Science Education International
35(3),270-280
https://doi.org/10.33828/sei.v35.i3.10

ORIGINAL ARTICLE

# Bibliometric Analysis of Virtual Reality in Science Education over the Three Decades (1993-2023)

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## ABSTRACT

This study aims to conduct a bibliometric analysis of the use of virtual reality in science education over three decades (1993–2023). The method involved data from Google Scholar-indexed publications using Publish or Perish with keywords related to “virtual reality” and “education” over the past 3 decades. Nine hundred and eighty-six publications were obtained with a total of 131,130 citations with an average of 133 citations/paper and 4371 citations/year. The collected data were then screened to ensure its quality. Next, VOSviewer software was conducted to perform co-authorship and co-occurrence analysis. The results of the co-authorship analysis showed that there were 164 authors eligible to be visualized and divided into 88 clusters, indicating a high level of collaboration among authors in this field. Co-occurrence analysis shows that “virtual reality” has an occurrence of 696 in cluster 5 and “science education” is only 16 in cluster 2 with word networks formed only on the words “virtual reality,” “education,” and “field.” This study emphasizes the need for better VR in science education and more research on its impact on students’ science literacy. It outlines VR usage trends in science education, informing future studies. The findings particularly highlight the importance of investigating VR’s effectiveness in formal educational settings.

**KEY WORDS:** Bibliometric analysis; education; science; virtual reality

## INTRODUCTION

Science literacy has become a basic skill in a highly complex world and improving it is a necessity in 21st century education (Ding, 2022). This increase in literacy can only be achieved through a learning process that is in line with the times. In the context of modern education, traditional methods are no longer adequate as the education paradigm has transformed toward digital (Crittenden et al., 2019). Moreover, the COVID-19 pandemic has further accelerated this transition with the introduction of distance learning due to school closures, adding long-term challenges such as the use of technology in the classroom, thus adding long-term challenges such as the use of technology in the classroom (Barry et al., 2021; Putranto et al., 2022). This use of technology has an impact on the learning characteristics of students who tend to prefer to utilize technology coupled with the era of disruption that occurs, resulting in a changing learning paradigm (Oke and Fernandes, 2020). The OECD reported that about three-quarters of students confirmed that they experienced increased confidence using various technologies, including learning management systems, school learning platforms, and video communication programs (OECD 2023). Dubovi (2022) reports that the use of this technology increases learner engagement and cognitive and emotional learning achievement by 51% (Dubovi, 2022). Schleicher (2023) reported that based on PISA 2022 data, student learning outcomes improved when using digital devices for 1 h compared to not utilizing these technologies (Schleicher, 2023). Hence, this challenge highlights the importance of adaptive strategies in future science education.

One of the digital technologies that Generation Z is currently interested in, especially as students, is virtual reality (VR). Based on research, as much as 62.9% of Generation Z shows interest in this technology and prefers it over traditional learning methods. This is because they were born and raised in a digital era characterized by rapid technological advancements (Gar Chi et al., 2021). This technology includes visual and auditive experiences that produce an environment similar to the real world. The use of VR can increase students’ understanding, knowledge, and engagement which leads to meaningful learning (Barry and Kanematsu, 2022).

Opportunities for using virtual reality technology have been widely reported in various fields such as health (Javaid and Haleem, 2020; Xie et al., 2023), agriculture (Anastasiou et al., 2023), tourism (Calisto and Sarkar, 2024; Stienmetz et al., 2022), and manufacturing (Eslami et al., 2023). It is interesting to discuss the challenges in applying VR technology in education, especially in science learning which demands a comprehensive understanding of abstract material (Uriel et al., 2020). So far, learning that is supposed to increase the conceptual cognitive domain is often only a factual domain

(Stevens et al., 2013). As a result, students are unable to connect ideas about the material they obtain with understanding that leads to an understanding of scientific phenomena (Schwarz et al., 2009). This is one of the causes of low PISA scores of students in some countries (*PISA 2022 Results (Volume II)*, 2023). Therefore, the use of virtual reality to enhance research in education and its applications has emerged as a significant research direction. The increasing volume of publications regarding VR in education makes this scope of research interesting for further review (Cook et al., 2019; Ifanov et al., 2022; Molina-Carmona et al., 2018; Suri et al., 2022).

Although many studies have reviewed the research landscape on these technologies from various educational perspectives, bibliometric analyses that present a complete overview of these studies are still rare. The few studies that have conducted bibliometric analysis in the field of education are often partial, such as the study of virtual and remote laboratories (Heradio et al., 2016), the use of augmented reality for education (Hincapie et al., 2021), and most studies in the field of health education (Onchonga and Mohamed, 2023; Ortiz-Martínez et al., 2021). This analysis is important for qualitative and quantitative analysis of the application of virtual reality in science learning that needs attention (Fauzi, 2022). Especially in the era of disruption, 21st-century education emphasizes the use of technology in the learning process (Nikoghosyan et al., 2019; Psotka, 2013). This study has never been reported in a review of the past few decades. Therefore, this study aims to conduct a bibliometric analysis using VOSviewer software to comprehensively review the development trends of virtual reality technology in the field of science education over the past 3 decades. Thus, this study can provide an overview of future research directions.

