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Research Trend Virtual Reality in Education: Bibliometric Analysis

Thoriqi Firdaus[1*], Erlina Wardani[2], Silvi Eka Pratiwi[2], Salsa Kurniasih[2], Nurul Hidayah[3], Moch. Ferdi Oktava Putra[2]

[1]*Department of Natural Science Education, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Indonesia*

[2]*Department of Natural Science Education, Faculty of Education, Trunojoyo Madura University, Indonesia*

[3]*Department of Chemistry, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Indonesia*

ABSTRACT

Virtual Reality (VR) has emerged as a groundbreaking technology transforming the global educational landscape. This study seeks to contribute to the understanding of VR's full potential in fostering more inclusive and adaptive learning environments for the future. Employing a quantitative research approach through bibliometric analysis, the data sources were derived from the Scopus database, restricted to the past decade (2014–2023), encompassing a total of 14,958 research documents. Of these, 5,951 articles met the study's eligibility criteria and bibliometric metadata requirements. The average publication age of the documents analyzed is 3.99 years, with an average of 18.72 citations per document. A total of 21,583 authors contributed to the body of research. Journals such as Surgical Endoscopy and the Journal of Surgical Education demonstrated high productivity in terms of publication volume. However, Computers and Education stands out for its citation impact, underscoring the broader influence of research focused on educational technology within the academic community. The United States leads with 1,100 published articles, while keywords frequently associated with virtual reality in education include "Virtual Reality," followed by "human," "Education," "humans," "Clinical Competence," "Female," "adult," and "User-Computer Interface." The surge in publications post-2017 reflects VR's evolution from an experimental technology to a widely accepted educational tool. This study has significant implications for the development of educational technology and the application of Virtual Reality (VR) across various educational levels. With a steady upward trend in publications and high citation rates, the findings underscore VR's immense potential to revolutionize traditional teaching methodologies and create more immersive learning experiences.

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[1] Corresponding author's address: Universitas Negeri Yogyakarta
e-mail: thoriqifirdaus.2023@student.uny.ac.id

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1. Introduction

The development of technology in the Society 5.0 era has transformed educational paradigms through the digitization of learning processes (Firdaus, 2023). Virtual Reality (VR) has emerged as one of the leading technologies revolutionizing the education sector. The integration of VR in education offers immersive learning experiences that enhance conceptual understanding and student engagement in the learning process (Guo et al., 2024). This technology provides realistic simulations enriched with interactivity, creating new opportunities for exploring complex concepts in a safe and controlled environment.

Recent advancements in educational technology, including artificial intelligence and VR, have been shown to facilitate higher-order thinking skills and critical thinking development (Firdaus et al., 2024; Firdaus, 2022). For instance, the integration of interactive multimedia and metaverse-based technologies has been highlighted as a key component in supporting the Merdeka Curriculum for science education, fostering deeper engagement and understanding of scientific concepts (Alifiyah et al., 2023). These advancements align with Society 5.0's vision of merging technology and human-centered approaches for better educational outcomes.

Virtual Reality (VR) is a three-dimensional computer-generated representation in which users are immersed in a real or imaginary environment using headsets (Siivola et al., 2024). This advanced technology allows users to experience a simulated reality via artificial sensory stimulation without affecting their physical surroundings (Lee & Han, 2022). VR systems are categorized into three types: immersive, semi-immersive, and non-immersive. Immersive VR systems fully immerse users in a virtual environment using devices equipped with head-mounted displays, motion sensors, and virtual world experiences. Semi-immersive VR systems provide partial immersion, offering limited presence in the virtual world through larger devices and specialized gloves. Non-immersive VR systems represent the most basic form of VR, allowing interaction with the environment using gamepads, mice, or keyboards (Nicolaidou et al., 2023).

Research trends in VR for education indicate a significant increase in adoption, reflecting the growing integration of digital technology across various educational institutions (Gudyanga, 2024). Bibliometric analysis has become a crucial approach for exploring these trends, enabling the identification of research patterns, key themes, and collaborations among researchers and institutions (Yeoh et al., 2025). Bibliometric studies also highlight VR's contributions to educational innovation, particularly in the post-pandemic era when digital learning has gained heightened relevance (Aldana-Trejo et al., 2024). However, research on VR in education has also addressed challenges, including the need for adequate infrastructure, educator training, and the high costs of implementation (Maryanti et al., 2023).

Virtual Reality (VR) has emerged as a revolutionary technology reshaping the global educational landscape. With its ability to create immersive learning experiences, VR offers a novel approach to understanding complex concepts and facilitating more interactive learning processes (Guo et al., 2024). Despite its promising benefits, several fundamental challenges hinder the adoption and development of this technology in the education sector. One major issue is the lack of systematic mapping of VR research trends in education, including insufficient data on publication patterns, researcher collaboration, and emerging key research themes over recent decades (Gudyanga, 2024).

Virtual Reality (VR) technology in education has been shown to enhance students' confidence and competency development (Rainford et al., 2023). It allows learners to engage deeply with their environment, improving conceptual understanding and facilitating interactive simulations that enable the exploration of complex ideas. These features have been proven to positively impact learning engagement and comprehension (Al-Ansi et al., 2023). For instance, VR simulations in education have been utilized in healthcare training, replicating clinical practices (Rainford et al., 2023). Beyond healthcare, VR technology can also be applied across diverse educational settings, such as exploring historical sites, conducting virtual scientific experiments, and interacting with abstract concepts (Al-Ansi et al., 2023). While VR holds significant potential to transform learning methods, realizing this

potential requires overcoming challenges and fostering strong collaborations to create effective learning strategies. Barriers to VR adoption include high costs, content availability, infrastructure limitations, classroom integration, and clear evaluations of its educational effectiveness (Al-Ansi et al., 2023).

