shaded area labeled "Core Sources" represents these key sources, which account for the majority of articles. These core sources are journals or publications that consistently publish the most articles on a given topic, significantly outnumbering other sources. Beyond the core area (after the gray-shaded section), the curve begins to flatten, signifying that non-core sources contribute only a small number of articles.

Figure 7 illustrates the concept of Bradford's Law, which states that articles in a particular field of study are distributed across several layers of sources. The first layer consists of core sources, comprising a small number of journals that contain a large number of articles. Subsequent layers include progressively more journals, but each contributes fewer articles.

In this context, core sources account for the majority of articles, while the remaining sources provide fewer articles and are more dispersed. Overall, Figure 7 highlights that for a specific topic or field, only a small number of journals or sources serve as the primary contributors of relevant articles. Other sources make significantly smaller and more scattered contributions. This insight guides researchers to prioritize core sources when seeking key literature for their topics of interest.

Figure 8 that show The National Taiwan University of Science and Technology and the University of Copenhagen initiated their publications earlier in the observed timeframe, approximately in 2009. The increasing volume of publications from these institutions over time indicates their emergence as significant contributors to research in science education and creativity. Their significance and impact within the field have steadily increased. Examining these trends offers researchers and academics valuable insights into the growing popularity and impact of specific journals and institutions in the discipline.

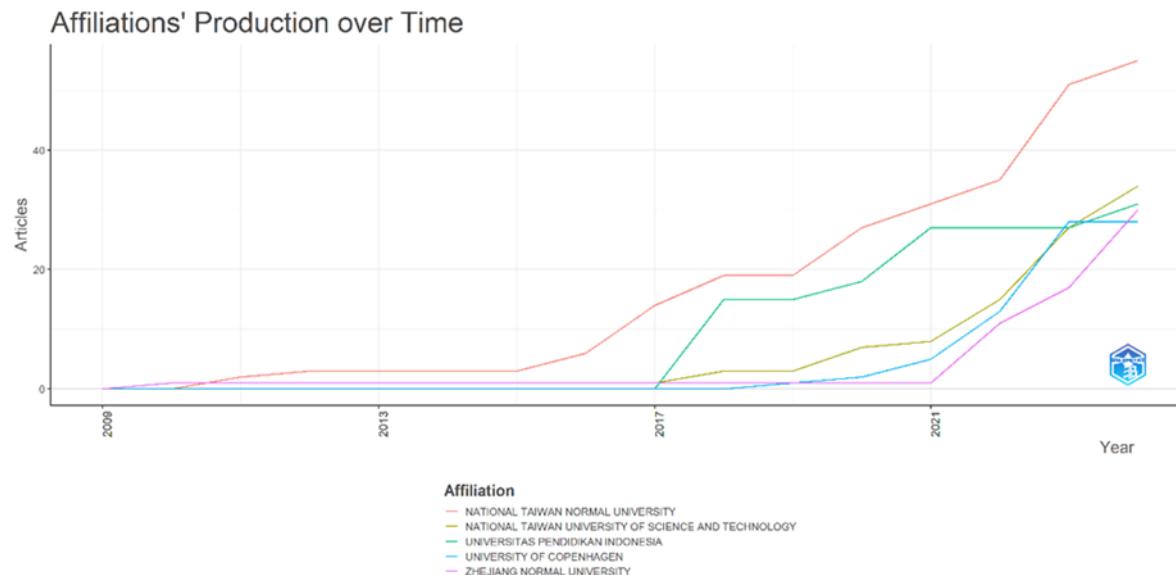


Figure 8. Publication Growth of Leading Sources

3.3. Most Influential Literature

Table 4 displays a compilation of frequently cited articles in the field of virtual reality research, which have had a substantial impact on subsequent studies and have spurred further investigation into this fascinating and multifaceted subject. Most of these articles employ meta-analysis methods.

The top-ranked article is by Merchant Z (2014), which examines the overall effects and the effect of specific instructional design principles in the context of virtual reality-based teaching (such as games, simulations, and virtual environments) in both K-12 and higher education settings. Following this, Hew KF (2010) conducted a study focusing on the use of immersive three-dimensional virtual worlds in educational environments such as K-12 and higher education. Ranked third, Lindgren R (2016) explored how learning and engagement can be enhanced through embodied interaction in mixed reality simulations.

Table 4. The Most Cited Virtual Reality Paper from 1995 to 2024

Rank	Total Citation	TC per Year	Author(s)/years	DOI	Source
1	1058	96.18	Merchant Z/2014	10.1016/j.compedu.2013.07.033	Comput Educ
2	365	24.33	Hew KF/2010	10.1111/j.1467-8535.2008.00900.x	Br J Educ Technol
3	358	39.78	Lindgren R/2016	10.1016/j.compedu.2016.01.001	Comput Educ
4	280	25.45	Lee Ea-L/2014	10.1016/j.compedu.2014.07.010	Comput Educ
5	271	38.71	Markowitz Dm/2018	10.3389/fpsyg.2018.02364	Front Psychol
6	270	18.00	Desai Ra/2010,	10.1542/peds.2009-2706	Pediatrics
7	233	46.60	Chien S-Y/2020	10.1016/j.compedu.2019.103751	Comput Educ
8	233	17.92	Chen C-M/2012	10.1016/j.compedu.2012.03.001	Comput Educ
9	228	22.80	Wei X/2015	10.1016/j.compedu.2014.10.017	Comput Educ
10	222	44.40	Sahin D/2020	10.1016/j.compedu.2019.103710	Comput Educ

3.4. Top Countries And Affiliations

Table 5 presents the quantity of scientific publications by country. The United States ranks first with 1,156 publications, while China holds the top position in both total and average article citations, with 815 articles. Indonesia, Italy, and Spain follow with 260, 240, and 201 articles, respectively. The United States' dominance in publication output can be attributed to its strategic policies and initiatives designed to foster advancements in science, technology, and innovation.

Figure 9 illustrates the number of articles produced per country from 2009 to 2024, highlighting trends in article production across five countries: China, Indonesia, Italy, Spain, and the United States. China (red line) shows a significant increase in article production starting in 2015, with a sharper rise compared to other countries and continued growth through 2022. Indonesia (green line) demonstrates relatively consistent article production with slight year-over-year growth, albeit at a slower pace compared to other nations. Italy (blue line) exhibits steady growth with a modest incline, consistently increasing from 2015 to 2022. Spain (yellow line) follows a similar trend to Italy, showing slow but stable growth in article production. The United States (purple line) records the highest number of articles overall and displays the most significant upward trend from the beginning, maintaining consistent growth through 2022.