# METHODOLOGY

## Bibliometric Analysis

Bibliometric analysis can be defined as a quantitative and qualitative evaluation that studies the travel map of research directions through published scientific articles (Zupic and Čater, 2015). This type of study has gained a lot of attention from academics and is considered one of the literacy methods that use network-based scientometric data through data integration and visualization (Boyack and Klavans, 2014). Hence, this analysis can provide a scientific overview for the study of future research directions by allowing monitoring of trends in a topic under investigation and this case virtual reality in the field of science education. In this bibliometric analysis stage, several stages are carried out starting with collecting data, analyzing the data, and ending by providing an overview of future trends from the results of the analysis.

## Stage 1: Data Collection

The data in this study used data from scientific articles using Publish or Perish 8 Version 8.9.4554 software. The keywords used in this study are related to (1) virtual reality and (2) education. The scientific articles selected as data in this study come from Google Scholar-indexed journal articles for the past 30 years (1993-2023) by limiting 1000 publications with the article type over the 3 decades. Google Scholar-indexed journals were chosen because of their broad coverage and inclusiveness of various scientific articles that are sometimes not indexed in other databases. In addition, the Google Scholar algorithm is more often updated to provide flexibility to access new article publications more quickly (Singh et al., 2021). Google Scholar is also free to access, giving it an inclusive advantage for researchers who do not have institutional access to databases such as web of Science or Scopus (Jensenius et al., 2018). Before proceeding to bibliometric analysis and ensuring data quality, all publications were reviewed for consistency and duplication issues (Zupic and Čater, 2015). Based on the limitation of the information used, 986 publications were obtained with a total of 131,130 citations with an average of 133 citations/paper and 4371 citations/year (data extracted on December 26, 2023, at 19:41) published in Google Scholar-indexed journals.

## Stage 2: Analyzing the Data

The data that have been collected and screened previously, then analyzed using VOSviewer Version 1.6.20 software developed by Nees Jan van Eck and Ludo Waltman in 2023 (Jan van Eck and Waltman, 2023). This software is widely used for bibliometric analysis by visualizing a publication's relationship with other publications, in this context, the relationship between the keywords, virtual reality, and education through topic-based color-coding will deeply interpret trends and patterns in the literature (Donthu et al., 2021). VOSviewer provides three different forms of visualization namely network (showing the closeness of a relationship from each publication), overlay (showing the range of years the article was published), and density visualization (showing how often the topic is discussed with a cloud view) which is used to identify publications in the form of co-authorship and co-occurrence analysis (Kusuma and Nida, 2024). This analysis also provides grouping data based on the closeness of the research topic which is hereinafter referred to as a cluster (Rossetto et al., 2018). These clusters will provide a scientific overview of the relationship between the proximity of virtual reality and education topics so that it can improve the results of the analysis.

## Co-authorship Analysis

Co-authorship refers to collaboration between authors, an important feature of recognizing co-authorship on various research topics. These collaborations can usually occur within an organization (between departments, institutions, or research groups) as well as outside the organization (international collaborations). This analysis benefits from identifying the leading authors in a particular research area provided by VOSviewer through a visual display (Glänzel and Schubert, 2004).

In this analysis, based on 986 data, 2406 authors were found. To filter authors who have more significant contributions with the keywords virtual reality and education, the author set a minimum criterion that the author must have written at least two articles from the overall data used in this study. After these criteria were applied, 164 authors were selected to be analyzed by VOSviewer.

### Co-occurrence Analysis

VOSviewer contributes to analyzing co-occurrence and has been studied by many researchers in bibliometric studies (Donthu et al., 2021; Eck and Waltman, 2010; Kusuma and Nida, 2024; Rossetto et al., 2018) Co-occurrence analyzes the relationship of words that appear frequently from three categories, namely, title, abstract, and keywords (Bernatović et al., 2022). The size of the node indicates the frequency of occurrence of the word while the co-occurrence of two keywords is shown by the thickness of the line connecting them (Tan Luc et al., 2022).

The words extracted for this analysis came from the title and abstract categories of the publications, totaling 4837 words. To focus on the words that are most relevant to the keywords used, a minimum threshold was set where the word must appear at least three times in the data used for analysis. Based on this setting, 526 words out of 4837 words were obtained and analyzed for co-occurrence.

## RESULTS AND DISCUSSION

This analysis reviewed the frequency of publications, authors, and citations according to the keywords used in publish or perish software with a database spanning the past 3 decades (30 years).

### Publication Performance Analysis

Figure 1 shows the relationship between the frequencies of publications each year from 1993 to 2023, respectively, based on the cumulative (bar graph) and the number of publications each year (line graph). Reviewing Figure 1, the publication has an increasing trend from 1993 to 2016, and there is a sharp increase from 2016 to 2020, but there is a decrease in publications from 2020 to 2023.