Furthermore, disparities in access to technology, particularly in developing regions, continue to pose significant challenges. Studies in public health compliance during the COVID-19 pandemic illustrate how resource limitations can impact the equitable adoption of advanced tools, including VR (Firdaus et al., 2022). Addressing these disparities requires targeted policy interventions and investment in infrastructure. Infrastructure limitations and high implementation costs are significant challenges, particularly in developing countries with limited access to advanced technology (Maryanti et al., 2023). This disparity creates a digital divide between well-resourced educational institutions and those lacking sufficient resources. Additionally, while much research highlights VR's potential, empirical studies on its long-term learning outcomes and pedagogical implications remain limited (Yeoh et al., 2025). These obstacles underscore the need for interdisciplinary approaches to effectively integrate VR technology into education and maximize its impact. Addressing disparities in technological accessibility may involve leveraging broader philosophical and cultural perspectives to ensure inclusive innovation in education (Nurziana & Firdaus, 2025).

Research into VR trends in education is increasingly critical given the technology's potential to revolutionize learning across various educational levels. VR enables students to experience real-world simulations, providing deeper insights into complex concepts that traditional teaching methods cannot achieve (Guo et al., 2024). It also offers opportunities to create inclusive learning environments, allowing students from diverse backgrounds to engage in more interactive and personalized learning experiences (Maryanti et al., 2023). As the demand for technology-based learning grows in this digital era, a comprehensive understanding of VR adoption is essential to support pedagogical innovation.

Without systematic mapping of VR research trends, gaps in the use of this technology in education may persist. Bibliometric analysis provides valuable insights into research patterns, key themes, and emerging collaborations, which are crucial for guiding future research directions (Gudyanga, 2024). However, infrastructure limitations and high VR implementation costs remain significant barriers for educational institutions, especially in developing nations (Maryanti et al., 2023). Therefore, this research is not only relevant for advancing educational technology but also for creating a more inclusive and efficient education system.

Furthermore, with the growing need to adapt learning to global challenges such as the pandemic, VR emerges as a highly promising tool for supporting remote learning and ensuring educational continuity (Yang et al., 2024). This study aims to extend the exploration conducted by various prior studies on VR's application and impact in education. Maryanti and Sopandi (2023) demonstrated that VR use in biology education not only enhances students' understanding of complex concepts but also offers a more engaging and interactive learning experience. In a broader context, Guo et al. (2024) highlighted how VR in healthcare education has created opportunities for safe, immersive, and practice-based learning simulations, showcasing the technology's flexibility across disciplines.

This study aligns with findings by Toygar et al. (2024), who emphasized how VR and augmented reality (AR) can expand remote learning in maritime education, particularly through analyzing digital trends in the sector. Moreover, research by Gudyanga (2024) on VR adoption in Africa is particularly relevant for identifying implementation barriers in regions with infrastructure challenges. Through bibliometric analysis, this study seeks to address gaps in previous research by providing a more comprehensive understanding of VR publication patterns and trends across various educational contexts. It not only reinforces earlier findings but also offers new perspectives on the dynamics of researcher and institutional collaboration in developing VR as an innovative educational technology. Thus, this research contributes to efforts to realize VR's full potential in creating more inclusive and adaptive learning environments for the future.

This study aims to address a significant deficiency in the current body of research: the lack of a systematic bibliometric analysis of Virtual Reality trends in education. By exploring publication patterns, identifying key research themes, and analyzing collaborative networks among researchers and

institutions, this research provides a comprehensive mapping of VR studies in education over the past decade. Such insights are critical for guiding future research directions and addressing barriers to VR adoption, such as infrastructure limitations and high implementation costs. Additionally, this study seeks to contribute to the development of strategies for more inclusive and effective integration of VR in diverse educational contexts.

2. Virtual Reality

Virtual Reality (VR) is an advanced technology with transformative potential in education, offering opportunities to enhance learning through a higher level of technological engagement (Al-Ansi et al., 2023). VR is recommended as an effective learning tool because it provides immersive and authentic environments. Research demonstrates that VR can improve learning outcomes, reduce learning anxiety, and boost students' creativity (Nicolaidou et al., 2023). Additionally, VR in education facilitates the delivery of complex material, supports deeper learning styles, and offers tangible benefits for the growth of VR technology within the education sector (Al-Ansi et al., 2023).

Technological advancements continue to transform our pedagogical methodologies, with Virtual Reality (VR) being acknowledged for its substantial potential to revolutionize education. VR offers immersive and interactive learning experiences, widely recognized within educational contexts, particularly in the STEM (Science, Technology, Engineering, and Mathematics) disciplines, where it can simulate intricate environments and scenarios (Christopoulos et al., 2024). The conceptual framework reveals that frequently used terminology predominantly includes search-related terms. Words with a high frequency of use include “virtual reality, students, education, student motivation and attention, e-learning, learning systems, immersive learning, immersive virtual reality, and teaching.” It indicates the extensive range of topics explored within the context of VR in education, demonstrating its application not only in general learning but also in various specialized domains (Rojas-Sánchez et al., 2023).

Empirical studies indicate that Virtual Reality (VR) technology holds significant promise in enhancing learning across multiple fields. Research by Sun et al. (2010) demonstrated that a three-dimensional virtual reality (3-D VR) model called the Sun and Moon System aids elementary school students in comprehending abstract and challenging astronomical concepts, such as the relative positions and movements of the sun, moon, and earth. The study revealed that students exposed to the 3-D VR model achieved notably higher grades than those in traditional classrooms. Furthermore, over two-thirds of the students expressed enthusiasm for the 3-D VR model and a desire to share it with peers. These positive outcomes underscore the recommendation to develop additional 3-D VR learning environments.

Another study by Zhang & Liu (2012) explored the application of Virtual Reality technology and physical system simulation in Physical Education and Athletic Training. Simulation technology facilitates replicating directed movements within a virtual environment, enabling participants to exhibit scientifically accurate, rational, and standardized techniques. Recent research highlights that the immersive elements of VR enhance knowledge acquisition, though the complexity of the subject matter influences the impact. Additionally, this study underscores the importance of contextualized learning design to optimize educational outcomes and mitigate disparities. It challenges the “one-size-fits-all” approach to VR education, advocating for a more tailored pedagogical strategy. Consequently, the study emphasizes collaboration between educators and VR developers to create culturally and contextually appropriate interventions (Christopoulos et al., 2024). It illustrates that VR is already employed across various educational fields, improving knowledge acquisition, facilitating understanding of abstract concepts, and enhancing physical training, with results indicating improved student performance and comprehension.

