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A Bibliometric Analysis of Virtual Reality in Higher Education: Research Trends and Productivity

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Abstract

This bibliometric study examines the overall research trends and productivity in virtual reality in higher education based on published articles (2010–2024). Initially, we identified 1,412 studies from the Scopus database using the search string ("virtual reality" AND "higher education" OR "tertiary education"). Finally, we selected 1,128 articles for analysis after filtering by articles, book chapters, review, and conference papers published in English within social science, psychology, multidisciplinary, arts, and humanities subjects. Utilizing Biblioshiny (R Studio) and VOSviewer software, we observed a significant upward trend in publications from 2010 to 2023. Most studies (31.8%) were in Computer Science, and the USA is the dominant contributor, followed by China and international collaborations with other countries. Gregory, S. (n = 14 articles) is the most prolific author, while the Catholic University of Avila is the leading institute (n = 22 articles). The leading source is the "ACM International Conference Proceeding Series" (n = 38 articles). The article "A Systematic Review of Immersive Virtual Reality Applications for Higher Education: Design Elements, Lessons Learned, and Research Agenda" by Radianti et al. (2020) was highly cited (1060). 'Virtual Reality' and 'Higher Education' were the most common co-occurrences among the authors' keywords. The most prominent theme based on the author's keywords is "Innovative Education Ecosystems in the Digital Age." This study provides valuable insight into the research landscape of VR in HE. The study suggests a comprehensive review and meta-analysis of relevant studies for improved generalization.

Keywords: *Virtual Reality, Higher Education, Bibliometric Analysis, Research Trends.*

INTRODUCTION

Information and Communication Technologies (ICT) are vital in enhancing students' attitudes toward learning and preparing them for life, work, and global citizenship (Rojas-Sánchez et al., 2023; Kamińska et al., 2019). ICT enhances educational environments that can be virtualized into safe learning environments for experiments rather than the real world (Tzanavari & Tsapatsoulis, 2010). The virtual platforms enable learners to comprehend complex concepts and experiment with their ideas in a secure atmosphere, promoting more profound understanding and critical thinking. Virtual learning technologies have revolutionized at all academic levels, and educators are adopting them to improve students' learning experiences (Castillo, 2010). Traditional classroom settings may not always provide a complete learning experience where virtual reality (VR) is the most effective way to enhance learning experiences (Folgado-Fernández et al., 2020). VR is an entirely immersive computer-generated world that provides a three-dimensional (3D) experience, where users may interact with this environment using many sensory channels, including touch and position (Rojas-Sánchez et al., 2023).

This VR technology was first used in education in the 1960s, but there was significant interest in using VR for professional education and training in the 1980s, Particularly flight simulator training and exercises (Merchant et al., 2014; Hawkins, 1995). In the 1990s, VR technology was introduced to K-12 and higher education (HE) settings (Youngblut, 1998) and utilized as peripheral devices for immersive learning experiences (Merchant et al., 2014). VR became more commercially accessible in the 1990s and technologically advanced in the 2000s

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(Marougkas et al., 2023). The development of VR educational content led to its integration into curricula and the establishment of VR labs in the 2010s (Piovesan et al., 2012). The COVID-19 pandemic further accelerated the use of VR for remote learning, showcasing its potential for immersive educational experiences (Chen, 2023). It has become a new field of science and technology due to increasing demand and continuous progress (Borodkin, 2022).

VR is important in education, offering an immersive, interactive, real-world simulated 3D learning environment that allows students to comprehend challenging concepts more effectively (Marougkas et al., 2023). VR technology enables participants to interact with virtual learning environments and develop various learning experiences, including virtual field trips and complex simulations, which engage students and enhance their learning in real time (Jeon & Yang, 2023; Predescu et al., 2023; Bermejo et al., 2023). This technology promotes active and deep learning, which is mainly beneficial for understanding complex subjects, where visualization plays a crucial role by providing 3D learning interaction (Soon et al., 2023; Dobhal et al., 2023). For example, VR enhances the learning experience, especially in hospitality, science, engineering, medicine, technology, etc. VR technology is increasingly utilized in HE to revolutionize traditional learning methods that enhance student engagement, motivation, enjoyment, cognitive performance, teaching-learning experiences, and academic achievement by providing practical training as well as bridging the gap between traditional classroom instruction and practical exposure (Kumar et al., 2023; Ding & Li, 2022; Bolo Romero et al., 2023). It is predominantly integrated into various programs, courses, and simulations, showcasing effectiveness as a teaching strategy (Rashid et al., 2021) that enrich learning environments and improve educational outcomes.

VR technology has recently gained considerable academic attention in HE, as indicated by several extensive studies of systematic literature reviews (SLR). For example, Bolo Romero et al. (2023) examined digital tools used in university teaching and emphasized the need for more apparent conceptual distinctions and comprehensive research. Marougkas et al. (2023) recognized educational theories such as constructivism, experiential learning, and gamification as fundamental ideas that support utilizing VR to improve learning experiences. Bermejo et al. (2023), Lin and Mawela (2023), and Ding and Li (2022) studied on VR technology in various specific fields (HE) such as hospitality, medicine, engineering, and science, etc. They highlighted the long-term impact on student learning outcomes, performance, motivation, and the potential for cognitive overload, which remains underexplored. Ghanbarzadeh and Ghapanchi (2023) revealed that 3D virtual worlds are widely used in HE across various application areas and platforms, enhancing teaching and learning through diverse virtual environments and tools. Rashid et al. (2021) performed a bibliometric analysis that revealed a significant increase in VR research and highlighted noteworthy contributions from Australia and an interdisciplinary approach. These extensive reviews demonstrate a strong and developing interest in the potential of VR to revolutionize HE while emphasizing the need for more comprehensive research and enhancements. So, this study aims to examine the research trends on VR technology in HE through bibliometric analysis.