The publications on the use of virtual reality (VR) in education are increasing every year due to the paradigm shift in learning approaches (Elmqaddem, 2019). VR technology has been considered a potential tool to enhance student's learning experience by providing an immersive and interactive simulated environment (Calvert and Hume, 2022). When reviewing publications in 2016–2020, the increase in publications increased significantly compared to previous years. In 2016, virtual reality technology was marketed by Facebook Inc. with the product name Oculus Rift. At the time of the first marketing, virtual reality technology received a lot of attention until similar products developed such as HTC, VIVE, and others (Reer et al., 2022). Not only from the industry, academics have also conducted many studies that utilize VR technology in various fields as evidenced by the increase in publications in that year both in the health sector (Dennis and Patterson, 2020; Dyer et al., 2018; So et al., 2019; Tang et al., 2020), tourism (Kim and Hall, 2019; Mofokeng and Matima, 2018), and education (Aebersold, 2018; Mallam et al., 2019; Rosemary, 2016). The peak frequency of publications occurred in 2020 with a total of 106 papers. 2020 is the year of the COVID-19 pandemic with almost all countries implementing online learning (Aswie, 2023). Thus, many studies in that year reviewed the potential of virtual reality as a learning medium online (Dietrich et al., 2020; Singh et al., 2020; Vergara et al., 2022; Yarrow et al., 2020). Even in that year, publications that discussed the potential of virtual learning during the pandemic were the most discussed compared to the years after in all fields (Lin et al., 2020; Plancher et al., 2020; Stambough et al., 2020).

Although 2021–2023 is still in the phase of the COVID-19 pandemic and the transition of the learning process from online to hybrid (Blackmon and Major, 2023), the fact is that publications related to the use of virtual reality in

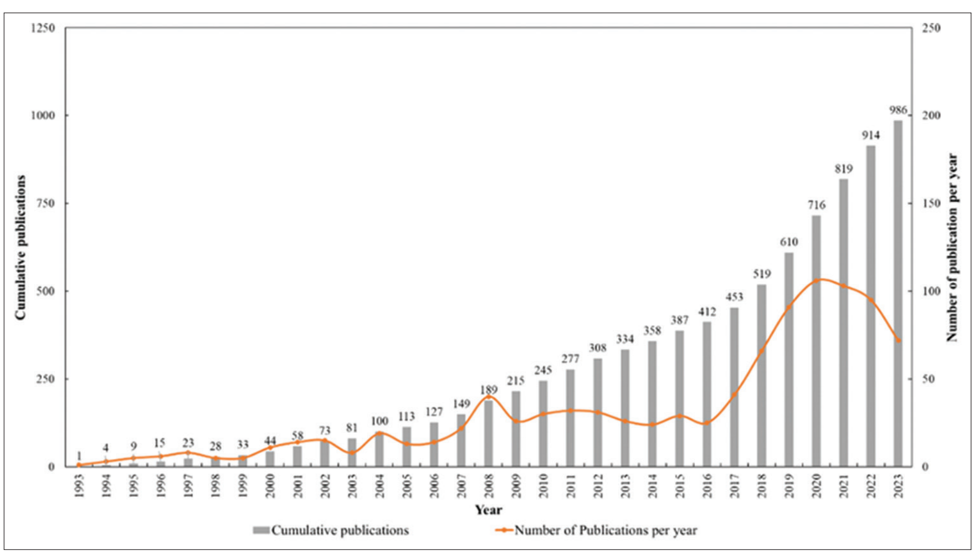


**Figure 1:** Publications about virtual reality in education in the range 1993 – 2023 (Source: Google Scholar Index Journal)

education have decreased from the peak in 2020. Based on the bibliometric analysis in the article Ng et al. (2023) report that the focus of research in the range of 2021–2023 is mostly on the impact of the COVID-19 pandemic on management education and online learning. These studies highlight current trends and best practices in this context and emphasize the challenges and opportunities faced by educators and students in dealing with the pandemic situation. Therefore, the impact of the COVID-19 pandemic on learning is the focus of research in this timeframe (Ng et al., 2023) such as learning loss (Jakubowski et al., 2023).

In addition, over the past 3 decades, several studies that have been reported were written by several authors who have a concentration in this field. Table 1 show that 20 authors are concerned about this based on data from Google Scholar. Elliot Hu-Au is ranked 1st in Colombia, followed by Gurkan Yildirim from Turkey and Ryan Lege from Japan who are in third position as authors who have the performance and impact of their publications. When viewed from the author's countries, 80% of the author's countries are the 50 most technologically advanced countries in the world based on the 2023 Global Innovation Index report issued by the World Intellectual Property Organization. The ranking on the Global Innovation Index refers to the relative position of a country in terms of innovation and technological progress by reviewing innovation factors, investment in research and development (R&D) including education, policies that support innovation, industry-academia collaboration, etc. (Tang, 2023). Countries that show high rankings in the GII typically have strong technological infrastructure, large investments in research and development, innovation-supportive policies, and cultures that promote innovation and adoption of new technologies. These countries tend to have better resources to adopt new technologies, including educational technologies such as virtual reality, in various fields, including education. The use of virtual reality in education requires adequate technological infrastructure, accessibility of devices, and availability of relevant educational content. Countries that are advanced in technology tend to have the ability to adopt this technology in their education curriculum as they have the necessary resources and infrastructure in place (Alalwan et al., 2020).