3. Method

3.1 Data Source and Search Strategies

The data source for this research consists of documents from the Scopus database focusing on virtual reality in education. The selection of documents is limited to the last 10 years, specifically between 2014 and 2023. The choice of the Scopus database is based on the platform's extensive

geographical and thematic coverage (Dindorf et al., 2023). The sample search utilizes article titles, abstracts, and keywords with the terms “Virtual Reality" OR “VR” AND "Education," or the following query: (TITLE-ABS-KEY ("Virtual Reality") OR TITLE-ABS-KEY (VR) AND TITLE-ABS-KEY (Education)) AND PUBYEAR > 2013 AND PUBYEAR < 2024.

The initial query resulted in 14,958 documents. These documents were filtered based on several inclusion criteria: (1) only peer-reviewed journal articles, (2) articles published in English, and (3) publications within the specified time frame (2014–2023). Additionally, exclusion criteria were applied: (1) duplicate records, (2) incomplete metadata, and (3) articles not related to the focus of virtual reality in education. After applying these criteria, the final dataset consisted of 6,020 articles, which were then exported in BibTeX format for further analysis.

3.2 Research Design and Data Analysis

This study employs bibliometric analysis. Bibliometric analysis is a quantitative method used to measure, monitor, and analyze scientific literature, providing a systematic and structured understanding of trends, influences, and interrelationships within academic research (Donthu et al., 2021; Roemer & Borchardt, 2015; Zhu et al., 2023). This method utilizes visual mapping techniques to illustrate the progression of article and journal productivity, connections between publications and authors, and patterns of scholarly collaboration (Donthu et al., 2021).

Bibliometric analysis is a statistical approach characterized by precision in exploring and analyzing large volumes of scientific data, revealing variations and highlighting developments within a specific field (Donthu et al., 2021). The purpose of applying bibliometric analysis in this study is to identify research trends in virtual reality over the past decade. The bibliometric analysis in this research follows three steps: defining the objective, selecting the sample, and performing statistical analysis.

Defining the objective

Bibliometric analysis involves several quantitative characteristics of publications, including the evolution of publication trends, the most globally cited articles, citation source analysis and local impact, collaboration analysis among countries and authors, and the development of research issues such as ChatGPT. These characteristics encompass the number of publications and citation frequencies, which reflect shifts in researchers' attention to specific studies over time. Keyword frequency highlights the main topics of research, while subject categories and contributing countries indicate the extent of research application across disciplines and regions.

Selecting the sample

Based on data from 2014 to 2023, a total of 14,958 research documents were published in Scopus. For this bibliometric study, the scope was limited to articles published in journals, resulting in 6,020 articles exported in BibTeX format. Prior to analysis, 69 articles that did not meet the bibliometrix metadata requirements were excluded, leaving 5,951 articles for analysis. The bibliometric metadata results are presented in Table 1.

Table 1. Bibliometric Metadata

MD	Description	MC	Missing %	Status
AU	Author	0	00.00	Excellent
DT	Document Type	0	00.00	Excellent
SO	Journal	0	00.00	Excellent
LA	Language	0	00.00	Excellent
PY	Publication Year	0	00.00	Excellent
TI	Title	0	00.00	Excellent
TC	Total Citation	0	00.00	Excellent
C1	Affiliation	54	0,063194444	Good
AB	Abstract	116	0,107638889	Good

DI	DOI	342	0,260416667	Good
DE	Keywords	721	12.12	Acceptable
RP	Corresponding Author	935	0,674305556	Acceptable
ID	Keywords Plus	1692	28.43.00	Poor
CR	Cited References	5951	100.00.00	Completely missing
WC	Science Categories	5951	100.00.00	Completely missing

MD: Metadata; MC: Missing Counts

Statistical Analysis

This study uses R Studio software with Biblioshiny for bibliometric analysis. R Studio is an Integrated Development Environment (IDE) for the R programming language, which is widely used for statistical analysis and data visualization. Biblioshiny is a web-based graphical interface for the bibliometrix package in R, designed specifically for bibliometric and scientometric analysis. This tool enables researchers to conduct quantitative analyses of bibliographic data extracted from the Scopus database.

4. Result

By employing bibliometric analysis, researchers can identify future research directions within a specific domain through comprehensive visualizations of relationships among articles, journals, keywords, citations, and co-citation networks. These visual representations provide insights into the scientific landscape, identifying foundational studies and mapping potential areas for further exploration (Feng et al., 2017). A recent survey by Ardha et al. (2024) utilized the Scopus journal database to conduct a bibliometric analysis, uncovering research trends in physical education over the past century.

4.1 Descriptive Analysis: Evolution of Publications and the Most Globally Cited Articles

The average age of published documents is 3.99 years, with an average of 18.72 citations per document. A total of 21,583 authors have contributed to research in the field of virtual reality. Upon examination of author contributions, 487 single-author publications were identified, with an average of 4.8 co-authors per document, and international co-authorships accounting for 20.87%. The frequency of research output between 2014 and 2023 is depicted in Figure 1.