Bibliometric analysis is a systematic method to evaluate publications, authors, institutions, and countries in specific research areas (Prabowo et al., 2023). Bibliometric analysis of VR in HE is crucial for understanding research trends, productivity, and emerging research areas (Battal & Taşdelen, 2023; Masalimova et al., 2023). Such analysis reveals the most prolific countries, institutions, and journals, international collaboration, identifies common keywords, influential authors, and frequently cited studies by assessing publication trends and citation patterns to a better understanding of the scholarly landscape of VR research in HE (Ertem & Aypay, 2023; Dwikoranto, 2023). Research trends and the productivity of VR in HE is crucial for understanding the evolution, growing interest, and advancements in immersive technologies for educational purposes (Shynatay & Shyndaliyev, 2023) and analyzing research trends (Sümer & Vaněček, 2022). This knowledge aids in shaping future research directions, optimizing decision-making, and enhancing the overall quality of VR-based educational experiences for students (Ma et al., 2022). However, the present study examines research trends and productivity of VR in HE over the last 15 years (2015–2024). Therefore, the current study investigates the following research questions:

What are the research trends in VR in higher education?

Who are the leading and influential authors?

What are the leading and influential institutions and countries regarding international collaborations?

What are the leading sources contributing to this field?

What are the major thematic clusters of the author's keywords in the field?

METHODOLOGY

Bibliometric analysis is a quantitative technique for analyzing data from the scientific literature using citation patterns and research productivity in a particular field (Rashid et al., 2021). This study retrieved scientific literature from the Scopus database, one of the world's largest databases prioritizing bibliometric studies (Baas et al., 2020; Jabali et al., 2020). Therefore, we used the Scopus database to search the literature. Search keywords were identified based on previous literature. We constructed a search string ("Virtual Reality" AND "Higher Education" OR "Tertiary Education") to search for data in the titles, abstracts, and keywords search field of the Scopus advance search on March 6, 2024.

Data Collection Process

The data extraction and filtration process are given in Figure 1. The data were identified by applying a search string in Scopus. Initially, we entered the search string into Scopus and found 1,412 documents. Then, the Screening process (inclusion and exclusion criteria) was applied to refine the data. First, we filtered the publication year from 2010 to 2024 and removed 151 records. Subsequently, document types (journal articles, book chapters, conference papers, and review articles) were included, and 97 records were excluded. Further, 36 records were removed after filtering the English language. Finally, 1128 documents were selected for analysis, and all eligible data were exported into the CSV file.

