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Educational Landscape of Virtual Reality in Higher Education: Bibliometric Evidences of Publishing Patterns and Emerging Trends

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Abstract: This bibliometric study examines the overall research trends and productivity in the field of virtual reality (VR) in higher education. Bibliometric data were retrieved from Scopus databases. The findings suggest a rising trend in terms of citations and publications showing increased interest in the VR domain have been seen during the last few decades. The year in which the most citations of this type occurred was 2009, in which 1913 citations were recorded, whereas 2019 was the most productive year, as 127 documents on this subject were published in that year. The data analysis revealed that all the top ten researchers belong to Australia. Further, the top three researchers (Gregory S., Lee, M.J.W., and Wood, D.), countries (United States, the United Kingdom, and Australia), organizations (Charles Sturt University, Queensland University of Technology, and University of New England, Australia), journals (Computers and Education, International Journal of Emerging Technologies in Learning, and Journal of Surgical Education) and collaborations (Australia and New Zealand, United States and the United Kingdom, and Australia and the United Kingdom) belong to developed countries. Virtual reality, virtual worlds, augmented reality, e-learning, and simulations are the top keywords used in the VR domain. The thematic evolution of the keyword shows the importance of "Virtual Reality" as a keyword throughout the 27 years of its existence (1994–2020). Furthermore, the main finding of the study is the interdisciplinary nature of the VR domain, which extends from the field of computer sciences to other disciplines.

Keywords: virtual reality; bibliometric; augmented reality; artificial environment; virtual worlds; immersive multimedia; higher education; citation analysis

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1. Introduction

The use of virtual reality (VR) in the field of education can be traced back to 1966 in the form of a training course for the US air force [1]. Since then, the use of VR for a diverse range of educational purposes went through many stages of acceptance and rejection [2]. It emerged in the shape of arcade games in 1991 [3], which were discontinued in 1993 [4]. Following this pursuit, many VR gaming software (such as the Virtual Boy [3]) came into light and disappeared. However, a steady increase in the acceptance of VR in education was noted over the years [2]. Recently, the role of VR has started gaining currency in teaching and learning [5]. VR have been defined as "an artificial environment which is experienced through sensory stimuli (as sights and sounds) provided by a computer and

in which one's actions partially determine what happens in the environment; also, the technology used to create or access a virtual reality" [6]. The peculiar features of VR are immersion, interactivity [7], and presence [8].

A positive impact of VR has been documented on teaching and learning in terms of students' engagement [9], motivation [10], enjoyment during learning [11], deeper learning [12], and knowledge acquisition and retention [13]. At a higher education level, VR tools are used for various educational purposes; for example, e-field trips [14], lectures [5], and tutoring [15]. VR is also used by teams from various countries and universities for project collaborations [16,17]. Such virtual collaborations are known to have saved travel and other associated costs. For example, with the help of rumii (a social VR software), students of Harvard and Zhejiang University worked together as avatars in a VR-equipped classroom [18]. Similar social VR software are being used for collaboration not only among students [19] and exchange programs [20,21] but also among researchers and academicians working on various projects [22]. Such VR applications have the potential to increase engagement and collaboration while concurrently reducing the burden on finances [23].

Although VR is considered to be a promising tool in the field of education, its implementation design lacks a theoretical basis and a well-defined pedagogical approach [2]. According to Liu, Bhagat, Gao, Chang, and Huang [24], three learning theories serve better as theoretical bases for VR educational environments. The first learning theory is constructivism, which can promote the construction of new knowledge with the help of situated, experiential, and collaborated learning in a VR educational environment [25]. Similarly, autonomous learning (which focuses on learners' independence and control of their own learning) [26], is parallel to the VR educational environment's requirement for learners to develop their self-control skills [27]. Furthermore, the creation of multiple sensory modalities and rich simulation may create working memory overload, limiting the affordability of educational VR for students [28], which can be dealt by designing the VR learning process based on cognitive load theory.

Although both gamification and VR borrow similar concepts of motivation and engagement among participants, they have distinctly different methods of design and implementation [29]. Gamification aligns with the learning goals and outcomes clearly demonstrating that learning can be evaluated and achieved, whereas VR drive personal transformation by generating an attitude of acceptance of the challenge, motivation to achieve, and constant innovation through participant commitments [30]. In the VR condition, participants experience a significantly higher level of interest compared to the non-VR condition (gamification) [31]. Due to this reason, a recent study studying VR and gamification's respective roles in marketing higher education [32] used different queries for both, meaning that they did not add both keywords (gamification and VR) in a single search. Hence, these concepts cannot be used interchangeably [32], but are related (to the extent that both may be used for more engaging learning experiences [33]). As mentioned by [34], gamification is different from alternate reality games (ARGs). Based on these arguments, we will not consider both concepts as similar in the current bibliometric study.

The first bibliometric study can be traced back to 1920s; however, the term bibliometric was used for the first time in 1969 by Pritchard [35], who defined it as "the application of mathematical and statistical methods to books and other media communication" (p. 348). Since then, the field of bibliometrics has gone through many stages of its procedural and exponential growth [36]. Later in 2008, Forsman labelled it as statistical bibliography due to its affordability in terms of the statistical analysis of various features of scientific publications [37]. Ivanović and Ho [38] further added that this quantitative approach focused on analyzing the published data in a scientific domain in a certain geographical area. Overall, a bibliometric study is a statistical method to examine the publishing trends, patterns, and behavior of scholarly published literature.