A total of 986 publications were published between 1993 and 2023 related to the keywords used. Of these articles, the data in Table 2 show the 20 articles with the most citations. Based on the titles of the articles with the most citations, virtual reality is generally related to the health field, namely 8 out of 20 publications. Five articles review the technical aspects of utilizing virtual reality in education, including applications, simulations, and practices. Meanwhile, Seven other articles discuss the trends and development of virtual reality in education. Interestingly, out of the 20 articles with the most citations, no report discusses the bibliometric analysis of virtual reality utilization in the field of science education. This gap suggests an opportunity to contribute new, more relevant and specific literature in this area, especially in relation to science literacy and the digital age. Therefore, this has the potential to be reported as a future research topic. Through this potential, it can provide a more relevant academic landscape related to the correlation of virtual reality in the field of education in improving science literacy to support 21st-century education that is more directed toward the digital era.

**Table 1: Top 20th authors rank of virtual reality in the education field**

| Authors | Country | Rank | | |
|---|---|---|---|---|
| | | Publish or Perish | Education's Country | GII* Rank |
| Elliot Hu-Au | Colombia | 1 | 83 | 66 |
| Gurkan Yildirim | Turkiye | 2 | 67 | 39 |
| Ryan Lege | Japan | 3 | 33 | 13 |
| Heebok Lee | Republic of Korea | 4 | 12 | 10 |
| Nurzhanat Shakirova | Kazakhstan | 5 | 65 | 81 |
| Noureddine Elmqaddem | Morocco | 6 | 86 | 70 |
| Gregory L. Taylor | Colombia | 7 | 83 | 66 |
| Pablo Ruisoto Palomera | Spain | 8 | 47 | 29 |
| David Hamilton | United Kingdom | 9 | 38 | 4 |
| Mustufa H. Abidi | Saudi Arabia | 10 | 51 | 48 |
| Zhi-Ling Sun | China | 11 | 11 | 12 |
| Heng Luo | China | 12 | 11 | 12 |
| Ahmed Al-Gindy | United Arab Emirates | 13 | 56 | 32 |
| Enda McGovern | United States | 14 | 45 | 3 |
| J Pottle | United Kingdom | 15 | 38 | 4 |
| Mikko Vesisenaho | Finland | 16 | 8 | 6 |
| Anna Flavia Di Natale | Italy | 17 | 49 | 26 |
| Guey-Fa Chiou | Hong Kong, China | 18 | 18 | 17 |
| Lynna J Ausburn | United States | 19 | 45 | 4 |
| Santiago González Izard | Spain | 20 | 47 | 29 |

*Global Innovation Index 2023

**Table 2: The Top 20th Most Cited Articles (Data Based on Google Scholars)**

| Cites | Publication | Year | Journal Publication | CPY* | CPA* |
|---|---|---|---|---|---|
| 2653 | A survey of augmented reality technologies, applications, and limitations | 2010 | International Journal of Virtual Reality | 204.08 | 1327 |
| 2173 | What are the learning affordances of 3-D virtual environments? | 2010 | British Journal of Educational Technology | 167.15 | 1087 |
| 1975 | Teaching surgical skills-changes in the wind | 2006 | New England Journal of Medicine | 116.18 | 988 |
| 1619 | Augmented reality trends in education: a systematic review of research and applications | 2014 | Journal of Educational Technology and Society | 179.89 | 540 |
| 1470 | Randomized clinical trial of virtual reality simulation for laparoscopic skills training | 2004 | British Journal of Surgery | 77.37 | 368 |
| 1415 | Simulation-based learning in nurse education: systematic review | 2010 | Journal of Advanced Nursing | 108.85 | 708 |
| 1395 | The utility of simulation in medical education: what is the evidence? | 2009 | Mount Sinai Journal of Medicine | 99.64 | 349 |
| 1384 | Augmented reality: An overview and five directions for AR in education | 2011 | Journal of Educational Technology Development and Exchange | 115.33 | 461 |
| 1144 | Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching | 2009 | British journal of educational technology | 81.71 | 1144 |
| 1139 | Education 4.0 made simple: Ideas for teaching | 2018 | International Journal of Education and Literacy Studies | 227.80 | 1139 |
| 1133 | The evolution of distance education: Emerging technologies and distributed learning | 1996 | American Journal of Distance Education | 41.96 | 1133 |
| 1109 | A brief history of the development of mannequin simulators for clinical education and training | 2008 | Postgraduate medical journal | 73.93 | 555 |
| 1051 | Affordances of augmented reality in science learning: Suggestions for future research | 2013 | Journal of science education and technology | 105.10 | 526 |
| 1043 | Second Life: an overview of the potential of 3-D virtual worlds in medical and health education | 2007 | Health Information and Libraries Journal | 65.19 | 348 |
| 1017 | Simulation-based learning: Just like the real thing | 2010 | Journal of Emergencies, Trauma and Shock | 78.23 | 1017 |
| 954 | Virtual technology trends in education | 2017 | Eurasia Journal of Mathematics, Science and Technology Education | 159.00 | 239 |
| 905 | A global assessment tool for the evaluation of intraoperative laparoscopic skills | 2005 | The American Journal of Surgery | 50.28 | 226 |
| 903 | Three-dimensional virtual worlds and distance learning: two case studies of Active Worlds as a medium for distance education | 2005 | British Journal of Educational Technology | 50.17 | 903 |
| 893 | Educational video game design: A review of the literature | 2007 | Journal of Applied Educational Technology | 55.81 | 893 |
| 888 | A controlled study of virtual reality exposure therapy for the fear of flying. | 2000 | Journal of Consulting and Clinical Psychology | 38.61 | 222 |