Table 5. Countries with the Most Documents and Citations

Country	Frequency	Total Citations	Average Article Citations
USA	1156	4417	33,7
China	815	3156	16,7
Indonesia	260	131	3,1
Spain	201	869	24,1
Italy	240	192	5,8
Korea	95	233	9,7
Greece	123	622	27
Australia	100	646	29,4
Mexico	71	128	6,4
Malaysia	100	168	10,5

The United States and China are the leading countries in terms of article production, and the most significant upward trends. In contrast, other countries such as Indonesia, Italy, and Spain also show growth, but at a slower pace compared to the United States and China. Figure 9 indicates that the United States and China are more active in publishing and producing articles than the other countries.

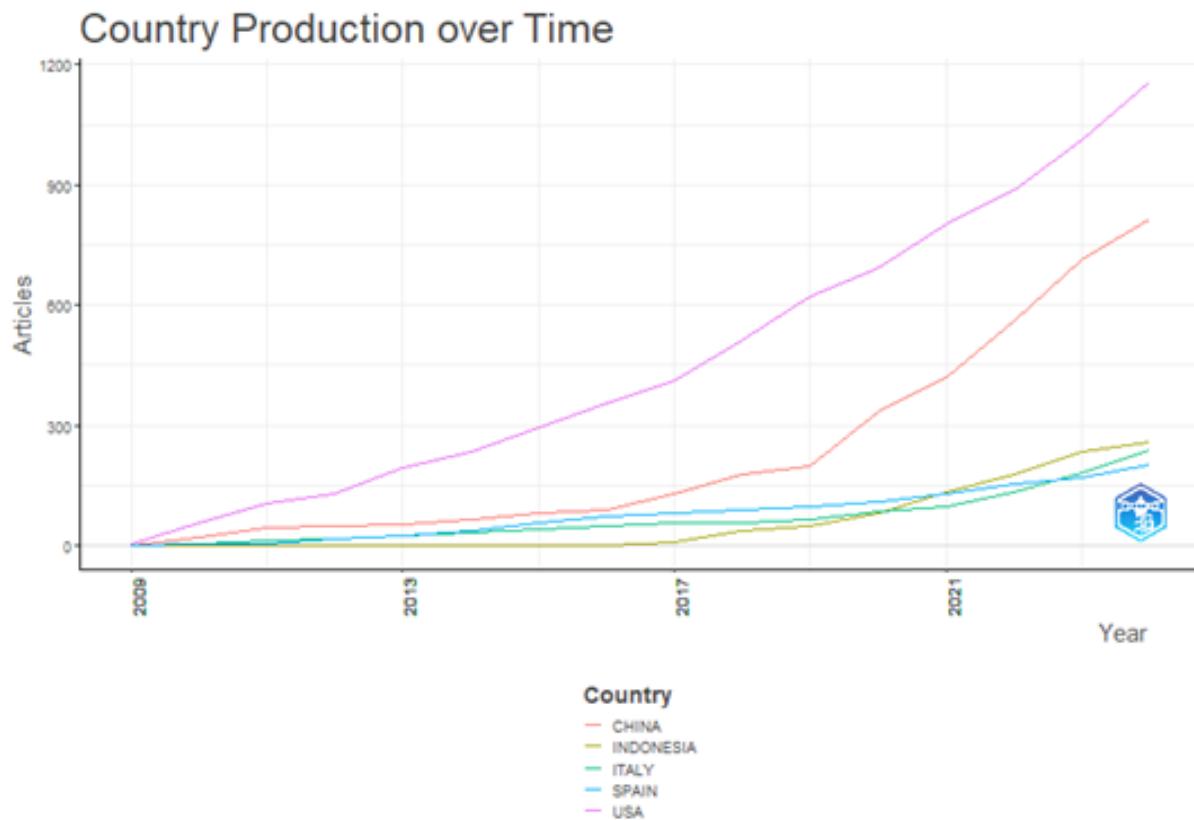


Figure 9. Growth of Virtual Reality Publications by Country

Figure 10 titled Most Relevant Affiliations, showcases institutions with the greatest influence or relevance based on affiliation counts or related metrics. Leading the chart is National Taiwan Normal University, achieving the highest citation score of 55. National Taiwan University of Science and Technology ranks second with a score of 34, followed by Universitas Pendidikan Indonesia with 31, underscoring its notable contribution to the field. Other universities, including Zhejiang Normal University, the University of Copenhagen, and the University of Central Florida, also feature in the chart but with citation scores lower than the top-ranking institutions.

National Taiwan Normal University stands out as the most relevant affiliation in Figure 10, with a significant margin over other institutions. This indicates their substantial influence in the field of virtual reality. Three other institutions—National Taiwan University of Science and Technology, Universitas Pendidikan Indonesia, and Zhejiang Normal University—also demonstrate considerable citation counts or influence, but still fall far behind National Taiwan Normal University. These figures may reflect the volume of research produced, the level of collaboration, or the frequency with which the work from these institutions is cited by others.

Each data point is represented by a circle of varying size. The size of the circle correlates with the citation count or relevance score; the larger the value, the bigger the circle. National Taiwan Normal University has the largest circle, reflecting its top citation score.

Figure 10 reveals that several leading academic institutions have a much greater influence than others. In this case, National Taiwan Normal University dominates in terms of relevance, as measured by citations and recognition. This indicates that the institution is either more productive in academic publications or is more frequently referenced as a primary source in research.