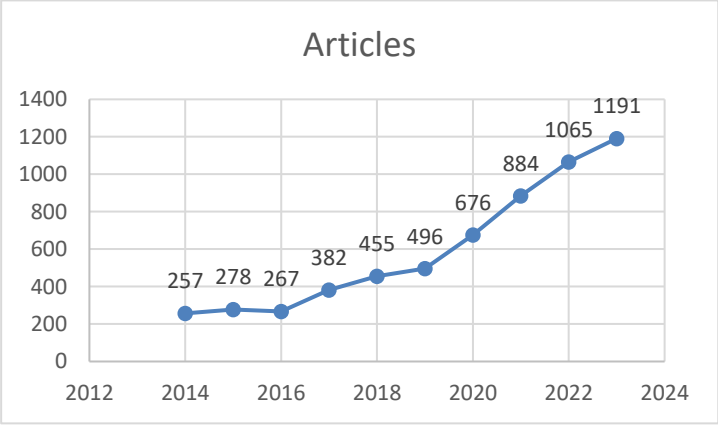

Figure 1. Annual scientific production

Figure 2 illustrates the publication trends for documents discussing virtual reality in education, which show a significant annual increase. While there was a slight decline in publication activity in 2016, the period from 2017 to 2023 exhibits a consistent upward trajectory. The steady growth in

publications highlights the increasing impact of virtual reality within the educational domain. This trend is further supported by the average citation per year metrics presented in Table 2.

Table 2. Average citation per year

Year	MTCA	N	MTCY	CbY
2014	34,86	257	3,17	11
2015	30,35	278	3,04	10
2016	31,30	267	3,48	9
2017	28,36	382	3,54	8
2018	30,82	455	4,40	7
2019	27,75	496	4,62	6
2020	26,64	676	5,33	5
2021	15,73	884	3,93	4
2022	9,84	1065	3,28	3
2023	3,89	1191	1,95	2

MTCA: Mean TC Per Art;
MTCPY: Mean TC Per Year;
CbY: Citable Years

Table 2 presents metrics on the average citation per year from 2014 to 2023, including the average citation rate per article, the number of cited articles, the yearly average citation percentage, and total citations for each year. The highest average citation per article was recorded in 2014 at 34.86, which declined to 3.89 in 2023. This decline is not indicative of the lack of impact of recent articles but rather reflects the foundational role of 2014 research as a reference point for subsequent studies. Articles published earlier typically accumulate more citations over time. This aligns with the decline in the number of citable years, decreasing consistently from 11 years in 2014 to just 2 years in 2023.

The number of articles published increased significantly from 2014 to 2023. In 2014, 257 articles were published, rising to 1,191 articles in 2023. This increase reflects the growing productivity and availability of resources for publication. Additionally, the average citations per year remain relatively stable, with some fluctuations over the years. The highest average, 5.33, was recorded in 2020, while the lowest, 1.95, occurred in 2023. These fluctuations may result from factors such as trending research topics or changes within the academic community. These data are also closely related to citation sources and local impact.

4.2 Citation Source Analysis and Local Impact

Figure 2 presents a horizontal bar chart illustrating the number of documents published by various journals or sources. Surgical Endoscopy emerges as the journal with the highest number of publications, totaling 115 documents. This highlights its productivity in publishing research related to virtual reality. Following this, the Journal of Surgical Education ranks second with 89 documents, emphasizing its focus on surgical education and significant contributions to the scientific literature in this field.

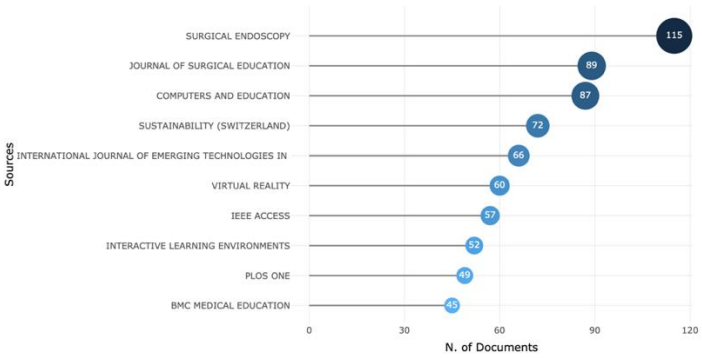

Figure 2. Most productive sources

Computers and Education and Sustainability (Switzerland) have published 87 and 72 documents, respectively, reflecting a strong interest in research on computer-based education and sustainability-focused studies. The International Journal of Emerging Technologies in Learning has published 66 documents, underscoring its focus on emerging technologies in education, while the journal Virtual Reality, with 60 documents, showcases the growing interest and significant attention toward research in virtual reality applications.

IEEE Access and Interactive Learning Environments contributed 57 and 52 documents, respectively. IEEE Access is a broad open-access journal covering various engineering and technology fields, whereas Interactive Learning Environments focuses on interactive learning environments. Additionally, PLOS ONE and BMC Medical Education have each published 49 documents. PLOS ONE is a wide-reaching open-access journal covering various scientific disciplines, while BMC Medical Education concentrates on medical education.

The journals included in Figure 2 were selected based on their productivity in publishing the highest number of documents on virtual reality in education. These journals represent key sources within the field, contributing significantly to advancing VR-related knowledge and applications. Their inclusion provides insights into the most active platforms for disseminating VR research in education.

This analysis reveals a range of journals with diverse focuses, from surgical endoscopy to educational technology and sustainability. The number of published documents reflects the productivity and research emphasis of each journal. The relevance of sources is visually distinguished by a gradient pattern, with the most productive sources marked by darker blue tones, transitioning to lighter blue as relevance diminishes. Alongside the data on the most productive sources, attention should also be given to the local impact metrics presented in Table 3.

Table 3. Source Local Impact

Source	h_index	g_index	m_index	TC	NP
Computers and Education	43	87	3,909	8449	87
Surgical Endoscopy	27	49	2,455	3047	115
Journal of Surgical Education	26	50	2,364	2832	89
Sustainability (Switzerland)	23	36	2,091	1470	72
Interactive Learning Environments	22	38	2,2	1511	52
British Journal of Educational Technology	21	38	1,909	1462	41
Virtual Reality	21	47	2,333	2231	60
Plos One	19	31	1,727	1026	49
Ieee Access	18	33	2,25	1143	57

International Journal of Emerging Technologies in Learning	18	32	1,636	1148	66

Computers and Education has the highest h-index, indicating that a significant number of its articles are highly influential. With strong g-index and m-index metrics, the journal demonstrates consistent and impactful contributions to computer-based education research. Its high total citation count underscores its frequent referencing in scientific literature. While Surgical Endoscopy has the highest number of publications (115), its h-index and g-index are lower than those of Computers and Education. Nevertheless, its high citation count signifies substantial local impact in surgical endoscopy research. The Journal of Surgical Education, with an h-index approaching that of Surgical Endoscopy and a slightly higher g-index, shows that its articles in surgical education are both impactful and productive.