Noyons, Moed, and Van–Raan [39] pointed out that bibliometrics could be divided into two categories: performance analysis (which utilizes publications and citation data to evaluate various scientific factors such as countries, institutions, etc. [40]), and science

mapping analysis (which evaluates the cognitive and social structure of a research field [41]). Bibliometric analysis focuses on productivity, measured in terms of research output [42,43] as well as co-occurrence/collaboration among authors [44], which helps evaluate the quantitative aspects of the published research [45] within a scientific domain in a certain geographical region. Researchers [46,47] have quantified the quality of research, with the number of its citations established as its impact; hence, bibliometric studies also help evaluate the qualitative [48] aspects of the published data through determining the number of their citations.

A considerable number of bibliometric studies have been done on VR in the field of education. However, these tend to be from very narrow perspectives; for example, the impact of VR on motivation of students [49], the role of VR in science [50], VR as an educational tool for high-functioning autism spectrum disorder (ASD) children [43], and virtual labs in scientific education (engineering) and its affordability in various educational disciplines [51]. Nevertheless, all of the bibliometric studies conducted in the VR domain from an education perspective focus on one specific aspect and are diverse in their educational settings (such as primary, elementary, and tertiary education). The present study focuses only on higher education and includes all disciplines in order to present a holistic view of the use of VR at a higher education level. This holistic view is especially important due to the multidisciplinary nature of higher education. The present study aims to explore research productivity, international collaborations, top universities and authors, citations and journal impact, keywords, and the thematic evolution of VR research in higher education over the last 27 years (1994–2020). Hence, the following research questions are explored in the present study:

1. What is the intellectual structure (in terms of publications and citations) of VR research from 1994–2020?
2. Which institutions, countries, and authors most influence the VR research globally?
3. What are the most influential papers and journals in the VR domain in a higher education context?
4. What are the dominating or most highly cited publications in VR domain?
5. What are the research collaboration and authorship patterns in the VR research?
6. What are the topics (keywords and themes) associated with VR research in higher education context?

The rest of the article is divided into four major sections: the 'Methodology' section highlights the criteria for inclusion, exclusion, and keyword selection, while the 'Results' presents the findings of the study, followed by the discussion and conclusion sections.

2. Methodology

Bibliometric analysis (a statistical method of the quantitative data analysis of scholarly literature particularly related to articles, conference papers, books, book chapters and other publications) was applied to investigate the research productivity and citation trends of VR in higher education. We used the Scopus database to retrieve scholarly literature in the field of VR in higher education. Scopus is one of the world's largest data sources of peer reviewed scientific literature [52]. Furthermore, Scopus indexed 75 million items and updates the data on a daily basis, and 32% of the overall content indexed in Scopus consists of social sciences literature [53]. Alongside this, there are a number of studies that prioritize Scopus (over other databases such as Web of Science, Dimensions, etc.) for bibliometric studies due to it being the largest data source of its kind [54,55]. Therefore, we decided to use the Scopus database for this bibliometric study.

2.1. Keywords Selection

The keywords for the present research were identified with the help of previous literature, keyword analysis of the various databases, and prior knowledge of the topic on the part of the research team. We entered "virtual reality" AND "higher education" OR "Higher Education Institution" AND "virtual reality" OR "University" AND "virtual reality" OR

"Universities" AND "virtual reality" OR "Tertiary education" AND "virtual reality" in the keyword/abstract/title search field of the Scopus advance search on 2 February 2021.

2.2. Data Selection Process

Figure 1 presents the four stages of the data selection process. In the first stage (Identification), the relevant records were identified by applying search query in Scopus. From the initial search results (5885 documents), an inclusion and exclusion criteria were applied (Screening). Only journal articles, book chapters, books, conference papers, and review articles were included in the search. Language and geographical filters were not applied. The language filter was not applied because Scopus provides other languages' bibliographic data (author, title, abstract) in English and bibliometric studies mainly use abstract-level data. Short surveys, editorials, letters, Erratum, notes, and conference reviews were not included as they are not peer-reviewed. This criterion helped to exclude 153 records. We further removed 4586 irrelevant records after title and abstract screening. These removed records were mainly within the fields of computer science, engineering, geography, and history, wherein VR was used for non-educational purposes. Additionally, we also excluded 73 records published in 2021 so that we obtained the complete data as of 2020. Finally, 1073 eligible records were accessed and each record was counter checked by two authors reading the titles and abstracts to ensure the accuracy of the data. Hence, all 1073 relevant records were downloaded and included. The data coverage range was from 1994 to 2020 and consisted of articles (n = 500), review articles (n = 19), conference papers (n = 516), book chapters (n = 35), and books (n = 3). The accuracy of the data was ensured after repeating the process with two different team members of the research group.