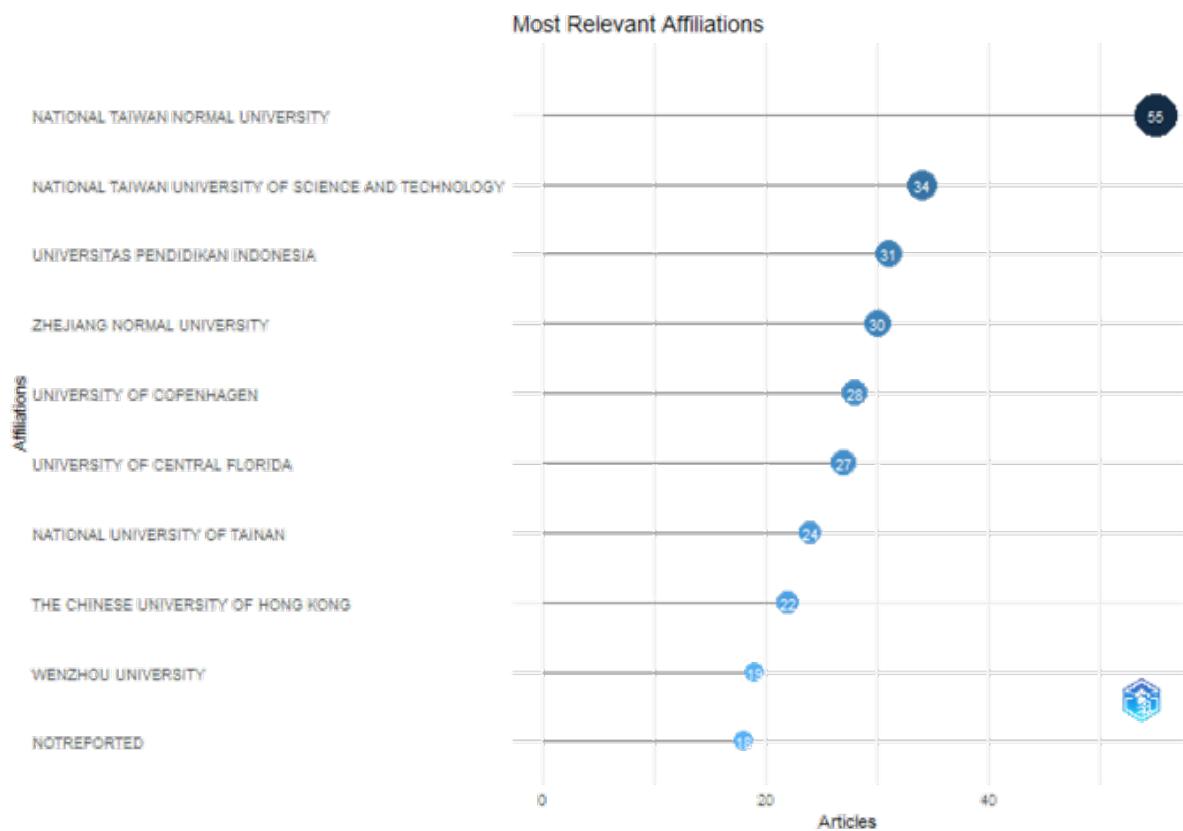


Figure 10. Top Affiliations

The graph indicates that National Taiwan Normal University has the greatest influence among the affiliations listed. This institution, alongside National Taiwan University of Science and Technology, Universitas Pendidikan Indonesia, and Zhejiang Normal University, plays a key role in advancing the field of virtual reality, as illustrated in Figure 10.

3.5. Keywords Trend

Figure 11 displays the distribution of the most relevant words, measured by the frequency of their occurrence within a specific context. The word with the highest frequency, appearing 958 times, is virtual reality, which is positioned at the far right of the graph. This indicates that virtual reality has significantly higher relevance and occurrence compared to other words in the dataset, making it the primary keyword.

Several words have moderate frequencies, such as student with 500 occurrences and e-learning with 423 occurrences. These words are also relevant, though not as prominent as the main keyword, suggesting that they frequently appear and hold significance in the context of this research. Words on the left side of the graph, such as teaching and education, show much lower frequencies, indicating that while they are relevant, their contextual usage is more limited or less frequent.

The size of the dots on the graph reflects that the frequency of appearance is closely related to relevance. Words like virtual reality and student, with high occurrence numbers, are marked with larger circles, indicating that the more frequently a word appears, the more important its position in the data.

From the distribution of the dots, it is evident that the majority of relevant words have low frequencies, while only a few words show very high frequencies. This may suggest a pattern where word usage is centered around a few core terms.

The cumulative frequency development of different terms associated with technology and education from 2009 to 2024 is shown in Figure 12. The term Virtual Reality (marked with a pink line) shows a significant increase in usage from 2018 to 2024, with the highest cumulative frequency by the end of the

period. The topic of Virtual Reality has grown in significance and widely discussed in the context of education.