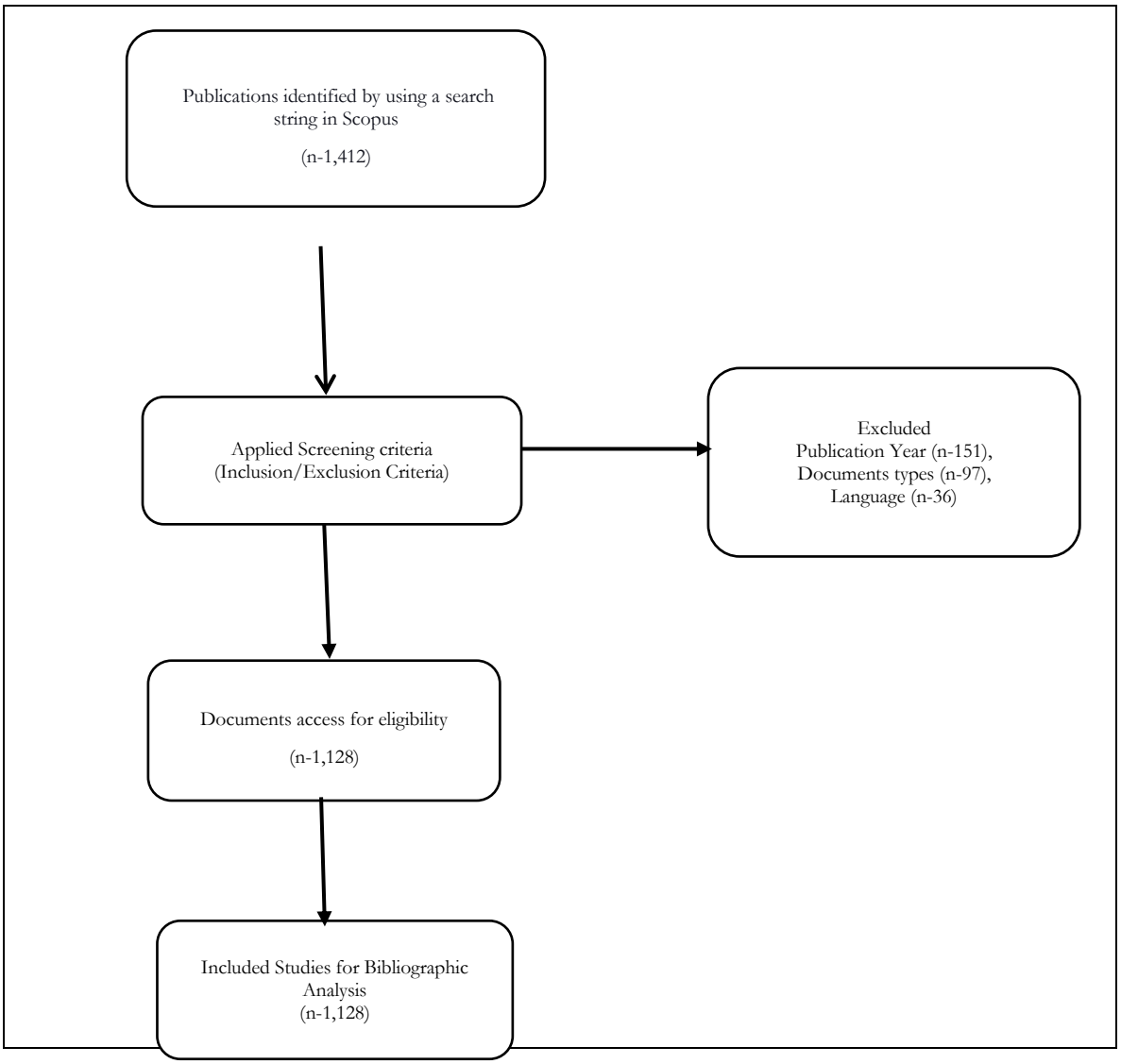

Figure 1. Data extraction and filtration process

Data Analysis

The present study analyzed publication trends, scientific productivity, performance analysis, and science mapping in VR in HE. Specifically, we examined yearly productivity, distribution of subject areas, author's ranks, countries' collaboration, leading institutions, sources, and influential articles based on the number of publications and citations. Further, we explored thematic clusters by employing co-occurrence analysis of the author's keywords. Bibliometric tools such as VOSViewer, Biblioshiny (R Studio), and Microsoft Excel are used for data analysis and visualization. Most of the bibliometric studies have used these tools for data analysis and visualization (Butt et al., 2020; Rashid et al., 2021).

RESULTS

Main Information About Data

Table 1: Primary information about the collected data

Description	Results
Timespan	2010 to 2024
Sources (Journals, Books, etc.)	622
Documents	1128
Annual Growth Rate:	1.15% (19.73% up to 2013)
Document Average Age	4.56
Average Citations Per Doc	10.16
References	35582
Keywords Plus (ID)	4575
Author's Keywords (De)	2667
Authors	3521
Authors of Single-Authored Docs	146
Single-Authored Docs	151
Co-Authors Per Doc	3.7
International Co-Authorships:	18.53%
Article	413
Book Chapter	77
Conference Paper	606
Review	32

Table 1 presents an overview of the primary information in the collected data. The results showed that VR research in HE is continuously growing in interest, as evidenced by the 1128 documents and an annual growth rate of 19.73% (up to 2023). There were more than ten average citations per document, and the average age of documents was 4.56.

Publications Trends

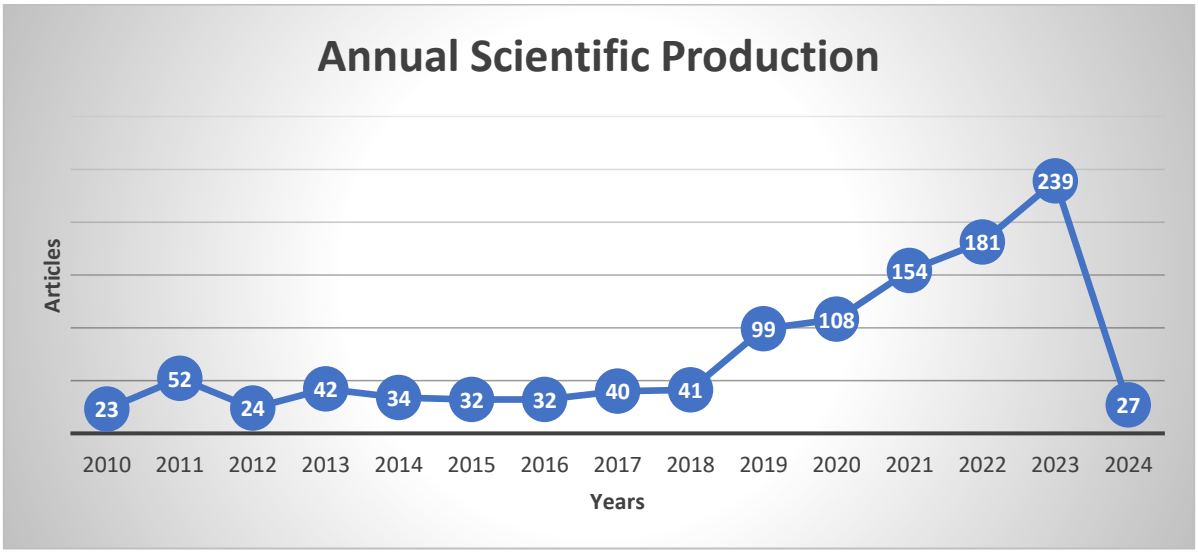

Figure 2: Research Trends of Annual Scientific Production

Figure 2 shows the total number of publications per year related to VR in HE from 2010 to 2024. The publication trends have been continuously growing in this domain. Productivity in the last five years has been

much higher than before. The growth is constant from 2018 onwards. However, 2023 was the most productive year, as 239 documents were published. In 2024, there were decries because we got the data on March 6, 2024.