2.3. Terminologies Used in Data

Some terms/abbreviations were used in the analysis tables for the ease of understanding and comprehension of the data presented. These terms/abbreviations are as follows: TP (total publication), TC (total citation), CI (citation impact), and Scopus metrics such as CiteScore, Q (quartile), SNIP (source normalized impact par paper), and SJR (SCImago journal rank). SJRCI is defined as the average number of citations received by a specific publication. In order to get the value for CI for the present study, the total number of citations was divided by the total number of publications. Moreover, VosViewer, CiteSpace software, RStudio (Biblioshiny model), and MS Excel were used for data analysis and representation. These are specialized bibliometric tools, and each one creates the best visualization. Other bibliometric studies have also used these tools to get the best data visualization [56–59].

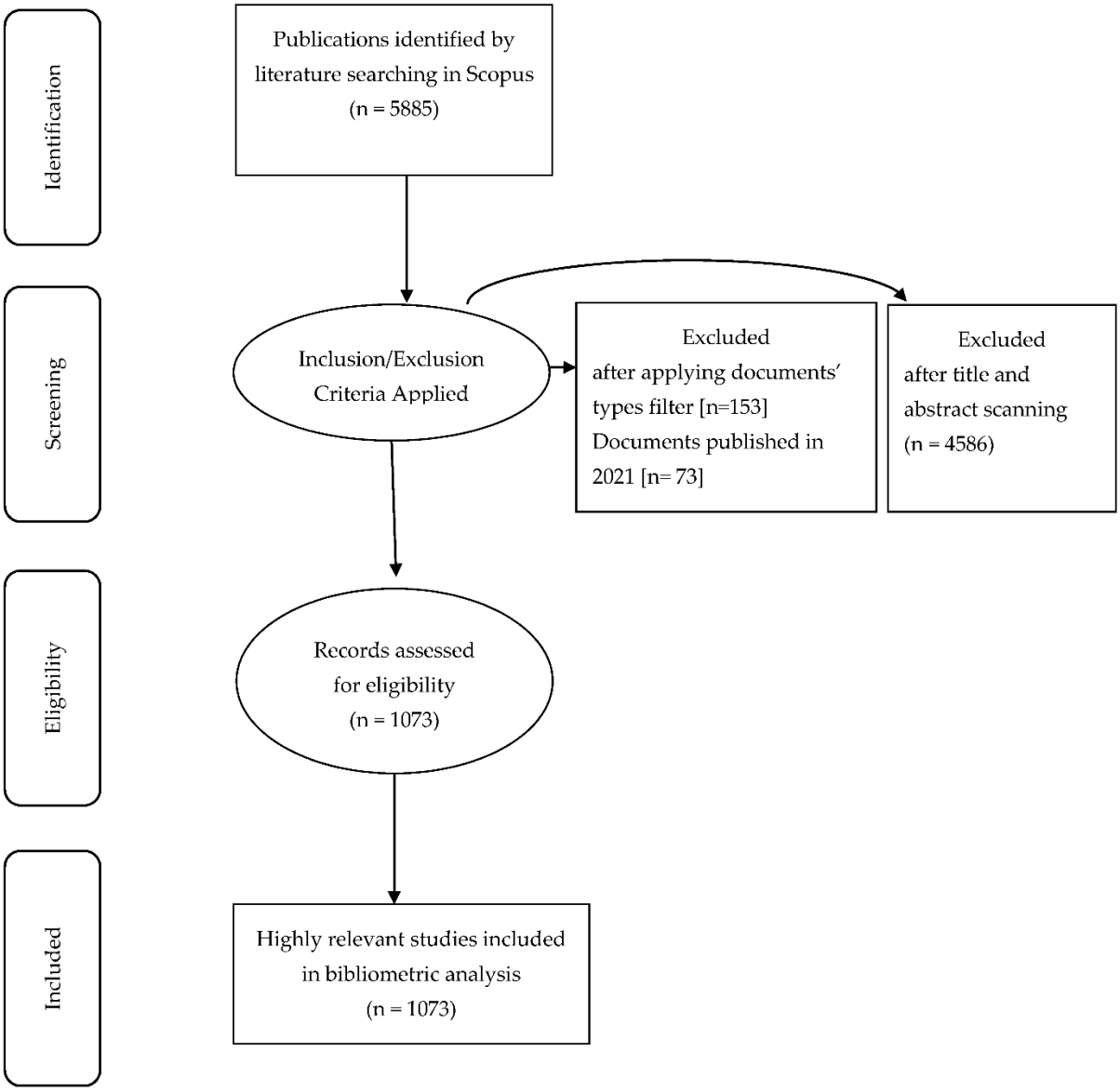


Figure 1. Four phase flow chart of the data extraction and filtration process.

3. Results

3.1. Publications and Citation Trends

The data presented in Figure 2 show the total number of publications and citations related to VR use in higher education. It is apparent that this area has been growing since 2004. The first decade (1994–2004) shows little progress, as the first publication appeared in 1994. There was no citation for the year 1995, as no publication was cited in that year. Notably, there are 34 publications in the first 6 years, which obtained 274 citations combined; however, this growth has increased in each year, especially since 2000. Some prominent publications were observed from 2007 to 2020, whereas the citations have gradually increased annually, especially since 2000. Apparently, the year with the highest number of citations was 2009, in which 1913 citations were recorded, whereas 2019 was the most productive year, as 127 documents were published in that year. The year with the least number of publications was 1995 (TP = 1), with no citations present at all.