CPY: Cites per year, CPA: Cites per author

## Co-authorship Analysis

Co-authorship analysis is used to review authorship networks. For example, author X writes with anyone so that the author networks with other authors in writing articles. The level of collaboration of an author is an indicator of cutting-edge research in a scientific field (Cretu and Morandau, 2020). In addition, Azevedo et al. (2024) also stated that this co-authorship analysis is more capable of focusing on network identification so that co-authorship analysis can provide more precise results (Azevedo and Azevedo, 2021).

In this study, 164 authors were eligible to be visualized and divided into 88 clusters. The term “cluster” refers to groups or clusters of authors that have a high degree of collaboration between them and are distinguished by color changes. In other words, authors in a co-authorship cluster tend to work together in publications.

Based on Figure 2, 164 authors can be visualized. Each node refers to the name of the author, and the size of the bullet indicates the more publications of the author. There are five authors with publications that have the most collaboration networks related to the keywords used (virtual reality; education) including Kim, JH (six papers); Wang, X (five papers); Aggarwal, R (five papers); Yang, Y (five papers); and Satava, RM (five papers). In addition, based on Figure 2, there are also clusters consisting of 39 clusters that have a relationship of at least two authors who collaborate and 49 clusters that do not have a collaboration network (marked with a gray circle). Of 39 clusters that have author networks, two clusters have the largest number of authors, namely, cluster 1 which is red, and cluster 2 with green color.

Based on Figure 3, we can see the network visualization of co-authorship that has the most author networks compared to other clusters. In cluster 1, there are 11 authors including Chen, G; Chen, Y; Li, L; Lv, Z; Song, H; Wang, J; Yang, J; Yin, T; Zhang, L; Zhang, X; and Zheng, J. Chen, G (publication of two papers) has the strongest total link strength compared to other authors in cluster 1. Total Link Strength provides an overview of how closely authors work together in a co-authorship network and can be used to identify significant collaboration patterns or strong relationships between authors in a field (in this study it is related to virtual reality and education). Chen, G has conducted a joint study with six other authors including Chen, Y; Lv, Z; Yin, T; Zhang, L; Zheng, J; and Wang, J. While in cluster 2, 9 authors collaborate including Han, S; Kim, JY; Kim, S; Kim, YS; Lee, J; Lee, JH; Lee, JS; Lee, JY; and Park, YS with author Lee, JH (3 publications) having the highest level of collaboration which is together with 5 other authors including Kim, JY; Kim, S; Kim, YS; Lee, J; and Park, YS.

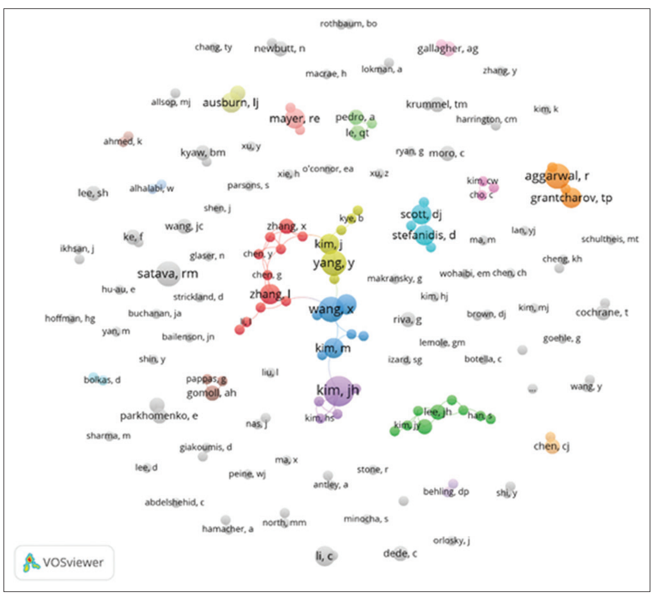


**Figure 2:** Co-authorship network visualization of bibliometric analysis

## Co-occurrence of Keyword Analysis

Keyword co-occurrence analysis in a bibliometric context, with a focus on virtual reality and education, provides a holistic picture of relationships and emerging trends in the academic literature (Arici et al., 2019). Using VOSviewer, related keywords, and concepts that often co-occur in research on the use of virtual reality in education can be identified (Kusuma and Nida, 2024). This analysis helps to illustrate the structure of the research, identify topic trends, and provide insights into how the concepts are related in the scientific literature, supporting a deeper understanding of the development and influence of virtual reality in educational contexts (Chen et al., 2022; Yerden and Akkuş, 2020).