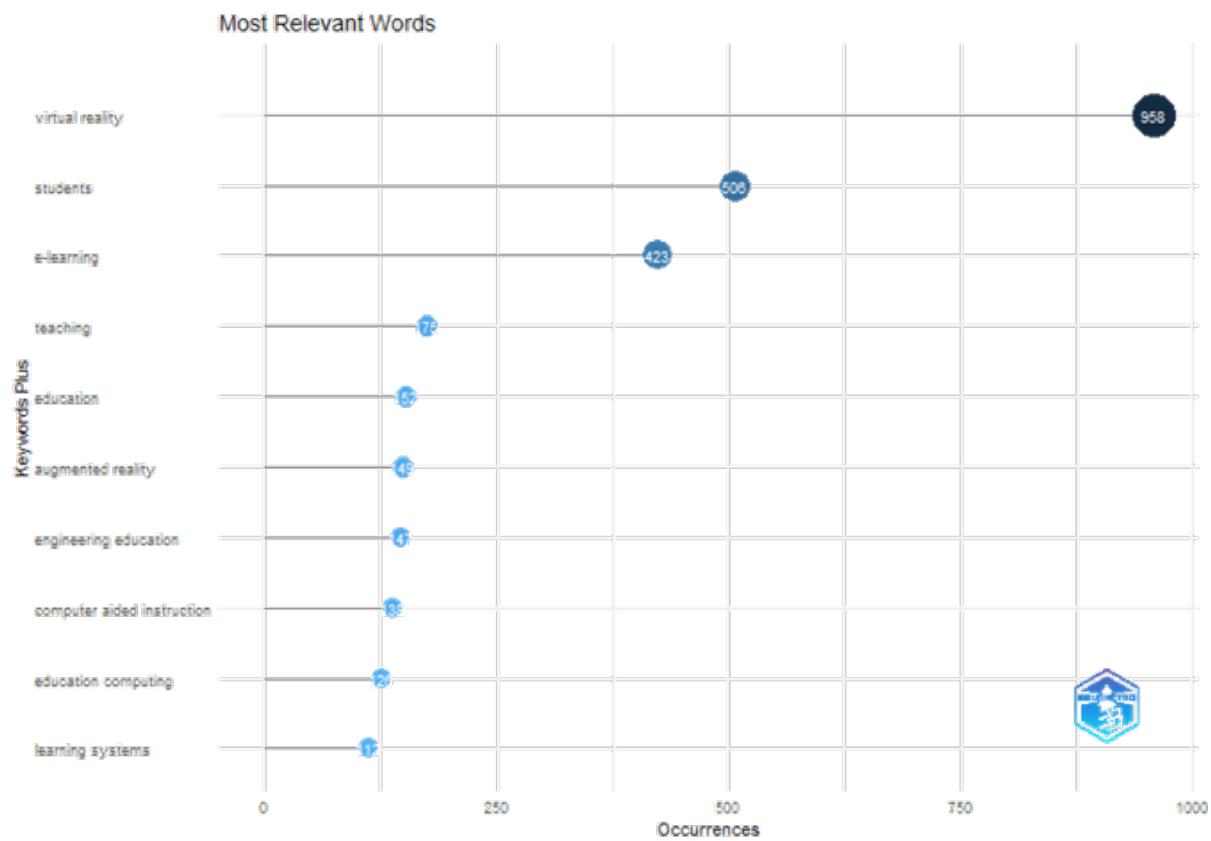


Figure 11. Most Frequent Words

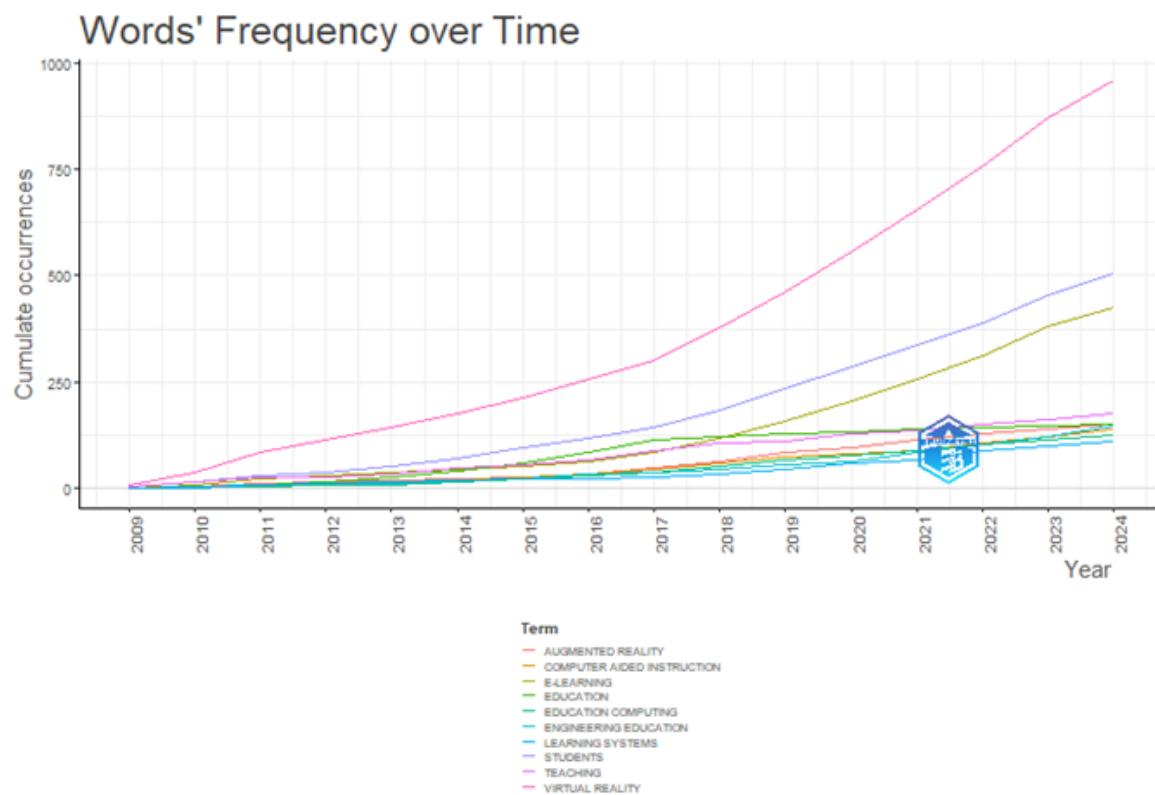


Figure 12. The Occurrence of Words Over Time

Other terms that appear frequently include Augmented Reality and e-Learning, indicating that these technologies also received significant attention in the educational literature. Terms like Education and Computer-Aided Instruction show a steady trend from the start of the period, although their increase is not as pronounced as that of Virtual Reality. E-Learning also demonstrates steady growth over time, in line with the development of digital technologies and the growing adoption of online learning.

Figure 12 demonstrates a notable increase in nearly all terms beginning in 2018. This growth can be linked to the swift progression of technological developments and the shifting educational demands that emphasize greater integration with technology. The shift towards digital education, accelerated by the COVID-19 pandemic, further contributed to this trend.

While all terms have seen growth, there are notable differences in the rate of their occurrence. Terms like Engineering Education, Students, and Teaching have seen slower increases compared to technology-focused terms like Virtual Reality and Augmented Reality. This suggests a shift in focus from traditional educational concepts to more interactive, technology-based learning methods.

Based on Figure 12 research and interest in the field of education are increasingly focused on immersive technologies (VR and AR) and digital learning methods (e-Learning). This shift may influence how curricula are designed and how teaching methods are developed, with an emphasis on technologies that enhance student engagement.

3.5.1 Analysis Of Knowledges Structures

Bibliometric analysis for scientific mapping can explore three primary categories of research questions, providing these insights: (1) Conceptual structure, which enables the examination of prominent research within a particular topic or discipline; (2) Intellectual structure, which helps uncover the core knowledge foundation of a specific research area; and (3) Social network structure, which identifies the contributions of various scientific communities. (Amiruddin et al., 2025).

3.5.2 Structure of Concepts

The concept map or network of relationships between keywords related to virtual reality and students is shown in Figure 13. The words connected to both topics are divided into two main groups, marked in different colors: red and blue. In the blue group, surrounding the terms virtual reality and students, there are words related to technology and education, such as interfaces, learning environments, interactive media, augmented reality, and educational technology. This group represents topics related to the use of VR in learning contexts, interactive learning experiences, and educational technologies applicable to students.

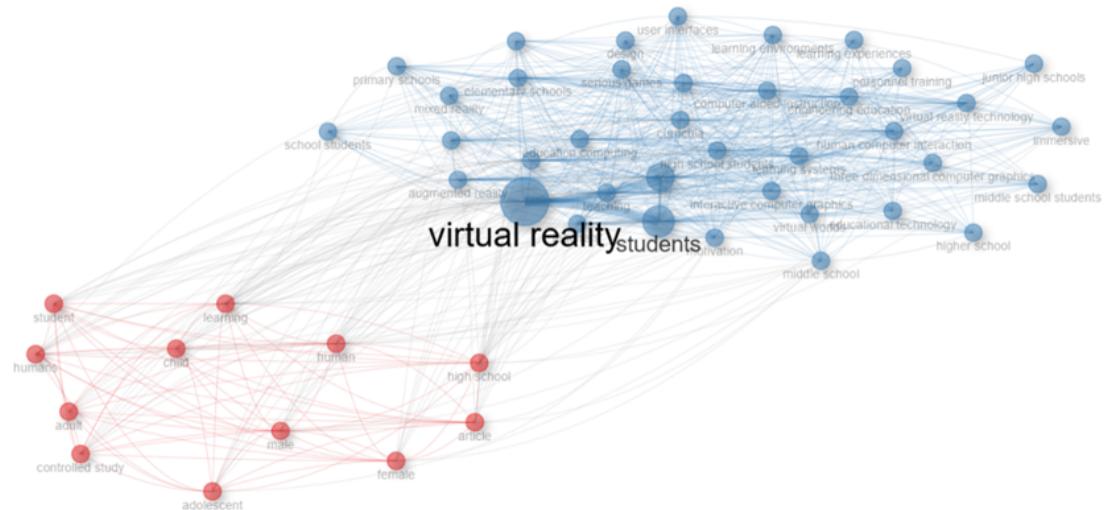


Figure 13. Network of Co-Occurrences

The red group consists of words such as adolescent, male, female, human, and controlled study. This indicates that the red group focuses on demographic aspects and study characteristics. Terms like high school, adolescent, and controlled study suggest that the research also explores VR in the context of specific age groups (such as teenagers) and refers to controlled study designs aimed at understanding the impact of VR on these groups.