Distribution of Subject Areas

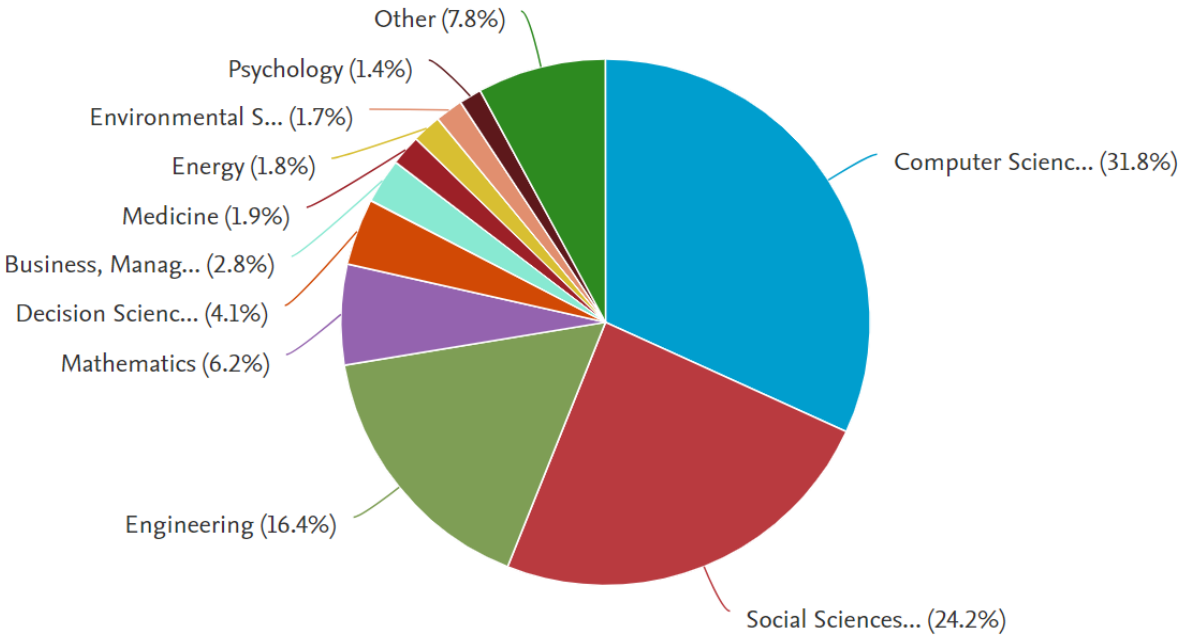

Figure 3: Distribution of subject area

Figure 3 displays the distribution of subject areas. The highest number of studies published in computer science is 31.8% of the total area, followed by social sciences and engineering, which contributed 24.2% and 16.4%, respectively. Most VR research in higher education is conducted in these three disciplines.

Leading Countries and International Collaboration

Table 2: Most Leading Countries

Country	TP	TC	CI
United States	144	2027	14.08
China	112	624	5.57
United Kingdom	104	1311	12.61
Australia	84	911	10.85
Spain	80	819	10.14
Mexico	66	272	4.12
Germany	51	1553	30.45
Portugal	38	243	6.39
Malaysia	32	123	3.83
Greece	30	595	19.83
India	30	148	4.93
Finland	26	316	12.15
Russian Federation	25	50	2
Colombia	24	155	6.46
Italy	23	290	12.61

Table 2 demonstrates the top 15 leading countries that published the highest number of articles, along with the 'total number of publications' (TP), 'total citations' (TC), and 'citation impact' (CI) (TC/TP). The United States published the most articles (144), gained the highest citations (2027), and had a 14.08 citation impact. China followed them with 112 publications and 624 citations, followed by the UK, Australia, Spain, Mexico, and Germany with 104, 84, 80, 66, and 51 publications, respectively. Germany is the second highest cited country (1553), publishing 51 articles and gaining 30.45 citation impact, while India ranked 11, publishing 30 articles and 148 citations.

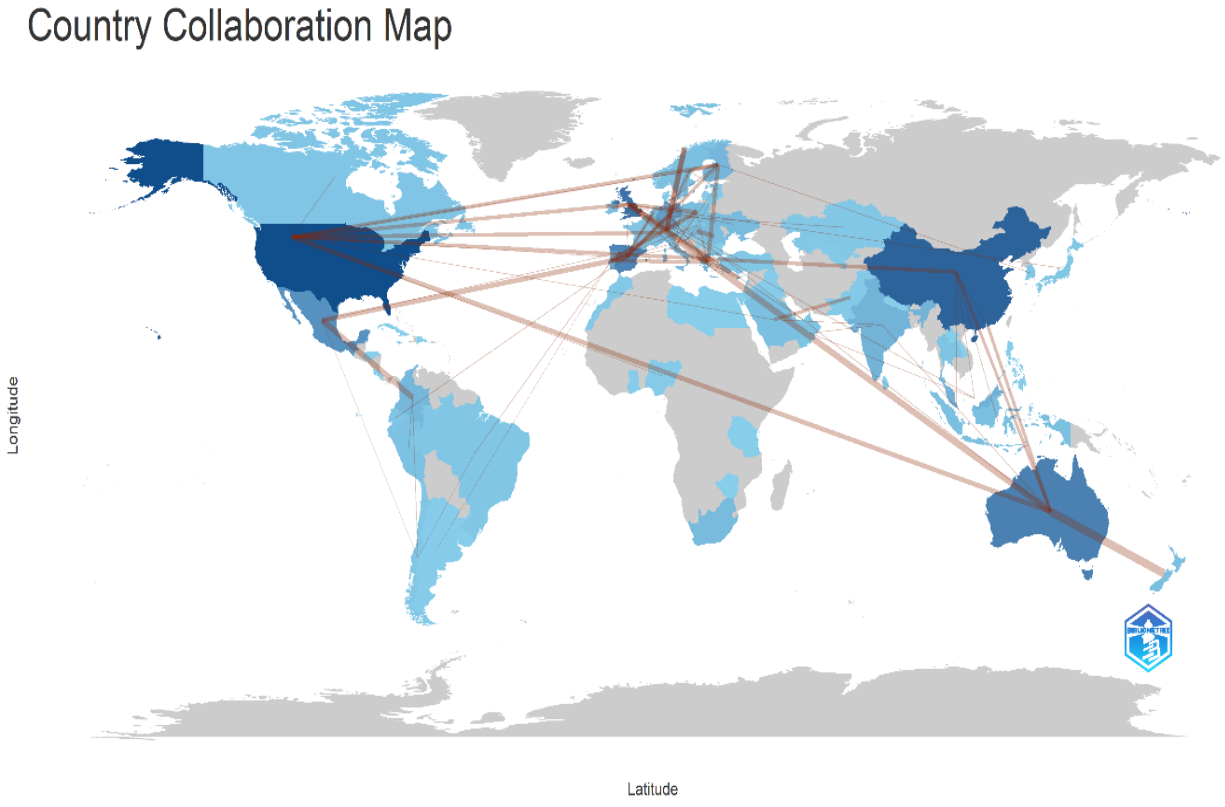

Figure 4: Collaboration between countries

Figure 4 displays the international collaboration, which gives an understanding of the authors' social structure and the countries they belong to. The collaborative relationships between the USA, China, Australia, Spain, Mexico, and Germany, along with others, are the most important.