Sustainability (Switzerland) emphasizes sustainability research with a relatively high h-index, reflecting its significant influence within the local academic community. Interactive Learning Environments, focusing on interactive learning, demonstrates metrics indicating a substantial local impact in the scientific community. Although the British Journal of Educational Technology has a lower publication count, its high h-index and g-index highlight its considerable influence in educational technology research. Meanwhile, Virtual Reality, focused on virtual reality applications, shows metrics confirming the strong impact of its articles within the scientific community interested in this technology.

As a broad open-access journal, PLOS ONE has metrics indicating moderate impact across various scientific fields. IEEE Access, emphasizing engineering and technology, demonstrates metrics showing significant impact within the scientific community. The International Journal of Emerging Technologies in Learning highlights new technologies in education, with metrics indicating its articles have a notable local impact within the academic community.

Overall, the table demonstrates that various journals have significant local impacts within their respective scientific communities, as evidenced by metrics such as the h-index, g-index, and citation counts. Journals like Computers and Education and Surgical Endoscopy show particularly strong impacts, while others, such as Virtual Reality and Sustainability (Switzerland), also wield substantial influence in their respective fields.

4.3 Collaboration Analysis: Countries and Authors

Table 4 presents a list of the most productive authors based on the number of articles they have written and the fractionalized count of their contributions. The fractionalized count means the articles are weighted according to the contribution of each author.

Table 4. Most productive author

Authors	Articles	Articles Fractionalized
Konge L	60	10,75
Andersen Saw	32	7,23
Wang Y	30	6,87
Liu Y	29	8,05
Li J	28	6,26
Wang X	27	6,86
Li Y	26	4,60
Zhang Y	26	6,55
Sørensen Ms	24	5,56
De S	22	2,85

According to Table 4, Konge L leads the list with 60 articles and a fractionalized value of 10.75, indicating that despite having the highest number of articles, his contribution per article is relatively smaller compared to some other authors. However, much of Konge L's research focuses on medicine, particularly due to the longstanding adoption of virtual reality (VR) simulation training in aviation and its rapid adoption in medical education (Konge et al., 2014).

Andersen Saw and Wang Y follow with 32 and 30 articles, respectively. Their fractionalized values are 7.23 and 6.87, reflecting significant contributions, though not as extensive as Konge L. Liu Y has authored 29 articles but with a higher fractionalized value (8.05) compared to Wang Y, indicating a greater contribution per article. Authors like Liu Y and Zhang Y demonstrate relatively high fractionalized values compared to their total article counts, signifying significant input to each article they authored. Conversely, authors such as DE S, with a fractionalized value of 2.85 for 22 articles, indicate that many of the articles were collaborative with minimal individual contributions.

Table 4 provides critical insights into the most influential authors in a scientific domain based on their article counts and fractionalized contributions. It aids in identifying key contributors to scientific research and serves as a foundation for further analysis of collaboration trends and productivity within the academic community. Beyond the relevance of authors, it is essential to analyze the local impact of authors as presented in Table 5.

Table 5 highlights the local impact of leading authors based on several indices and scientific metrics. The h-index measures an author's productivity and scientific impact, determined by the number of publications that have received at least as many citations as the count. The g-index assesses the cumulative citation distribution, placing greater emphasis on highly cited articles. The m-index represents the ratio of the h-index to the number of years since the author's first publication, indicating the growth rate of research impact.

Table 5. Authors Local Impact

Author	h_index	g_index	m_index	TC	NP
Konge L	22	38	2	1613	60
Del Maestro Rf	16	18	1,455	827	18
Winkler-Schwartz A	16	22	1,6	925	22
Ahmed K	14	18	1,4	679	18
Andersen Saw	14	26	1,4	742	32
Dasgupta P	13	17	1,3	650	17
Li Y	13	22	1,182	505	26
Makransky G	13	19	1,857	1850	19
Sørensen Ms	13	22	1,3	523	24
Azarnoush H	12	13	1,2	591	13

Konge L leads with an h-index of 22, a g-index of 38, and an m-index of 2, with 1,613 citations from 60 publications. This indicates not only high productivity but also significant scientific influence, as his work is frequently cited. Makransky G shares the same h-index as Li Y and Sørensen Ms but has a higher m-index (1.857) and a substantial total citation count of 1,850, highlighting significant contributions within a relatively short time frame.

Authors like Winkler-Schwartz A and Andersen Saw have h-indices of 16 and 14, respectively. Their relatively high g-indices demonstrate that their work has a broad impact across various highly cited publications. Makransky G has the highest m-index (1.857), indicating rapid growth in research impact, signifying that while his productivity may not match other authors, the scientific influence of his work is expanding quickly.

Authors like Konge L and Makransky G illustrate that a higher publication count does not always correlate directly with a greater number of citations; the quality and relevance of research also play critical roles in how frequently an article is cited. Andersen Saw and Winkler-Schwartz A demonstrate a good balance between publication count and impact measured through citations. Meanwhile, authors such as Azarnoush H, with an h-index of 12 and 591 total citations, indicate that despite fewer publications, their work holds significant influence in the scientific community, emphasizing the importance of research quality.

Author local impact is closely tied to the countries of corresponding authors. Table 6 provides data on the countries of corresponding authors, including the number of articles they have contributed, the percentage of articles, and the distribution of Single-Country Publications (SCP) and Multiple-Country Publications (MCP).