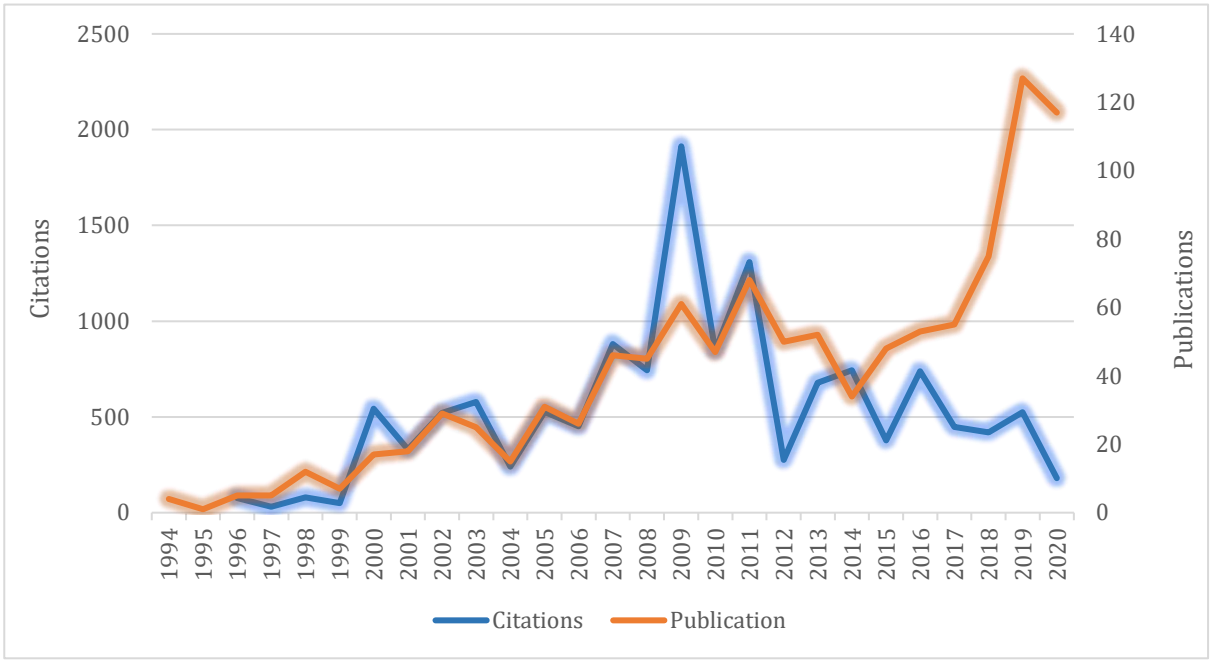


Figure 2. Publications and citation trends in VR from 1994–2020.

3.2. Leading Countries and Institutions

Table 1 demonstrates the top 10 countries and organizations that published the highest number of papers related to VR, along with the total number of publications (TP), total citations (TC), and citation impact (CI). CI is defined as the average number of the citations received by a specific publication. In order to get the value for CI for the present study, the total number of citations was divided by the total number of publications. The range of the number of publications was between 288 (maximum) and 24 (minimum). The United States emerged as a leading country in this field, producing the highest number of publications (288), gaining the highest citations (4758), and displaying a high citation impact (16.52). The UK follows the USA with 116 publications, 2426 citations, and the highest citation impact (20.91), followed by Australia, China, Spain, and Germany with 110, 69, 63 and 37 publications, respectively. Italy, Taiwan, Canada, and Greece lie in the bottom half of the table with 32, 31, 29, and 24 publications, respectively.

Table 1. Leading countries and institutions.

Top 10 Countries					Top 10 Organizations				
Rank	**Country**	**TP**	**TC**	**CI**	**Rank**	**Organization**	**TP**	**TC**	**CI**
1	United States	288	4758	16.52	1	Charles Sturt University	19	426	22.42
2	United Kingdom	116	2426	20.91	2	Queensland University of Technology	17	95	5.59
3	Australia	110	1270	11.55	3	University of New England Australia	17	131	7.71
4	China	69	563	8.16	4	Curtin University	15	526	35.07
5	Spain	63	791	12.56	5	Monash University	15	185	12.33
6	Germany	37	363	9.81	6	Auckland University of Technology	14	105	7.50
7	Italy	32	415	12.97	7	University of South Australia	14	108	7.71
8	Taiwan	31	314	10.13	8	University of Southern Queensland	13	110	8.46
9	Canada	29	360	12.41	9	Macquarie University	12	229	19.08
10	Greece	24	198	8.25	10	Southern Cross University	12	92	7.67

The UK and the USA also top the chart in the total number of citations and level of citation impact. The UK and the USA received 4758 and 2426 total citations, along with citation impacts of 20.91 and 16.52, respectively, followed by Australia, China, Spain, and

Germany with 110, 69, 63, and 37 citations, respectively. The bottom half of the table contains Italy, Taiwan, Canada, and Greece with 32, 31, 29 and 24 citations, respectively.