Most Prolific Authors

Table 3. Most prolific Authors

Authors	Affiliations & Country	NP	TC	CI	H-index
Gregory S.	University of New England, Australia	14	161	11.5	7
Farley H.	University of Southern Queensland, Australia	9	110	12.22	5
Antón-Sancho Á.	Catholic University of Avila, Spain	9	69	7.67	3
Fernández-Arias P.	Catholic University of Ávila, Spain	9	69	7.67	3
Gregory B.	University of New England, Australia	8	98	12.25	5
Jacka L.	Southern Cross University, Australia	8	58	7.25	4
Vergara D.	Catholic University of Ávila, Spain	8	69	8.63	3
Christopoulos A.	University of Turku, Finland	8	128	16	2
Liu Y.	San Jose State University, USA	7	80	11.43	4

Table 3 presents the most productive, influential, and cited authors. The top prolific author is Gregory S. from the University of New England, Australia, who published the highest number of articles (14), achieved the highest number of citations (161), and had the highest H-index. This was followed by Farley, H., Antón-Sancho Á., and Fernández-Arias P., who published nine articles each. Gregory B. has published eight articles with the highest citation impact (CI) (12.25).

Most leading Institutions

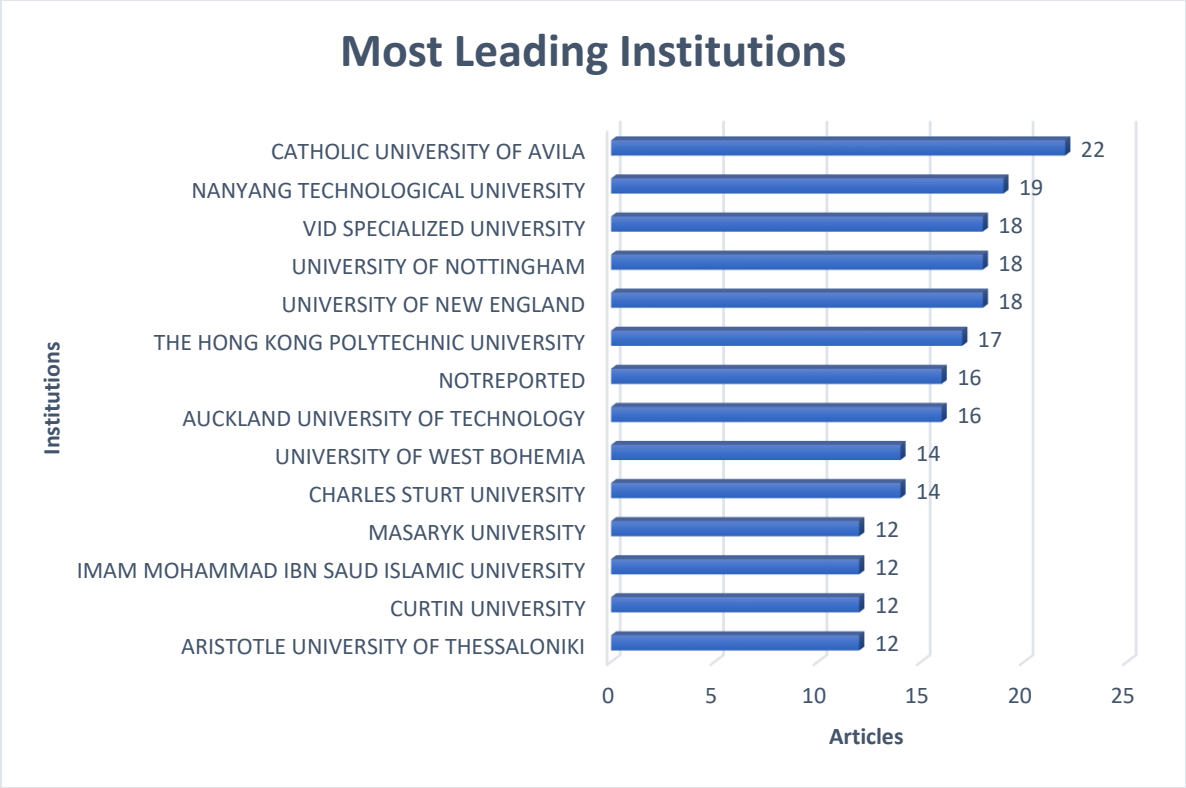

Figure 5: Top Most Leading Institutions

Figure 5 shows the leading institutions and the total publications. The Catholic University of Avila published the most articles (22). Nanyang Technological University published 19 articles, followed by VID Specialized University, the University of Nottingham, and the University of New England, each publishing 18 articles.

Most Leading Sources

Table 4. Most influential Sources

Source	NP	TC	CI	H_Index	PY_Start
"ACM International Conference Proceeding Series"	34	160	4.71	7	2013
"Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)"	29	63	2.17	5	2014
'Lecture Notes in Networks and Systems"	26	11	0.42	2	2020
"Communications in Computer and Information Science"	22	59	2.68	5	2015
"CEUR Workshop Proceedings"	19	139	7.32	5	2013
"Sustainability (Switzerland)"	18	291	16.17	8	2018
"Computers and Education"	17	2924	172	14	2010
"Advances in Intelligent Systems and Computing"	14	37	2.64	4	2013
"IEEE Global Engineering Education Conference, Educon"	12	26	2.17	3	2017

"ASEE Annual Conference and Exposition, Conference Proceedings"	11	19	1.13	2	2010

Table 4 represents the top ten leading sources that published articles on VR in HE. The "ACM International Conference Proceeding Series" published the most articles (34), achieving 160 citations. This was followed by "Lecture Notes in Computer Science" and "Lecture Notes in Networks and Systems," which published 29 and 26 articles, respectively. Notable, "Computers and Education" has the highest number of citations (2924), published 17 articles.