Table 6. Corresponding authors countries

Country	Articles	Articles %	SCP	MCP	MCP %
USA	1100	18,5	960	140	12,7
China	722	12,1	600	122	16,9
United Kingdom	286	4,8	205	81	28,3
Korea	227	3,8	193	34	15
Germany	208	3,5	166	42	20,2
Canada	193	3,2	127	66	34,2
Australia	175	2,9	129	46	26,3
Spain	175	2,9	130	45	25,7
Denmark	124	2,1	91	33	26,6
Italy	113	1,9	89	24	21,2

The USA leads with 1,100 articles, representing 18.5% of the total. Of these, 960 are SCPs involving only US authors, while 140 are MCPs from international collaborations, with an MCP rate of 12.7%. China follows with 722 articles (12.1% of the total), including 600 SCPs and 122 MCPs, indicating that most of China's research remains national, though its MCP rate (16.9%) surpasses that of the USA.

Countries with high international collaboration rates, such as Canada, demonstrate the highest MCP percentage at 34.2%, with 66 out of 193 articles published through international collaboration. The United Kingdom, with an MCP rate of 28.3%, also shows a strong inclination for international collaboration, with 81 of 286 articles resulting from such efforts. Germany, Spain, and Denmark also make significant contributions to international publications. While their total article counts are lower than those of the USA or China, their MCP rates are relatively high (20.2% for Germany, 25.7% for Spain, and 26.6% for Denmark), indicating active participation in global research collaborations.

Italy has an MCP rate of 21.2%, reflecting substantial involvement in international collaboration despite producing fewer total articles. Korea, with most of its research being national (SCP) and an MCP rate of 15%, also demonstrates notable international collaboration, though it lags behind several European countries. Corresponding author countries are closely related to countries' scientific production, as depicted in Figure 3.

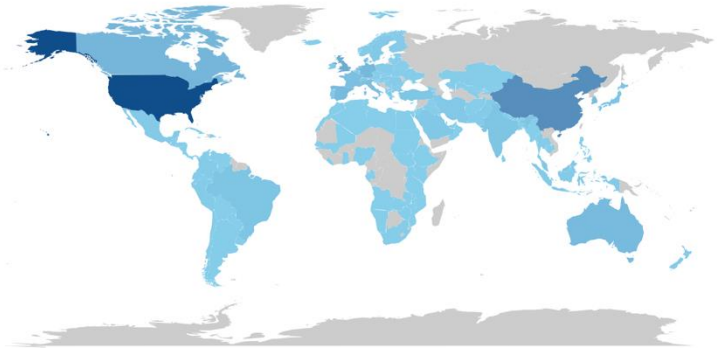

Figure 3. Countries scientific productions

Figure 3 illustrates a world map showing the scientific production on virtual reality in education by country. Countries are shaded in blue, with darker shades indicating higher scientific output, while lighter shades represent lower output. Some countries are shown in gray, indicating either unavailable data or very low production levels.

The United States appears in the darkest shade of blue, signifying its position as the leading country in scientific production. This aligns with its status as a hub for research and development, supported by numerous renowned universities and research institutions. Countries like Germany, the United Kingdom, and France also display darker blue shades, indicating high levels of scientific output. Europe as a whole demonstrates strong academic infrastructure and research programs contributing to high scientific output.

Asian countries like China and Japan also display dark blue shades, reflecting significant scientific production. Both nations have heavily invested in research and development, particularly in technology and science. Meanwhile, developing countries like India, Brazil, and South Africa show lighter blue shades, indicating scientific production, though at lower levels compared to developed nations.

Countries with high scientific production typically allocate substantial budgets for research and development. These budgets include funding for universities, research institutions, and scientific projects. Countries with numerous renowned universities and postgraduate programs tend to produce more scientific publications. International research collaborations also contribute to the number of publications, with many studies conducted through cross-country partnerships.

Table 7 provides data on the total citation count (TC) and average citations per article for various countries. It includes the total number of citations received by articles from each country and the average citations received per article.

Table 7. Most cited countries

Country	TC	Average Article Citations
USA	23420	21,30
China	9944	13,80
United Kingdom	8112	28,40
Australia	5079	29,00
Denmark	4974	40,10
Canada	4669	24,20
Spain	4030	23,00
Germany	3242	15,60
Korea	3073	13,50
Turkey	2189	21,00

The USA achieves the highest total citation count, with 23,420 citations and an average of 21.30 citations per article. This demonstrates that US research is not only prolific in terms of article count but also significantly impactful in the scientific field. China, despite its high article output, has a lower total citation count (9,944) and average citations per article (13.80) compared to countries like the USA and the United Kingdom. This suggests that while productivity is high, the per-article impact is relatively lower.

Denmark stands out with the highest average citation per article at 40.10, indicating that although Denmark produces fewer articles, the quality and relevance of its research are exceptionally high. Australia, with an average of 29.00 citations per article, also shows significant impact, with its research frequently cited in the global scientific literature.

European countries like the United Kingdom receive 8,112 total citations with an average of 28.40 citations per article, striking a balance between productivity and scientific impact. Germany and Spain, with average citations per article of 15.60 and 23.00 respectively, indicate that while their productivity is commendable, there is room to increase their scientific impact by focusing on globally relevant topics. Countries like China and Korea, with lower average citations per article (13.80 and 13.50), suggest that their articles, despite being numerous, do not consistently achieve the same impact as those from countries with higher citation averages. Turkey, with 2,189 total citations and an average of 21.00 citations per article, positions itself in the middle, showing that while its contribution is smaller compared to larger countries, its per-article impact is competitive.

4.4 Development of Virtual Reality Research Issues

Table 8, Most Cited Document, presents data on the 10 most-cited articles. The information includes the author names, year of publication, publication source, total citations, and average citations per year. The most-cited article is by Radianti J, with 1,262 citations, followed by Merchant Z with 1,023 citations, Dwivedi YK with 888 citations, Lee Ventola C with 785 citations, Jensen L with 758 citations, Makransky G with 698 citations, Li X with 663 citations, Chick RC with 642 citations, Potkonjak V with 583 citations, and Moro C with 530 citations.