Based on Table 3, the most dominant word is virtual reality as evidenced by the largest node compared to others. In addition, based on Table 3, 20 words have the most occurrences including virtual reality (696), education (432), study (163), use (131), training (129), technology (123), student (98), simulation (97), application (95), effect (86), virtual reality technology (86), augmented reality (81), research (75), reality (74), environment (70), development (70), system (67), experience (61), learning (57), and review (55).

It is important to understand that the total link strength in the co-occurrence analysis, as found in Table 3, provides deeper insight into the network structure of the concepts in the dataset. Total link strength reflects how closely related the elements or keywords are, and therefore, becomes an important indicator in identifying important centers or the most influential concepts in a particular domain (Zakaria et al., 2021).

In the context of this research, "virtual reality" has a high total link strength of 4838, which highlights the importance of this concept in the context being analyzed. The high total link strength indicates that "virtual reality" not only appears frequently but also has strong relationships with various other keywords in the dataset. Therefore, further research into "virtual reality" can provide a deeper understanding of its impact within the framework of the topic at hand.

In addition, understanding the total link strength for other keywords such as "education," "study," and "training" also provides insight into the underlying concept network of the

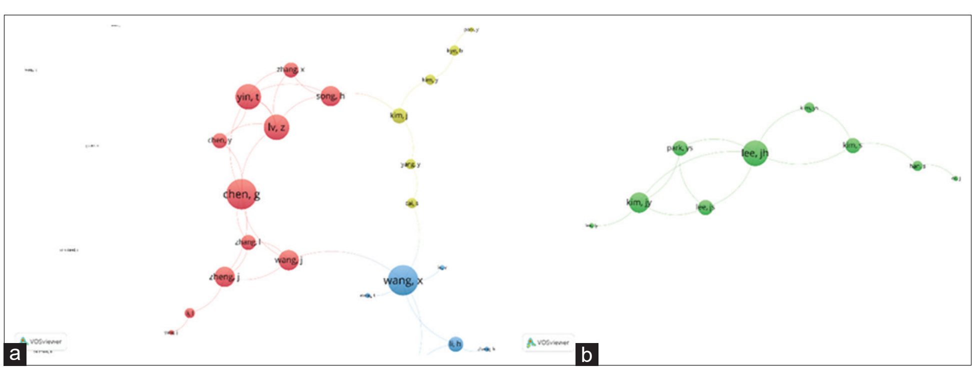


**Figure 3:** Co-authorship network visualization (a) Cluster 1, (b) cluster 2 based on total link strength

Table 3: Keywords with the highest occurrence

| Rank | Keyword | Cluster | Link | Total link strength | Occurrence |
|---|---|---|---|---|---|
| 1 | Virtual Reality | 5 | 519 | 4838 | 696 |
| 2 | Education | 2 | 485 | 3067 | 432 |
| 3 | Study | 3 | 345 | 1179 | 163 |
| 4 | Use | 2 | 345 | 1029 | 131 |
| 5 | Training | 5 | 300 | 937 | 129 |
| 6 | Technology | 7 | 319 | 937 | 123 |
| 7 | Student | 2 | 290 | 747 | 98 |
| 8 | Simulation | 1 | 259 | 695 | 97 |
| 9 | Application | 10 | 250 | 689 | 95 |
| 10 | Effect | 1 | 249 | 642 | 86 |
| 11 | Virtual Reality Technology | 10 | 237 | 585 | 86 |
| 12 | Augmented Reality | 2 | 233 | 599 | 81 |
| 13 | Research | 9 | 236 | 543 | 75 |
| 14 | Reality | 7 | 225 | 526 | 74 |
| 15 | Environment | 6 | 234 | 522 | 70 |
| 16 | Development | 12 | 203 | 496 | 70 |
| 17 | System | 5 | 200 | 454 | 67 |
| 18 | Experience | 3 | 206 | 436 | 61 |
| 19 | Learning | 4 | 212 | 431 | 57 |
| 20 | Review | 2 | 179 | 418 | 55 |

topic. This information can serve as a basis for designing a strategic approach or focus for further research, as elements with high total link strength tend to be central and play a key role in the context of the analysis. Thus, the discussion of total link strength not only identifies the relationships between concepts but also provides a basis for prioritization in further exploration or formulation of research strategies.

The total link strength analysis on the keyword "virtual reality" with a value of 4838 stands out in contrast to the lower value for "science education," which is only 112. The significant total link strength value for "virtual reality" reflects the depth of interconnectedness and interaction of this concept with various elements in the dataset. In contrast, "science education" with a lower total link strength indicates that its linkages and relations with other keywords are limited.