Most Cited Articles

Table 5. Most trending and cited articles

Title	Authors	Source Title	Year	TC	YAC
"A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda."	Radianti J.; Majchrzak T.A.; Fromm J.; Wohlgenannt I.	"Computers and Education"	2020	1060	265
"Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis"	Merchant Z.; Goetz E.T.; Cifuentes L.; Keeney-Kennicutt W.; Davis T.J.	"Computers and Education"	2014	956	9.56
"Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research"	Hew K.F.; Cheung W.S.	"British Journal of Educational Technology"	2010	349	24.93
"Educational games - Are they worth the Effort? A literature survey of the effectiveness of serious games."	Backlund P.; Hendrix M.	"5th International Conference on Games and Virtual Worlds for Serious Applications, VS-GAMES"	2013	179	16.27
"Virtual reality in engineering education: The future of creative learning"	Abulrub A.-H.G.; Attridge A.N.; Williams M.A.	"2011 IEEE Global Engineering Education Conference, EDUCON 2011"	2011	168	12.29
"Cross-cultural analysis of users' attitudes toward the use of mobile devices in second and foreign language learning in higher education: A case from Sweden and China."	Viberg O.; Grönlund Å.	"Computers and Education"	2013	162	14.23
"Virtual and augmented reality effects on K-12, higher, and tertiary education students' twenty-first-century skills"	Papanastasiou G.; Drigas A.; Skianis C.; Lytras M.; Papanastasiou E.	"Virtual Reality"	2019	155	31
"Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research"	Di Natale A.F.; Repetto C.; Riva G.; Villani D.	"British Journal of Educational Technology"	2020	149	37.25
"Gender divide and acceptance of collaborative Web 2.0 applications for learning in higher education"	Huang W.-H.D.; Hood D.W.; Yoo S.J.	"Internet and Higher Education"	2013	140	12.73
"Individual motivations and demographic differences in the social virtual world use An exploratory investigation in Second Life."	Zhou Z.; Jin X.-L.; Vogel D.R.; Fang Y.; Chen X.	"International Journal of Information Management"	2011	137	10.54

Table 5 represents the top ten most cited articles on VR in HE. Three of these ten articles were published in "Computers and Education." The top most cited article in the list, "A Systematic Review of Immersive Virtual Reality Applications for Higher Education: Design Elements, Lessons Learned, and Research Agenda," authored by Radianti J. et al. (2014), with 1060 citations (an average of 86 citations per year). This was followed by the second most cited article, "Effectiveness of Virtual Reality-based Instruction on Students' Learning Outcomes in K-12 and Higher Education: A Meta-analysis" by Merchant Z. et al. (2014), which received 956 citations. Both articles were published in 'Computers and Education". The third most cited article, "Use of three-dimensional (3-D) immersive virtual worlds in K-12 and higher education settings: A review of the research" by Hew and Cheung (2010), received 349 citations published in "British Journal of Educational Technology." The study also found that most of the highly cited articles have multiple authors.