With regard to leading organizations, Charles Sturt University ranks among the top 10 organizations producing literature on VR with 19 publications, 426 citations, and a citation impact of 22.42. On the contrary, Southern Cross University is at the bottom of the list with 12 publications and 92 citations. However, Charles Sturt University tops the list in terms of the number of citations, with 526 citations (15 publications) and has the maximum citation impact (i.e., 35.07). The Auckland University of Technology, followed by the University of South Australia, the University of Southern Queensland, Macquarie University and Southern Cross University constitute the bottom half of the table with 14, 14, 13, 12 and 12 publications, respectively.

3.3. Most Prolific Authors on Virtual Reality

Table 2 presents the top ten most influential writers or the most cited writers in VR scholarly literature over the years. It is remarkable that all of the prolific authors in the list belong to Australia. Sue Gregory from the University of New England, Australia, is on the top of the list with 16 publications along with 131 citations, followed by Lee M.J.W. and Wood D. with 12 publications each; however, Lee has gained a comparatively higher number of citations (252). Notably, the author 'Dalgarno B' has produced 10 publications and has the highest number of citations (338). Both Lee M.J.W. and Dalgarno B. have the joint highest H-index (8). The author 'Hillier M.' is at the bottom of the list with eight publications, 85 citations, and an H-index of 5.

Table 2. Most prolific authors on virtual reality.

Author	Affiliations & Country	TP	TC	Citation Impact	H-Index
Gregory, S.	University of New England, Australia	16	131	8.19	6
Lee, M.J.W.	Charles Sturt University, Australia	12	252	21.00	8
Wood, D.	Central Queensland University, Australia	12	94	7.83	5
Butler, D.	Queensland University of Technology, Australia	10	52	5.20	4
Dalgarno, B.	Charles Sturt University, Australia	10	338	33.80	8
Farley, H.	University of Southern Queensland, Australia	10	95	9.50	5
Gregory, B.	University of New England, Australia	10	85	8.50	5
Jacka, L.	Southern Cross University, Australia	10	51	5.10	4
Grant, S.	Monash University, Australia	9	120	13.33	5
Hillier, M.	Monash University, Australia	8	85	10.63	5

3.4. Most Influential Journals on VR

Table 3 exhibits the top ten core journals that produced literature on VR. These top ten journals published 184 papers in total (1994–2020) and all of the journals are well reputed in the field. The top 5 journals produced 130 publications with 5676 citations. The journal 'Computers and Education' (CiteScore = 12.7, SJR = 3.047, SNIP = 4.28, Q1) is on the top of the list, having 39 publications and the highest number of citations (3968), followed by the International Journal of Emerging Technologies in Learning (CiteScore = 1.7, SJR = 0.326, SNIP = 0.926, Q2) with 28 publications and 189 citations. The journal 'International Journal of Engineering Education' is at the bottom of the list, with eight publications and 83 citations. One of the six journals from the UK, the Computer and Education, has the highest CiteScore (12.7). Out of the rest of the four journals, two belong to the USA, one is from Germany, and one is from Switzerland.

Table 3. Most influential journals on VR.

Source	TP	TC	CiteScore	SJR	SNIP	Q	Publisher	Country
Computers and Education	39	3968	12.7	3.047	4.28	1	Elsevier	United Kingdom
International Journal of Emerging Technologies in Learning	28	189	1.7	0.326	0.926	2	Kassel University Press	Germany
Journal of Surgical Education	25	335	3.0	0.86	1.368	1	Elsevier	United Kingdom
British Journal of Educational Technology	23	1118	6.1	1.624	2.347	1	Wiley-Blackwell	United Kingdom
International Journal of Continuing Engineering Education and Life-Long Learning	15	66	0.9	0.148	0.548	3	Inderscience Enterprises Ltd.	United Kingdom
Cyberpsychology and Behavior; Renamed to-Cyberpsychology, Behavior, and Social Networking	15	531	4.9	1.352	1.296	1	Mary Ann Liebert	United States
Computer Applications in Engineering Education	12	124	2.1	0.395	0.930	2	Wiley-Blackwell	United Kingdom
IEEE Transactions on Education	10	584	5.5	0.877	2.264	1	IEEE	United States
Sustainability (Switzerland)	9	51	3.2	0.581	1.165	2	MDPI	Switzerland
International Journal of Engineering Education	8	83	1.9	0.448	0.801	2	SAGE Publications Inc.	United Kingdom

3.5. Most Trending and Cited Publications of VR

Table 4 represents the top ten most cited articles on VR in higher education. It is interesting to note that no article after 2014 made it onto this list. Out of these 10 articles, six were published in "Computers and Education". Two articles were published in "Internet and Higher Education". The remaining two articles were published in "British Journal of Educational Technology" and "Internet and Higher Education", respectively.

The latest article in the list, "Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and Higher Education: a meta-analysis" authored by Merchant Z. et al., in 2014, tops the list, with 516 citations (at an average of 86 citations per year). This article is basically a meta-analysis that examines the impacts of selected instructional designs in VR technology-based instructions. The findings revealed that technology-based instruction enhances students' learning outcomes. Similarly, the second most cited article, "Critical success factors for e-learning acceptance: Confirmatory factor models" by Selim H.M, received 489 citations.