Between the red and blue groups, several connecting lines indicate a relationship or connection between educational technology topics and demographic or study characteristics.

Overall, this network map illustrates the main topics and subtopics related to the use of virtual reality in education for students, with a focus on both technology and demographic aspects. It can be used to analyze the direction of VR research in education, its target audience, and the methods used in related studies.

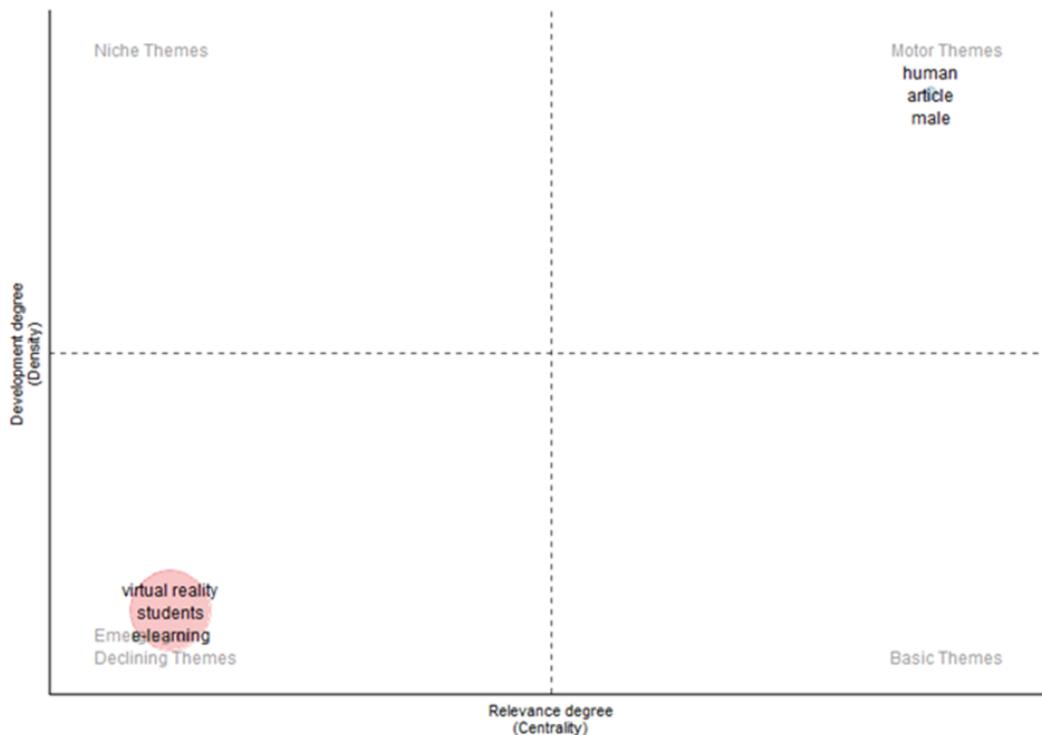


Figure 14. Thematic Map

Figure 14 displays a thematic map based on two dimensions: Development degree (Density) and Relevance degree (Centrality). Each quadrant contains themes with distinct characteristics, which helps to understand the positioning of various related topics within the research. According to this map, the topics of virtual reality and students fall into the category of Emerging or Declining Themes, suggesting that these subjects may still be in the early stages of research or are less relevant in current literature. In contrast, more established and frequently discussed themes, such as human characteristics (e.g., gender), are positioned in the Motor Themes quadrant. This map provides insight that research on VR in the context of students may require further development, while demographic aspects and human characteristics are more prominent themes in the related literature.

Figure 15 presents a flow diagram depicting the evolution of research themes related to virtual reality and various associated topics from 2009 to 2024. The diagram is divided into three periods. During the early period, from 2009 to 2019, research mainly focused on topics like inquiry-based learning, human-computer interaction, gamification, and virtual worlds. These themes suggest that early research in the field was still exploring the fundamental ways in which virtual reality could be applied in education and interaction.

In the period from 2023 to 2024, more advanced themes emerged, such as the metaverse, teacher professional development, empathy, health education, experiential learning, and augmented and virtual reality. This shift indicates that virtual reality is beginning to integrate with other technologies like augmented reality and the metaverse, enabling richer and more interactive learning environments.

This thematic map shows how research on virtual reality in education and skill development has progressed from basic exploration to more specific and complex practical applications. Themes such as the metaverse, empathy, and computational thinking in the most recent period highlight that VR is increasingly recognized as a valuable tool for developing skills beyond academics, including social and professional competencies.

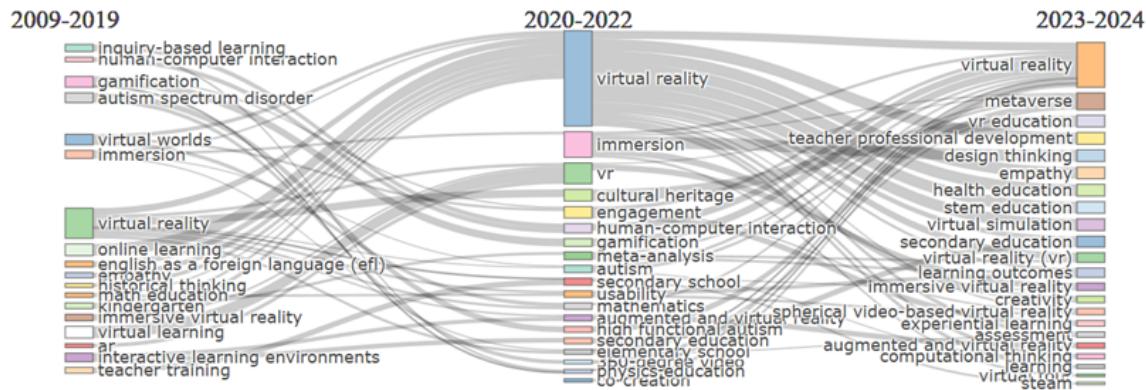


Figure 15. Thematic Evolution

Figure 16 illustrates the conceptual structure map produced using Multiple Correspondence Analysis (MCA). It visualizes various keywords related to learning, educational technology, and human-computer interaction within a two-dimensional space, bounded by Dimension 1 (6.94%) on the horizontal axis and Dimension 2 (5.27%) on the vertical axis. The clustering of keywords in specific areas helps provide insight into the relationships between concepts in educational technology research.