Co-occurrence of Author's keywords and Thematic Clusters

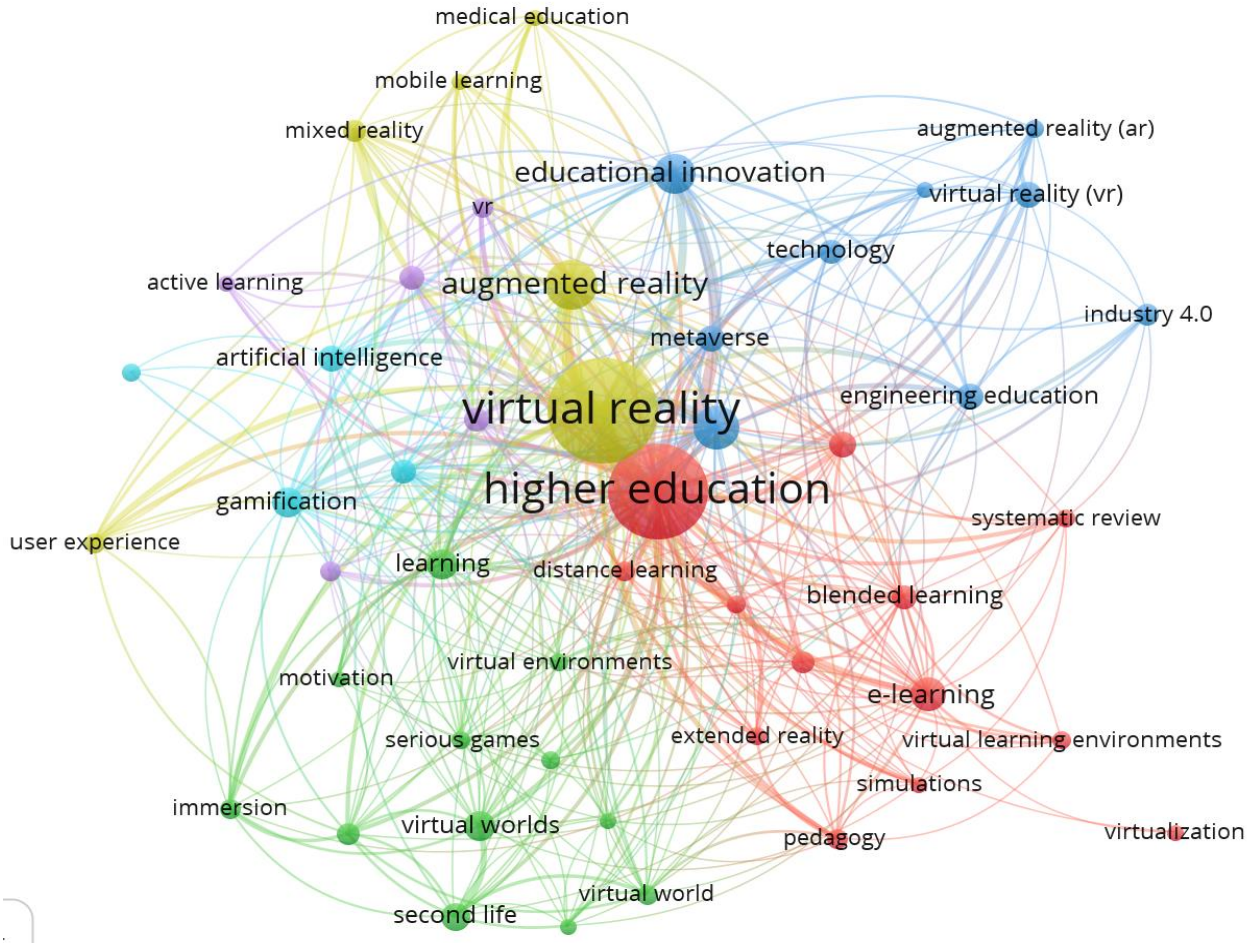

Figure 6. Co-occurrence of Author's Keywords

Figure 6 revealed the co-occurrence analysis of the author's keywords. The minimum co-occurrence for a keyword was set at 10. Out of 2667 authors' keywords, only 49 met the threshold criterion. The size and distance of the bubbles define the number of keyword's co-occurrences and associational links. These 49 keywords came under six main clusters. Each color represents the Cluster with associational links among the keywords.

The largest Cluster (with a red color) represented the studies relating to "Innovative Education Ecosystems in the Digital Age." These clusters discuss blended learning, extended reality, simulation, collaborative learning, virtual learning environments, pedagogy, higher education, e-learning, etc. Meanwhile, green represented the second Cluster, "Immersive Learning Landscapes and Gamified." This Cluster is associated with the keywords game-based learning, immersion, learning, motivation, second life, serious games, virtual environments, virtual learning, and virtual worlds. The blue Cluster is the third-largest Cluster related to "Emerging Frontiers in Educational Technology and Industry 4.0 Integration". It contains studies on systematic literature review, augmented reality (AR), VR, educational innovation, engineering education, metaverse, technology, and industry 4.0.

Similarly, the yellow colour cluster "Revolutionizing Medical Education through Augmented and Virtual Realities" highlights AR, VR, mixed reality (MR), mobile learning, user experience, and medical education. The purple color represented cluster 5, related to "Enhancing Active Learning with Immersive Educational Technologies," including active learning, educational technology, immersive virtual reality, and simulation. Lastly, the indigo color displayed in cluster 6 highlighted the "AI-Powered Experiential Learning and

Gamification in Virtual Reality" topic related to artificial intelligence, experiential learning, gamification, and virtual reality technology.

Table 6. Thematic Cluster based on Authors' Keywords

Cluster	Themes	Keyword	Occurrences	Total Link Strength
Cluster-1 (Red)	"Innovative Education Ecosystems in the Digital Age"	blended learning	20	46
		collaborative learning	13	31
		covid-19	24	45
		distance learning	15	31
		e-learning	44	66
		extended reality	12	29
		higher education	319	501
		online learning	18	27
		pedagogy	16	35
		simulations	10	20
		systematic review	12	25
		virtual learning environments	12	16
		virtualization	11	2
Cluster-2 (Green)	"Virtual Activity-based Learning Environment"	engagement	18	45
		game-based learning	12	15
		immersion	15	39
		learning	33	68
		motivation	10	19
		second life	29	41
		serious games	13	24
		virtual environment	11	17
		virtual environments	13	18
		virtual learning	11	22
		virtual world	16	33
		virtual worlds	35	55
Cluster-3 (Blue)	"Emerging Frontiers in Educational Technologies 4.0"	augmented reality (AR)	13	27
		education	72	108
		educational innovation	58	128
		engineering education	26	41
		industry 4.0	18	20
		metaverse	26	57
		systematic literature review	10	19
		technology	23	43
		virtual reality (VR)	26	34
Cluster-4 (Yellow)	"Mixed Reality Technologies in Medical Education"	augmented reality	91	205
		medical education	11	33
		mixed reality	19	56
		mobile learning	11	26
		user experience	15	39
		virtual reality	392	558
Cluster-5 (Purple)	"Active Simulated Learning in Virtual Reality Technologies"	active learning	10	18
		educational technology	22	42
		immersive virtual reality	16	20

		simulation	21	45
		VR	14	33
Cluster-6 (Indigo)	"AI-Powered Experiential Learning and Gamification in Virtual Reality"	artificial intelligence	24	39
		experiential learning	21	54
		gamification	32	68
		virtual reality technology	13	5

DISCUSSION

The VR technology is becoming more popular in educational research. The research trends revealed that yearly productivity has rapidly increased since 2018. This was evident in the growing number of papers and citations over the last decade (Rashid et al., 2021). It was possibly due to the new interest and the impact of the COVID-19 pandemic on VR technology (Rojas-Sánchez et al., 2023). The recent growth is consistent with the study's results and motivation in the educational field (Soto et al., 2020). However, this domain was interdisciplinary, where VR in HE research is famous in the computer sciences, social science, physical science, engineering, medicine, journalism, psychology, marketing, and other streams. These results were supported by Cipresso et al. (2018), Ambrosio and Fidalgo (2020), Mazurek et al. (2019), and Xue et al. (2019). Where Rashid et al. (2021) suggested that VR research is not confined to any specific discipline. For example, VR in medicine (Mazurek et al., 2019) and VR in education (Soto et al., 2020; Rojas-Sánchez et al., 2023).