This paper defines the critical success factors (CSFs) for e-learning (as viewed by university students) as mainly existing under four groups, namely students, instructors, information technology, and university support. A sample of 538 university students was used to assess the categorization. The findings revealed eight different types of e-learning CSFs, each with its own set of essential e-learning acceptance and performance indicators. Each group of CSFs was accessed through a confirmatory factor modelling approach. At the bottom of the list is, "In search of higher persistence rates in distance education online programs" written by Rovai A.P. and published in 2003 in "the Internet and Higher Education". It has been cited 252 times at an average of 14.82 citations a year.

Table 4. Most trending and cited publications on VR.

Title	Author	Journal	Year	TC	Yearly Average
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	516	86.00
Critical success factors for e-learning acceptance: Confirmatory factor models	Selim H.M.	Computers and Education	2007	489	37.62
Are digital natives a myth or reality? University students' use of digital technologies	Margaryan A., Littlejohn A., Vojt G.	Computers and Education	2011	465	51.67
Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching	Warburton S.	British Journal of Educational Technology	2009	404	36.73
Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life	Jarmon L., Traphagan T., Mayrath M., Trivedi A.	Computers and Education	2009	284	25.82
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	270	27.00
A study of teaching presence and student sense of learning community in fully online and web-enhanced college courses	Shea P., Sau Li C., Pickett A.	Internet and Higher Education	2006	267	19.07
Virtual laboratories for education in science, technology, and engineering: A review	Potkonjak V., Gardner M., Callaghan V., Mattila P., Guetl C., Petrović V.M., Jovanović K.	Computers and Education	2016	260	65.00
Development and evaluation of a virtual campus on Second Life: The case of SecondDMI	De Lucia A., Francese R., Passero I., Tortora G.	Computers and Education	2009	252	22.91
In search of higher persistence rates in distance education online programs	Rovai A.P.	Internet and Higher Education	2003	252	14.82

3.6. Authorship Pattern of the VR Researchers

The analysis of authorship pattern indicates a 1–21 author pattern (Figure 3). The top three authorship patterns were papers with three authors (260 publications, 3651 citations), papers with two authors (258 publications, 2532 citations), and papers with a single author (199 publications, 2363 citations). Most of the publications were produced based on collaboration. There was a significant decline in the number of studies with more than five authors, with 46, 22, 14, 3, and 28 publications recorded for 6, 7, 8, 9, and 10 authors, respectively.

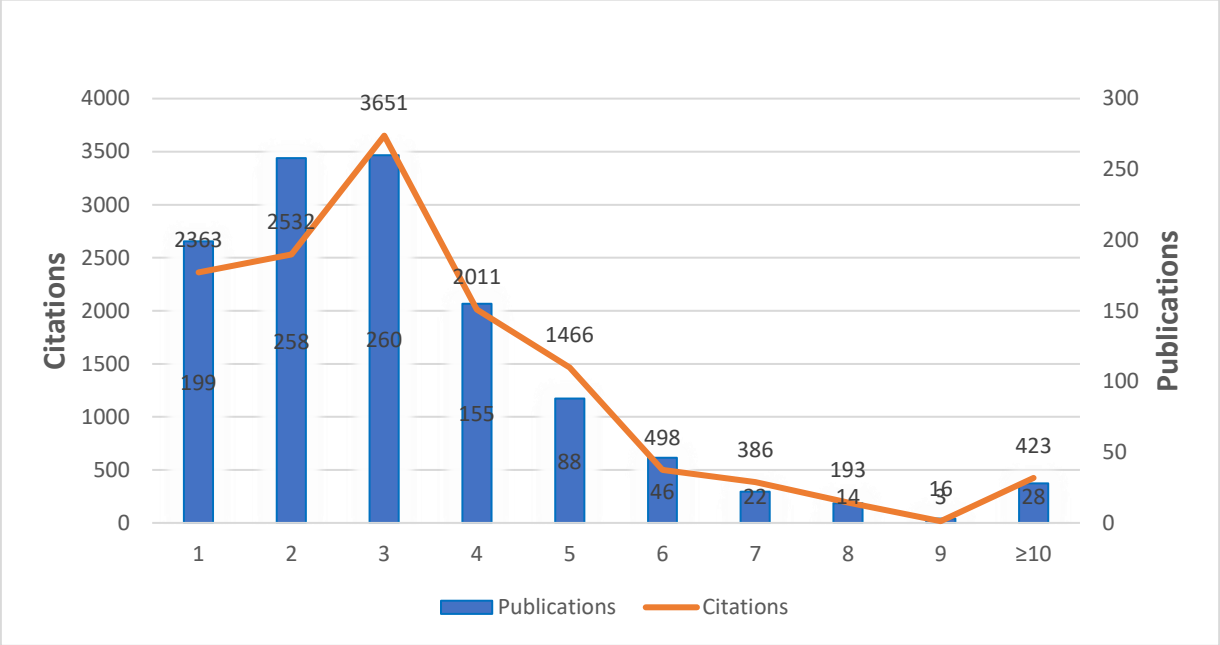
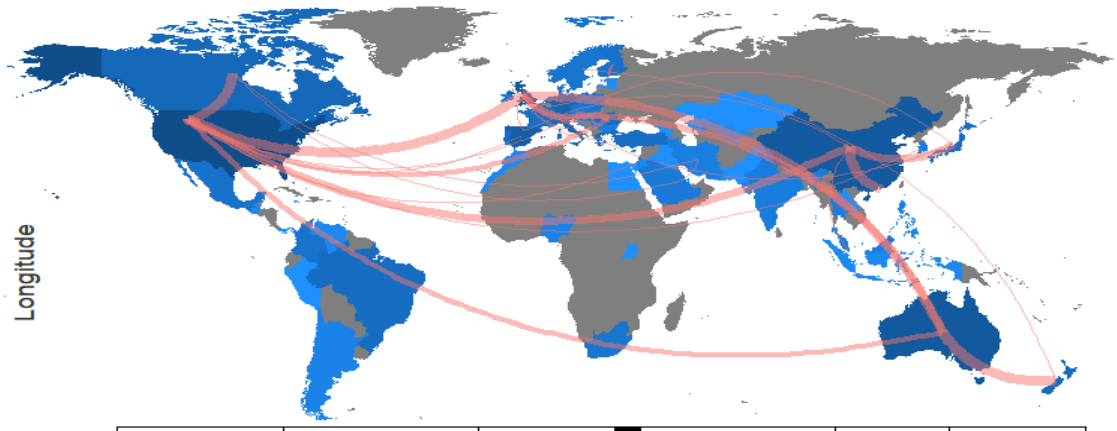