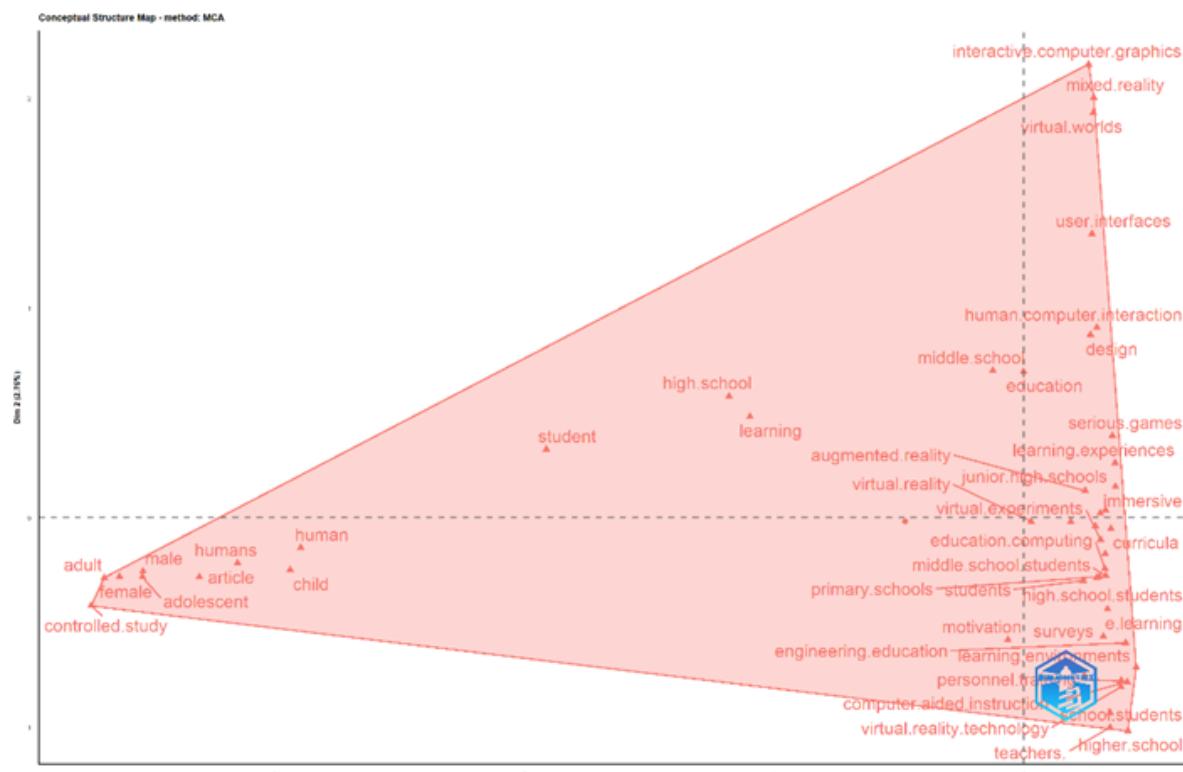


Figure 16. Factorial Analysis Conducted with MCA

In the lower-left area, potential research topics are more focused on demographic aspects or controlled studies involving human subjects. On the other hand, in the upper-right area, keywords like interactive computer graphics, virtual worlds, and user interfaces are more aligned with high-tech research fields such as virtual reality and user interface interactions.

In the lower-right area, there is a grouping of terms related to education, such as engineering education, computer-aided instruction, middle school, high school students, and teachers. This suggests a focus on secondary and higher education, particularly involving computer technology in teaching processes.

Overall, this figure provides a visualization of the relationships between concepts in educational technology. These groupings can serve as a foundation for understanding trends in virtual reality research, especially in exploring the connections between study participants' demographics, technological developments, and educational applications across different school levels.

Figure 17 presents a dendrogram generated from hierarchical cluster analysis, which is a visual representation showing the hierarchical relationships among elements in a dataset. These elements are grouped based on their similarity or proximity to each other.

The vertical axis in this dendrogram indicates the distance or dissimilarity between groups (clusters), with the higher the branching point, the greater the difference between the groups being merged. On the horizontal axis, the objects or variables are represented in red and grouped according to their similarities. From the dendrogram structure, we can observe several main branches that separate at higher levels, indicating that the dataset contains several major groups with significant differences.

At lower levels, these main branches are further divided into smaller subgroups, which show that there are groups with higher similarity among the elements within them. Observing these groups can provide insights into the natural clustering within the data. For example, when applied in research, this could reveal categories or classifications based on specific characteristics.

3.5.3 Structure of Intellectual Foundations

Figure 18 presents a visualization of citation and co-citation networks, depicting the connections between publications through shared references. Each node in the network represents a publication, with the author's name and publication year displayed nearby. The size and color of the nodes represent the significance or citation frequency of the publication, with larger and more prominently colored nodes, such as Makransky G., 2018, indicating higher citation counts or frequent mentions in related studies.