The co-occurrence number of only 16 for "science education" highlights that the focus of research or conversations related to the use of virtual reality in the context of science education is still quite limited. This could indicate that there are still few studies that specifically explore the integration of virtual reality in science learning. Therefore, this finding provides a strong basis to support the claim that virtual reality in the context of science education is still an area that is relatively unexplored or has received sufficient attention in the literature. This is reinforced by a study conducted by Li (2024) who reported that there is still a gap in gaining an understanding of immersive technologies in education. This includes the amount of research that has been reported, research themes, and emerging trends. At present, these have not been massively explored and there is inadequate analytical presentation (Li, 2024).

By analyzing the differences in total link strength between "virtual reality" and "science education," there are great opportunities for further research exploring the potential utilization of virtual reality in enhancing the learning experience in the context of science. This understanding can provide a foundation for educational researchers and practitioners to identify gaps in current research and design more in-depth studies to enrich our understanding of the application of this technology in the context of science education.

Based on Figure 4, there are 526 words from 986 publications divided into 14 clusters that can be visualized based on the keywords used. Based on these 14 clusters, the three main clusters that have the most word occurrence networks compared to the others are cluster 1 characterized by red-colored nodes and networks consisting of 84 words), cluster 2 with green-colored nodes and networks consisting of 68 words, and cluster 3 with blue color with a total of 54 words.

Figure 5 shows that the concept network in the context of "science education" is more focused on three key elements: "virtual reality," "education," and "field." Although the total link strength may show limitations, through co-occurrence mapping, we can identify closer interactions between the three concepts.

"Virtual reality" plays a central role in this linkage, standing out as the main element. Whereas "science education" only interacts with three keywords, namely, "virtual reality," "education," and "field." This indicates that in the literature or datasets analyzed, the implementation of virtual reality in the context of science education is still very limited and needs to be explored in other areas. The relationship between "virtual reality" and "education" illustrates the integration of technology in science learning, while the relationship with "field" highlights the relevance of virtual reality applications in scientific contexts (Lamb, 2023).

However, it is important to note that a large number of keywords, such as "application," "simulation," "training," and other keywords that have the most occurrences, are not yet fully involved in this concept network. Thus, the potential for future research can still be explored further, especially considering those keywords that have a high frequency of occurrence and are not yet fully intertwined in the co-occurrence mapping framework. This suggests that the study of virtual reality in the context of science education still has space to expand and involve more relevant keywords, opening opportunities for further research in this discipline.

## Future Trends

Based on the studies that have been carried out, it appears that publications that use specified keywords are increasing every year. However, further research requires wider exploration. Although this bibliometric analysis provides a clear picture of trends and patterns in the literature related to the use of virtual reality in science education (Zupic and Čater, 2015),