The study's findings reveal that the most influential and leading authors and institutions belong to developed countries. These findings were unsurprising, as developed countries have consistently benefited from significant resources, funding, and infrastructure for research and academic pursuits (Abu-Zidan & Rizk, 2005). Developing countries have the potential to advance in technological research and achieve significant economic growth, while developed countries currently lead in technological capabilities and innovation (Maulana, 2020; Mohamed et al., 2022). As a result, most of the authors and institutions of developed countries collaborated with developing countries. Caselli & Coleman (2001) and Rojas-Sánchez et al. (2023) supported these findings. This international collaboration was more important for producing quality research. Based on these findings, future VR studies in the HE domains are expected to come from developing countries (Rashid & Khattak, 2021).

The findings also revealed that most VR research articles were published in the conference proceedings, while highly cited articles were published in peer-reviewed journals. Rojas-Sánchez et al. (2023) and Rashid et al. (2021) supported this finding. They confirmed that "Computers & Education" and "The International Journal of Emerging Technologies in Learning" are highly cited and productive peer-reviewed journals. These journals also had the highest impact factor. Nevertheless, Conferences provide fast and regular publication of papers, bringing researchers together to present and discuss the paper with peers (Franceschet, 2010). On the other hand, peer-reviewed journals are more credible and receive higher citations due to stringent review processes and factors like quality reporting, industry funding, and large trials (Brainard, 2020). These findings suggested that researchers strategically present early findings at conferences and reserve their more developed work for journals to maximize their impact and academic reach. Another interesting finding was that highly cited articles had more than one author. Hosseini and Bruton (2020) and Kumar (2018) supported this finding and claimed that multiple authors are trending in influential articles. Multiple authorship was associated with higher quality, increased citations, and greater social attention (Sanfilippo et al., 2018). However, Rigby (2005) found no significant relationship between multiple authors and higher citation impact. Hollis (2001) found that more co-authorship was associated with higher quality, greater length, and greater frequency of publications. Recent research identified that the involvement of multiple authors enhances the quality and credibility of research, leading to increased recognition and influence within the academic community.

The study findings revealed that VR, HE, AR, education, educational innovation, blended learning, e-learning, second life, etc., were the most frequently used authors' keywords. This finding was supported by Rashid et al. (2021). These keywords are now the most prominent and often highlighted concepts among researchers. These concepts relate to the student's interaction and holistic engagement in HE (Ambrosio & Fidalgo, 2020). Heim (1993) found that VR technologies require several fundamental elements, including artificial intelligence,

network connections, simulation, immersion, and interactivity; these concepts are also the more frequently used terms. These trending concepts are interconnected in nature in contemporary educational research. These emerging technologies are significantly impacting HE and enhancing learning experiences and engagement.

However, this finding also revealed that the six thematic clusters were found in these authors' keywords, which provide valuable insights into VR in HE. These themes also showed the importance of VR research (Rashid et al., 2021) and covered various concepts/aspects of VR technology in HE. These thematic clusters highlight VR's diverse applications and potential to enhance educational experiences (Allcoat & Mühlenen, 2018) and focus on how VR can create immersive and interactive spaces for learning (Young et al., (2020). These clusters also emphasize the integration of advanced technologies to transform traditional educational practices (Hamilton et al., 2020). Combining AI and game elements with VR simulation increases engagement and personalize learning experiences. However, Maas and Hughes (2020) found that the common themes of VR in K-12 education include collaboration, communication, critical thinking, attitude, engagement, learning, motivation, performance or achievement, and technology. Depape et al. (2019) found four themes in their study: technological factors, student characteristics, learning outcomes, and recommendations for incorporating VR and AR in HE. Similarly, Lai et al. (2021) found five key themes underlying the lack of VR usage in HE: applicability to curriculum, cost, fear and familiarity, comfort and practicality, and content availability. These findings suggested that future researchers, practitioners, policymakers, and academicians should investigate these themes/areas. These varied research themes add to the complexity of educational technology research and its capacity to revolutionize pedagogical approaches.

CONCLUSION

The present bibliometric study provides valuable insights into the evolving landscape of research on VR in HE over the last 15 years (2010–2024). This domain has rapidly increased in popularity since 2018, possibly influenced by the educational impact of the COVID-19 pandemic. This vibrant research domain is now multidisciplinary nature, not limited to any specific discipline. With the dominance of developed countries in VR research, there is a suggestion that future advancements may emerge from developing nations in the field of VR in HE. Moreover, the vital publication outlets and collaboration trends indicated a preference for conference proceedings alongside highly cited peer-reviewed journals. Co-occurrence analysis of author keywords reveals thematic clusters related to innovative educational ecosystems, virtual learning environments, AI-powered experiential learning, and gamification in VR, among others. These results demonstrate the opportunity for VR to improve student performance and revolutionize approaches to learning, providing valuable insights for future research initiatives. To encourage lifelong learning and active student involvement, the study also emphasizes further investigation of digitalization and e-skills in education and the application of AI, AR, VR, and MR technologies. These varied research areas highlight the revolutionary potential of educational technology in reshaping the field's landscape and adding to its complexity.

The search was conducted using the specified keywords, and the study was restricted to the Scopus database. We justify choosing the Scopus database. However, reviewing the literature on VR technology only allowed us to narrow down the list of potential keywords. The fact that the emphasis is solely on higher education levels is another issue that needs work. Future studies might look into trends in VR education at the elementary and high school levels. Despite these limitations, the study offers a thorough overview of the field and highlights VR's international collaboration and interdisciplinary character in HE. Moreover, it can be an initial basis for subsequent examination of systematic reviews, meta-synthesis, meta-analyses, and the amalgamation of bibliometric analysis and systematic reviews.

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