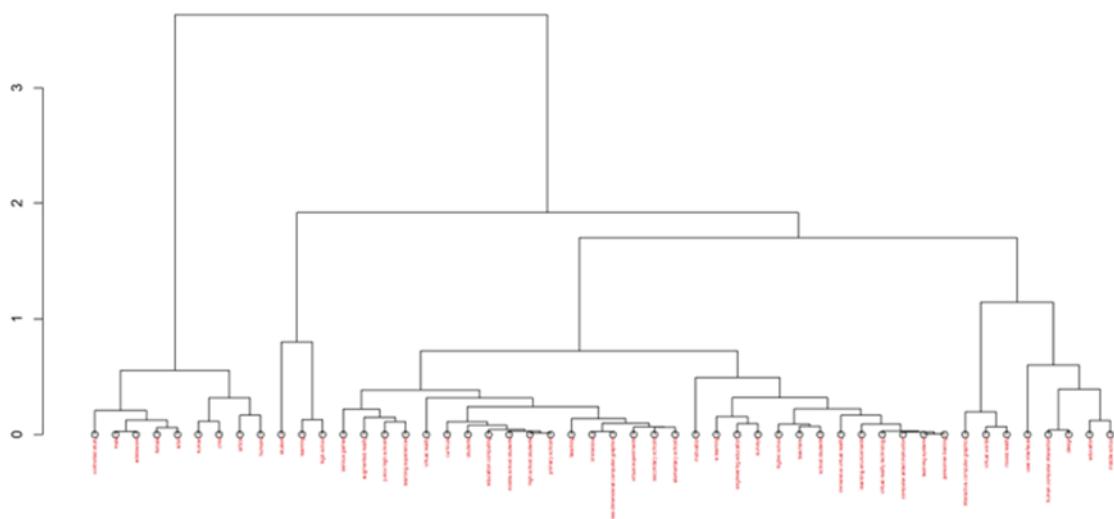


Figure 17. Thematic Dendrogram

The lines linking the nodes represent citation connections between two publications that are often referenced together in other articles. These connections reveal the relevance of the topics or similarities in the research, helping identify clusters or research groups within a specific field. For example, a specific color cluster indicates a group of publications focused on similar research topics or areas.

In Figure 18 several different color clusters are visible, representing distinct yet interconnected subfields of research. Clusters with specific colors, such as purple or green, indicate more specialized research areas, such as science education, educational technology, or learning theory. These clusters are

useful for understanding the direction and evolution of research topics, as well as identifying key studies that form the foundation for developments in the field.

This network visualization is highly valuable in bibliometric analysis, as it helps identify influential publications or authors within a specific research domain. Additionally, this analysis can assist researchers in spotting gaps in the literature and generating ideas for further studies based on frequently co-cited works.

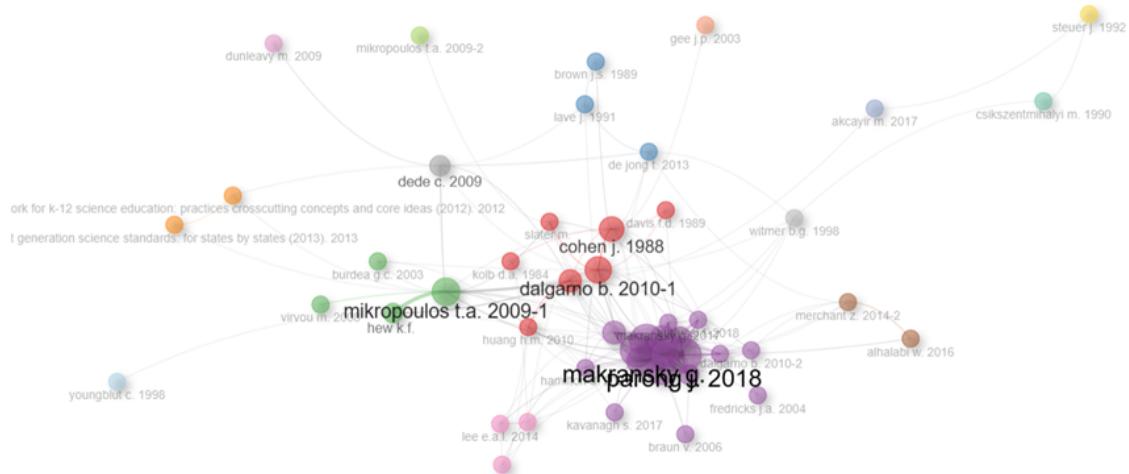


Figure 18. Co-Citation Network

Figure 19 presents a visualization of the academic citation network, which illustrates the citation relationships between research papers. Each point (node) represents a publication, and the lines connecting them indicate citation links between those publications. In academic articles, citation network analysis helps readers understand how research has evolved, identify key contributions in a particular field, and explore the relationships between various scholarly works. This type of visualization can also be used to identify collaboration patterns, dominant research topics, and influential studies that have shaped the direction of future research.

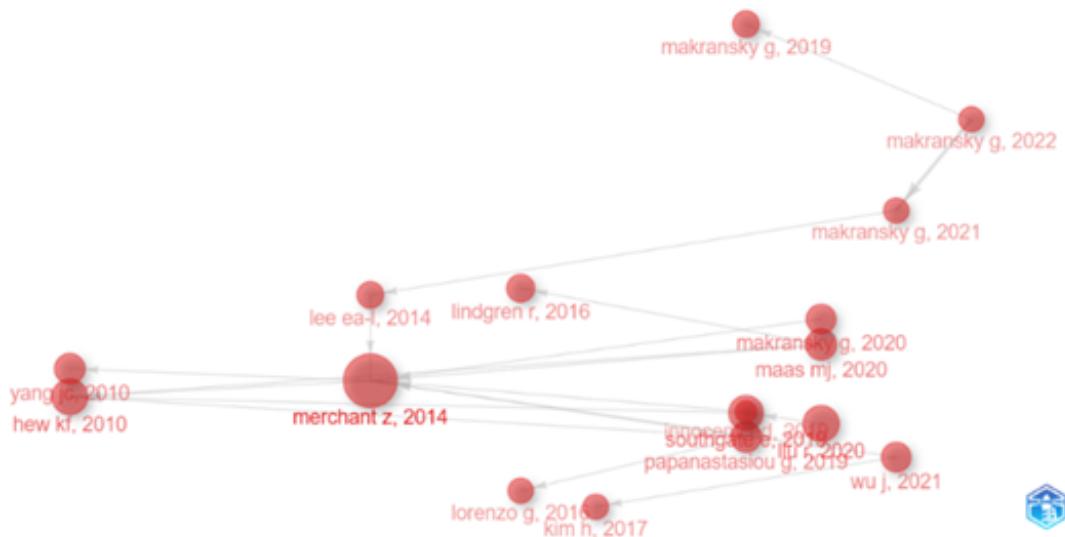


Figure 19. Historiograph Map

Merchant Z, 2014, is highlighted as a publication with a high number of citations or references from other studies within the network. This indicates that this article is a significant and influential reference in the field of study. In Figure 19, some articles appear more isolated or have fewer direct connections with

other publications, suggesting that these studies take a unique approach or focus on areas that may still be emerging and have not yet been widely cited by other research.

By analyzing citation patterns, researchers can identify gaps or opportunities for further investigation. If an article is isolated but addresses a still-relevant topic, there may be an opportunity to develop new research that connects that article with others in the network.

3.5.4 Sosial Structure

Figure 20 presents a visualization of the collaboration network among researchers or academics based on the names displayed. The points and lines connecting the researchers represent collaborative relationships based on joint publications or collaborative research. The size of the name or point reflects the level of connection or the number of collaborations a researcher has within the network.