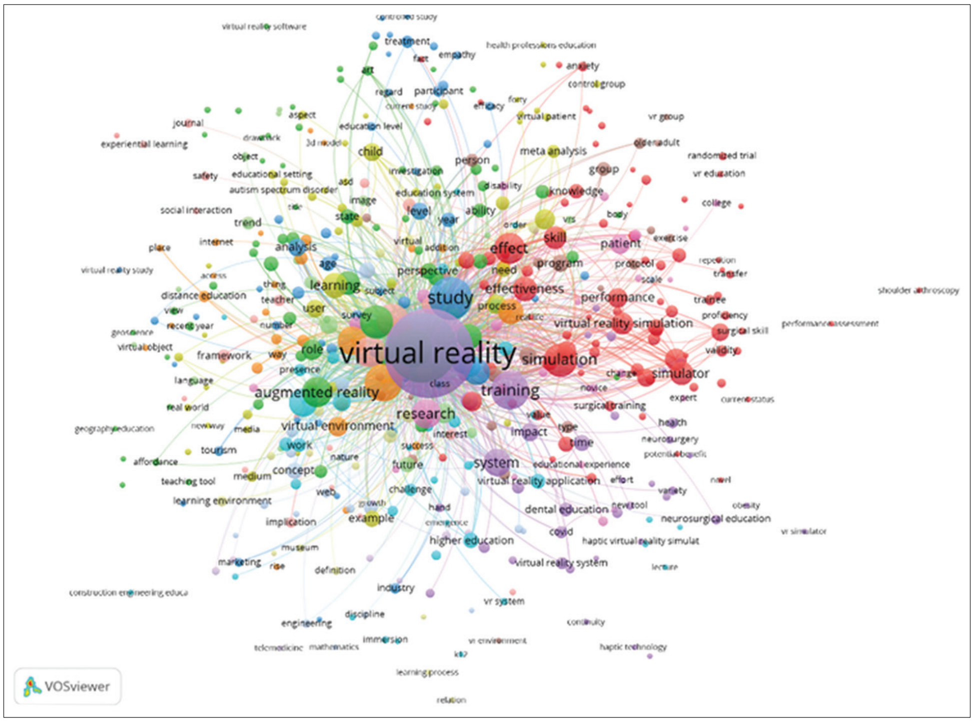


Figure 4: Keyword co-occurrence mapping of virtual reality and education

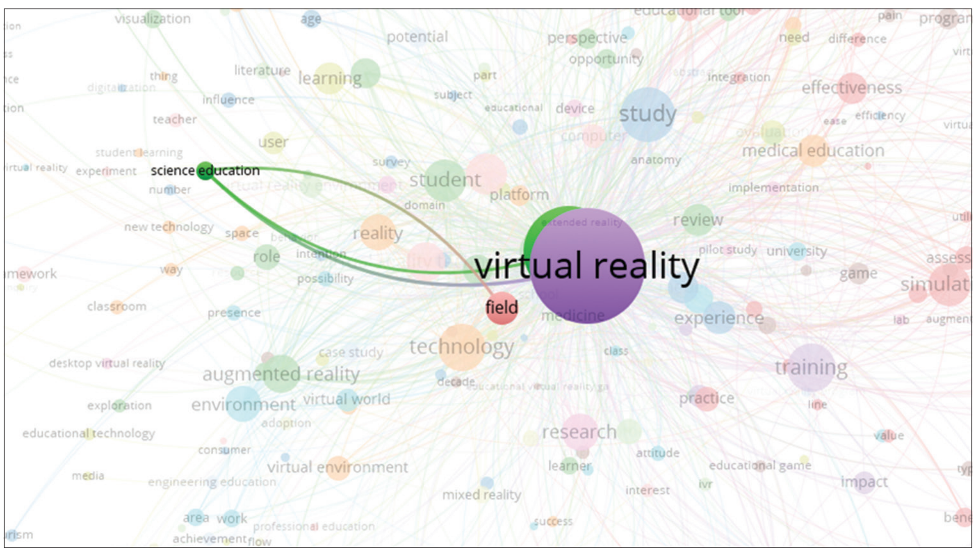


Figure 5: Keyword co-occurrence mapping of science education

there are still some things to consider for further research. So far, virtual reality-related studies are still a lot in the medical field of both simulations such as the study by Elq (2010) on simulation-based medical teaching and learning (Al-Elq, 2010) and Lee et al. (2023) on virtual reality simulation-enhanced blood transfusion education for undergraduate nursing students: A randomized controlled trial (Lee et al., 2023). Of course, studies related to the application of virtual reality in the field of medicine have had a positive impact in reviewing the anatomical issues of the body that are currently getting more attention in virtual technology. However, a future review of science education is necessary. The development of more sophisticated and affordable virtual reality technology for use in science education needs to be the focus of future research, especially its relevance to virtual reality simulators. This is because according to Figure 4, there is no network formed between science education and virtual reality simulators. In addition, based on Table 2, the top 5 articles that received citations were simulation-focused articles. In addition, based on the occurrence review, the word simulation also obtained the highest word from the results of the VOSviewer software analysis, so future reviews related to VR simulators in science education that focus on increasing literacy are important to discuss.

This will enable the use of virtual reality in scientific education to be more effective and efficient. Furthermore, further research on the effectiveness of the use of virtual reality in improving student science literacy, especially in the context of formal education, needs to be done. As far as the study is limited to the application of virtual reality in support of digital literacy (McLauchlan and Farley, 2019; Ylipulli et al., 2023). By understanding the effectiveness of using virtual reality to improve student science literacy, it can develop more effective and innovative learning strategies.

Further research on the influence of virtual reality on the motivation and interest of students in learning science was also a focus on further research. Moreover, given the tendency of Generation Z to have high digital competence, there needs to be an in-depth study of how this affects science learning (Aswie and Abdu, 2023). On bibliometric analysis, the results that the occurrence of motivation is only worth 9 with the total link strength being only 71. Hence, the influence of virtual reality in increasing student motivation in the field of science education is interesting to study further.

Besides, the assessment aspects of the use of virtual reality in science education also need further attention. This is because based on Figure 4, the co-occurrence between the assessment of virtual reality and science literacy has no relationship between the words. Hence, of course, this is a potential for further studies to add a more comprehensive research landscape. This is certainly important because, in the context of science education, the use of virtual reality can create an immersive and interactive learning environment, which allows students to experience scientific concepts firsthand (Hachaj and Baraniewicz, 2015). This study is important because it can help in identifying the potential for literacy-based assessment development that is more relevant to the demands of a more contextual science education curriculum. By leveraging virtual reality technology, science education assessments can be more easily adapted to a more representative learning context, thus providing a more accurate picture of students' achievements in understanding science concepts.

## CONCLUSION

The use of virtual reality technology in science education has shown significant progress over the past three decades. From the co-authorship analysis, it was found that 164 authors qualified for visualization and were divided into 88 clusters. It shows a high level of collaboration among writers in this field. In addition, from the co-occurrence analysis, 526 words were obtained that were relevant to the keywords used. "Virtual reality" and "science education" have an occurrence of 696 and 16. Moreover, "Science Education" only interacts with three keywords, namely, "Virtual reality," "education," and "field." This indicates that in the literature or datasets analyzed, the implementation of virtual reality in the context of science education is still very limited and the exploration of other areas is inadequate. Some further research focus may include the correlation of the effectiveness of the use of virtual reality in improving student science literacy, especially in the context of formal education. The development of more sophisticated and affordable virtual reality technologies for use in science education should be the focus of future research. With a deeper understanding of the positive impact of the use of virtual reality in science education, it is expected to develop more effective and innovative learning and assessment strategies.

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