Table 8. Most cited document

Paper	DOI	Total Citations	TC per Year
Radianti J, 2020	10.1016/j.compedu.2019.103778	1262	252,40
Merchant Z, 2014	10.1016/j.compedu.2013.07.033	1023	93,00
Dwivedi Yk, 2022	10.1016/j.ijinfomgt.2022.102542	888	296,00
Lee Ventola C, 2014	PMID: 25336867	785	71,36
Jensen L, 2018	10.1007/s10639-017-9676-0	758	108,29
Makransky G, 2019	10.1016/j.learninstruc.2017.12.007	698	116,33
Li X, 2018	10.1016/j.autcon.2017.11.003	663	94,71
Chick Rc, 2020	10.1016/j.jsurg.2020.03.018	642	128,40
Potkonjak V, 2016	10.1016/j.compedu.2016.02.002	583	64,78
Moro C, 2017	10.1002/ase.1696	530	66,25

Figure 4, Word Cloud, presents the most frequently occurring words related to virtual reality in education. The most prominent word is "Virtual Reality," followed by terms like "human," "Education," "humans," "Clinical Competence," "Female," "adult," and "User-Computer Interface."

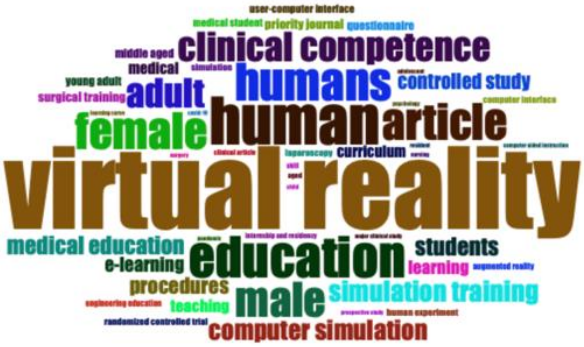

Figure 4. Wordcloud

The word cloud is a visual representation of textual data where the size of each word corresponds to its frequency in the text. In this word cloud, "virtual reality" is the most prominent term, indicating that the study focuses on the concept of virtual reality and related elements. Virtual Reality dominates the word cloud, highlighting it as the primary focus of the study or articles. Discussions around virtual reality encompass its applications, benefits, and potential impacts. Terms like "education," "medical education," and "training" suggest that VR is being explored as a tool for educational purposes, particularly in medical or clinical training environments. The integration of VR in these areas offers innovative methods for teaching and skill development. Frequent terms like "human," "male," "female," and "adult" point to the involvement of human subjects in these studies. These terms relate to study demographics or considerations of gender and age in research design.

The term "clinical competence" implies that the studies assess how VR can enhance clinical skills and competencies in healthcare professionals. This may include simulations or immersive experiences designed to improve practical skills. Words like "computer simulation" and "simulation training" underscore the focus on VR technology applications, exploring how simulations can serve as training tools in medical education.

The word cloud demonstrates that virtual reality is being explored as a critical tool in education and clinical settings. The emphasis on human participants, particularly in medical education contexts, suggests the practical application of VR in improving learning outcomes and clinical skills. Further research delves into the effectiveness of VR in these areas, comparing it to traditional methods and examining its long-term impact on clinical competencies.

Figure 5 presents a co-occurrence network, illustrating the connections between terms or keywords used in studies or articles. The network visualizes how these words are interconnected and how often they appear together in specific contexts. The size of each node represents the frequency of the term, while the thickness of the edges connecting the nodes indicates the strength of their co-occurrence.

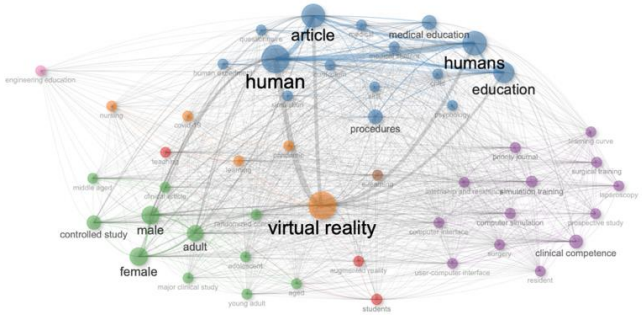

Figure 5. Co-occurrences network

Figure 5 shows Virtual Reality as the central node in the network. The term "virtual reality" occupies a central position with numerous connections to other terms, indicating that it is the main focus

of the study and closely related to many other discussed concepts. This highlights the central role of virtual reality in the research, connected to various other aspects. Additionally, terms like "human" and "article" also hold central positions with multiple connections, especially to "virtual reality." This suggests that the studies extensively discuss the role of humans in the context of virtual reality, focusing on participation, impact, or acceptance of the technology. The connection to "article" likely refers to literature references or theoretical frameworks involving human aspects in VR studies.

The terms "education" and "clinical competence" are also connected to "virtual reality," indicating that the studies explore how VR can enhance education, particularly in medical or clinical contexts. These connections reflect a focus on VR as a tool for teaching and practical training to improve clinical competencies. Meanwhile, terms like "male" and "female" appear lower in the network but remain connected to "virtual reality," suggesting that demographic factors, particularly gender, are considered in the studies. This could indicate how VR is perceived or utilized across different demographic groups.

5. Discussion

This study highlights various critical dimensions of Virtual Reality (VR) usage in education, demonstrating its continued evolution as a relevant and active field. The publication rate of an average of 3.99 documents per year and an average of 18.72 citations per document reflects the high quality and relevance of research in this domain. These figures indicate that VR research in education is not only active but also highly influential within the scientific community, with many articles serving as references for subsequent studies.