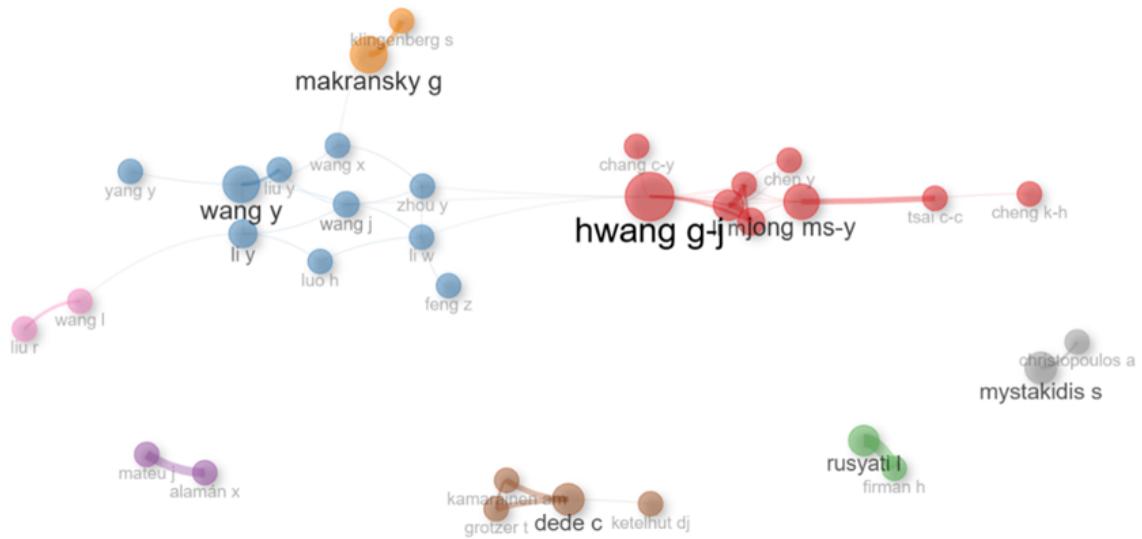


Figure 20. Collaboration Network

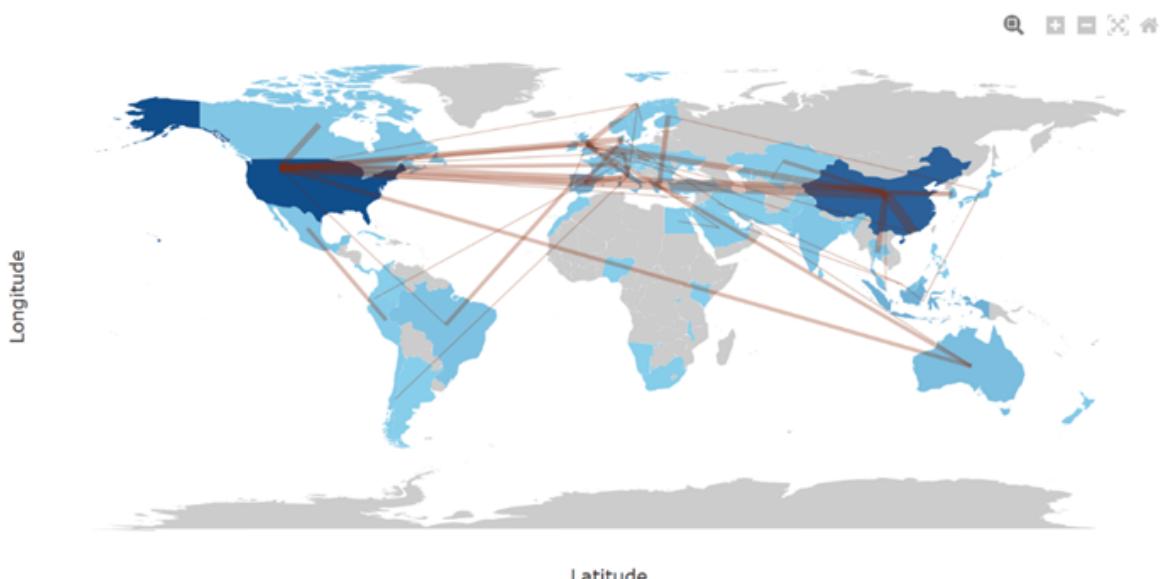


Figure 21. Country Collaboration Map

Names displayed in larger size, such as Hwang G.J and Wang Y, indicate they are central or key figures in the collaboration network. This suggests they are likely the researchers with the highest number of collaborations or have a significant influence within the network. The different colors on the nodes

(points) represent distinct communities within the network, each color signifying a different research topic, institution, or even geographic area that differentiates these groups of researchers.

The lines connecting nodes of different colors show interdisciplinary or cross-institutional collaborations, as well as research across different subjects. Points that are separated from the larger groups, such as Mystakidis S and Rusyati, indicate researchers who work more independently or on more specialized research areas, with fewer connections to the main research groups. This network visualization helps understand the social structure within the research world, revealing how scientific collaboration networks function, identifying collaboration trends, and highlighting potential new areas for collaborative research.

Figure 21 is a world map that uses color and lines to illustrate relationships, where the color intensity and line thickness reflect the strength or frequency of interactions between countries. Countries that are shaded darker (particularly the U.S. and China) act as key centers in this network highlighting their significant role in international relations. These countries have more connections than others, demonstrating their substantial influence within the network. Regions connected by numerous lines show a high level of interconnection with other countries, whether economically, politically, or culturally.

4. CONCLUSION AND IMPLICATION

Bibliometric studies reveal valuable understanding of the development of virtual reality research over the past two decades. As illustrated in Table 6, the field has experienced a remarkable growth rate of 20.68%, with forecasts suggesting continued growth in the future. The U.S. and China stand out as the primary contributors to research output in this field. Analyzing the most frequently cited study, Effectiveness of Virtual Reality-Based Instruction on Students' Learning Outcomes in K-12 and Higher Education: A Meta-Analysis, highlights that much of the prior research has concentrated on advancing virtual reality-based tools, such as games, simulations, and virtual settings, designed for use in K-12 and higher education environments.

Table 6. Overview of the Results

Variables	Information
Count of documents	1300
Yearly growth rate (%)	20,68
Total authors	4067
Leading author	Hwang GJ (14)
Count of sources	623
The leading source in terms of productivity	Computers And Education (n=48)
Top-cited article	Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis
The country with the highest number of publications	USA (n = 1156)
The university with the most documents	National Taiwan Normal University
The most commonly used keywords	Virtual reality, students, e-learning, teaching, education

Acknowledgment. Not Applicable.

Research Ethics. Not Applicable.

Data Availability Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The author declares no conflicts of interest.

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