Figure 3. Authorship pattern of the VR researchers.

3.7. International Collaboration in the VR Research

Figure 4 highlights the global collaboration patterns regarding VR research in higher education. There are a total of 139 collaboration entries worldwide regarding VR, and all contain below nine collaborations. The top two collaborations of maximum frequency (8) occurred between Australia and New Zealand (N = 8), and USA and UK (N = 7), followed by six collaborations each amongst the Australia and the UK, China and Hong Kong, and the USA and Canada. The lowest number of collaborations among the top ten countries was found between the UK and Hungary (N = 2). Overall, there are a limited number of international collaborative publications on VR in higher education.



From	To	Frequency	From	To	Frequency
Australia	New Zealand	8	China	Japan	5
United States	United Kingdom	7	United States	China	5
Australia	United Kingdom	6	Australia	Austria	4
China	Hong Kong	6	Romania	Hungary	4
United States	Canada	6	United Kingdom	Hungary	3

Figure 4. Country collaboration Map.

3.8. Author Keywords

Figure 5 reveals the cartography analysis, obtained using VOSviewer software. Such types of analysis help to identify the keywords under each research stream. The minimum selected scale of co-occurrence for a keyword was set at 6. Out of 2517 authors' keywords, only 35 met the threshold criterion. The distance and size of the bubble define the number of keyword occurrences and associational links. These 35 keywords are associated with four main clusters. Each color represents the cluster with associational links among the keywords.