Participation by 21,583 authors, including 487 independent contributors, reflects widespread interest in this topic. An average of 4.8 authors per document suggests a significant level of collaboration, an important indicator of the complexity and multidisciplinary nature of the research. International collaborations constitute 20.87% of all documents, highlighting the importance of global perspectives in understanding and advancing VR technology for education. Such collaborations foster knowledge transfer and the exchange of ideas across countries, contributing to innovation and diversification in research approaches. Global collaborations have been shown to enhance the adoption of technology in diverse educational contexts (Yeoh et al., 2025), addressing global challenges such as accessibility and scalability (Firdaus et al., 2025)

The publication frequency between 2014 and 2023 shows an upward trend, with a sharp increase after 2017. This growth can be attributed to factors such as broader technology adoption, reduced VR hardware costs, and increased awareness of VR's benefits in education. The temporary decline in 2016 may reflect early challenges in technology adoption, such as high costs, insufficient infrastructure, or technical barriers. However, the subsequent sharp increase demonstrates that VR is increasingly accepted as an effective tool for enhancing learning experiences. Prior studies have emphasized how advancements in hardware, such as affordable VR headsets, and software accessibility, have accelerated the adoption of VR in education (Lee & Han, 2022). The average citations per year reveal that older articles, particularly those published early in this period, have had a greater impact. This underscores the foundational role of early research in shaping future studies. For instance, foundational studies by Guo et al (2024) highlighted VR's potential in fostering engagement and conceptual understanding, paving the way for its adoption in various educational contexts

Journals such as Surgical Endoscopy and Journal of Surgical Education exhibit high productivity in publication volume. However, Computers and Education stands out for its citation impact, indicating that a focus on educational technology has broader influence within the scientific community. This is further supported by significant contributions from journals like Sustainability (Switzerland) and Interactive Learning Environments, which have high h-index and g-index values. These indicators show that research on sustainability and interactive learning through VR has garnered wide attention.

From the perspective of author collaboration, Konge L is the most prolific author with 60 articles. However, Liu Y has a higher fractional contribution value, indicating greater impact per article. From a country perspective, the USA leads in both publication count and citations, reflecting its

dominance in VR-based educational technology innovation. China, as a major competitor, demonstrates significant publication volume with a focus on advanced technology applications. Denmark and Australia, while having lower publication volumes, record high average citations per article, underscoring the quality and impact of their research. This observation supports prior analyses by Zhu et al (2023), who highlighted that high-impact publications are often driven by research quality and targeted applications in specific contexts

This study shows that VR in education not only attracts widespread interest but also has a significant impact on the global scientific community. International collaborations, comprising nearly one-fifth of all documents, suggest that the development of this technology is not isolated but driven by joint efforts across countries. Journal metrics and author contributions reveal that sustainability, interactive learning, and the pedagogical effectiveness of VR are central themes that attract broad attention.

The increase in publications after 2017 indicates that VR has transitioned from an experimental technology to a widely accepted educational tool. Journals like Computers and Education play a key role in disseminating knowledge about VR's effectiveness in education. In the context of authors and countries, cross-national collaborations and individual contributions, such as those from Liu Y and Konge L, enrich our understanding of this technology's potential. As noted by Roemer and Borchardt (2015), interdisciplinary collaborations play a pivotal role in addressing challenges such as accessibility and resource optimization in VR adoption

This study has significant implications for the development of educational technology and the application of Virtual Reality (VR) across various educational levels. With an upward trend in publications and high citation rates, the findings affirm VR's immense potential to revolutionize traditional teaching methods and create more immersive learning experiences. The analysis of high international collaboration suggests the need for cross-border synergy to address global challenges such as technological gaps and accessibility. Countries with high average citations per article, like Denmark and Australia, highlight the importance of quality over quantity, encouraging research that focuses on evidence-based solutions.

The word cloud provides valuable insights into the themes and trends dominating research on VR in education. The heavy emphasis on VR's application in medical education and training indicates that it is a well-established area of interest. The integration of VR in clinical and educational settings not only supports innovative teaching methods but also highlights its potential to address challenges in traditional pedagogical approaches, such as the lack of hands-on practice opportunities. Previous research by Al-Ansi et al (2023) also confirms the effectiveness of VR in improving practical skills through simulated training. The inclusion of demographic terms suggests a focus on understanding how VR impacts various groups of learners, ensuring its effectiveness and accessibility across different populations. This focus may inform the design of more inclusive VR applications tailored to diverse learning needs.

The study's findings also emphasize the need for policy support and investment in educational technology infrastructure. The productivity of journals such as Computers and Education, reflecting broad impact, underscores the importance of focusing on quality publications to enhance knowledge dissemination. These results provide a foundation for educational institutions and policymakers to advance VR adoption by integrating it into curricula, teacher training, and the development of interactive learning resources. Rainford et al. (2023) emphasize that such policy support is essential to overcoming barriers like high implementation costs and infrastructure challenges. Additionally, these findings can serve as a basis for academic and industry collaborations to develop more affordable and adaptable VR devices tailored to local needs, narrowing the gap between developed and developing countries.

6. Conclusion

Research in the field of Virtual Reality (VR) in education has shown a significant annual increase in the number of publications, despite a temporary decline in 2016. Journals such as Surgical Endoscopy and the Journal of Surgical Education play a pivotal role in publishing VR-related studies, particularly

in the context of surgical education. However, earlier studies remain key references, as evidenced by the higher average citations per article in earlier years. This indicates the sustained impact of VR research, with previously published articles still frequently cited in scientific literature.

International collaboration has also been a critical factor in the advancement of this research, with countries like the United States and China leading in publication volume. Prolific authors such as Konge L and Makransky G have demonstrated significant influence in the literature, even though their publication counts do not always correlate directly with citation numbers. Key topics in VR research, including "Virtual Reality," "Education," and "Clinical Competence," underscore VR's essential role as a tool for education, particularly in enhancing clinical competencies. Overall, VR research in education continues to grow both in quantity and quality, with significant contributions driven by global collaboration.

Future research should explore the long-term effectiveness of VR in education, particularly in diverse educational contexts beyond clinical and surgical training, such as STEM fields and arts education. Studies should also investigate the cost-effectiveness of integrating VR technologies into curriculums to ensure accessibility and scalability. Additionally, there is a need for deeper exploration of the psychological and cognitive impacts of VR-based learning on students and educators. Finally, fostering stronger interdisciplinary and cross-sector collaborations could yield innovative applications of VR, enriching its potential as an educational tool.

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