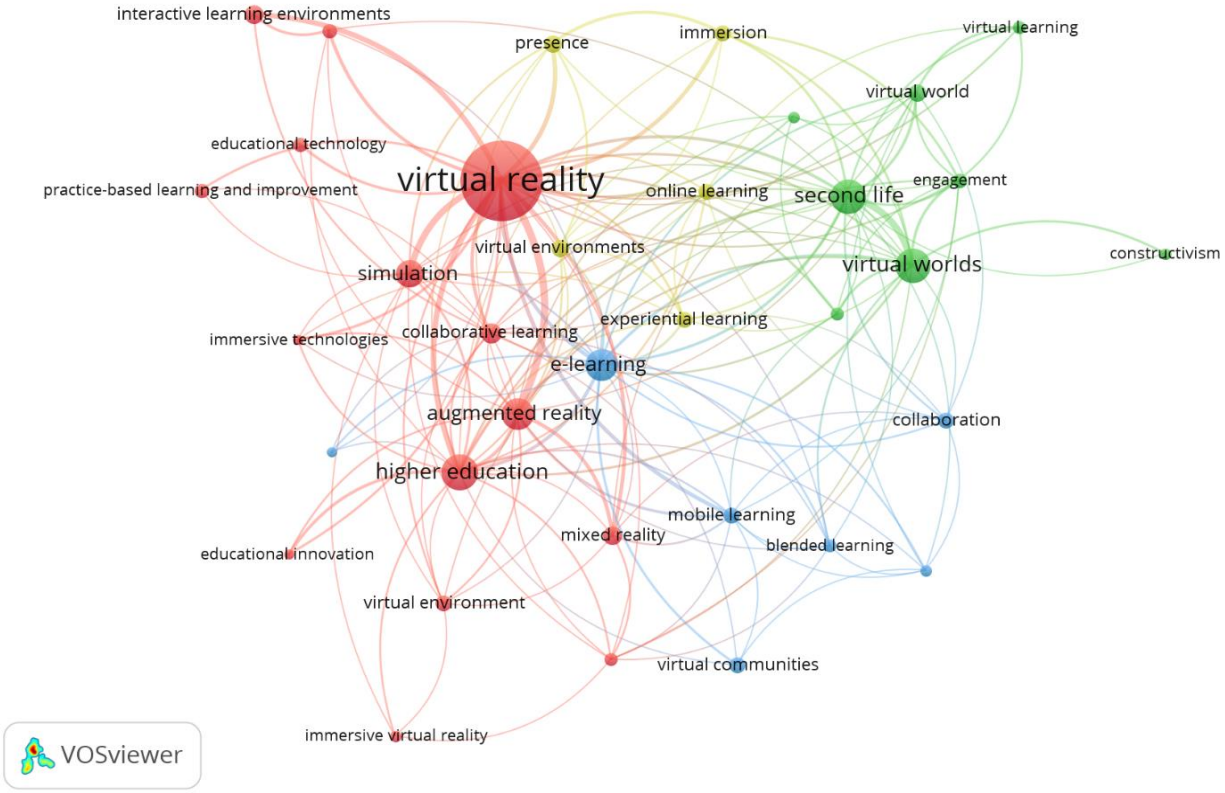


Figure 5. Figure 5 shows the cartography analysis through VOSviewer software. The purpose of the analysis is to identify the keywords under each research stream. The minimum selected scale of co-occurrence for a keyword is six.

The largest cluster (with a red color) represents the studies relating to virtual reality and higher education. These studies discuss the topics relating to virtual reality, augmented reality, simulation, collaborative learning, interactive learning environments, mixed reality, virtual environment, educational technology, practice-based learning and improvement in teaching/learning strategies, gamification, immersive virtual reality, educational innovation, and immersive technologies. Meanwhile, the green color represents the second cluster of the articles associated with the keywords second life, virtual worlds, virtual world engagement, game-based learning, virtual learning, constructivism, and immersive learning, etc. The blue cluster is the third-largest cluster; it contains studies relating to e-learning, collaboration, mobile learning, virtual communities, blended learning, and web 2.0. Similarly, the yellow color cluster highlights presence, virtual environments, immersion, online learning, experiential learning, and other related studies.

3.9. Most Cited Author Keywords with the Strongest Citation Bursts

Citation burst is an indicator of the most active area of research. A citation burst is a detection of a burst event, which can last for multiple years as well as for a single year. A citation burst provides evidence that a particular publication is associated with a surge

of citations [60]. In other words, it means that the publication evidently has attracted an extraordinary degree of attention from its scientific community in a specified period.

Figure 6 demonstrates the top twenty highly cited keywords regarding VR. This figure has been generated through CiteSpace software. The blue color presents the overall period of a citation and the red color presents the extraordinary degree of attention period. The top three keywords with the strongest citation bursts are 'virtual world' (strength = 18.87), interactive computer graphics (strength = 14.85), and world wide web (strength = 14.09). It is interesting to note that the keyword 'internet' has the longest citation burst period (1994–2009); however, the strength of this keyword is 12. Similarly, the keyword 'immersive virtual reality' possesses the shortest citation burst period (2018–2020) and possesses the minimum strength (6.23) amongst the top 20 keyword citation bursts.

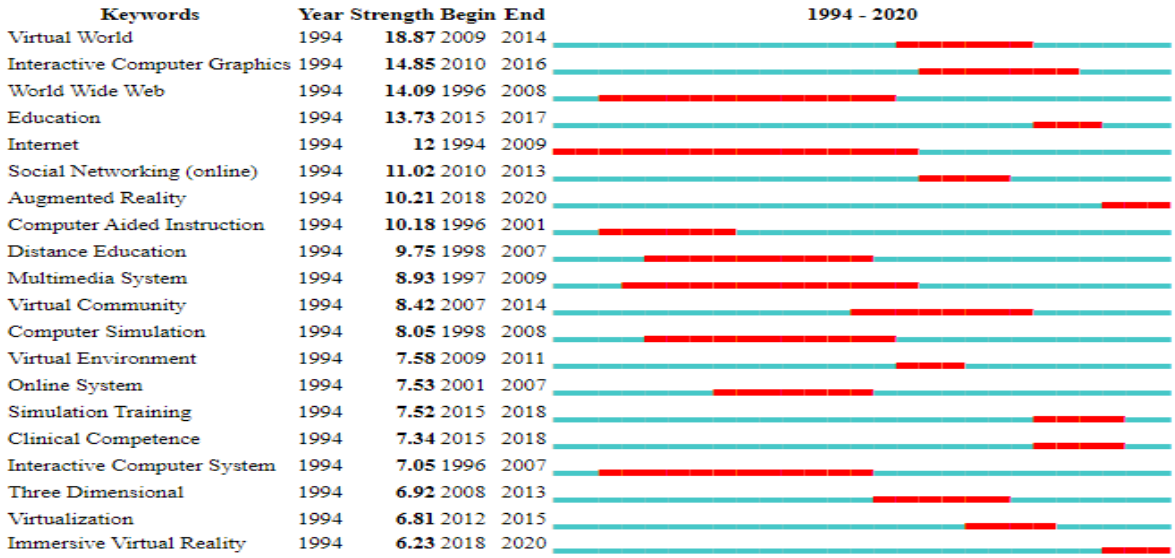


Figure 6. Top 20 keywords with the strongest citation burst.

3.10. Thematic Evolution of Author Keywords

The thematic evolution of keywords was created using the Biblioshiny package. It shows a clear shift in VR research streams during the last 27 years. The rectangle/square shapes from the left to the right sides show the chronological development of various thematic evolutions. The right side shows the thematic evolution from 1994–2010 and the left side shows the remaining period (2011–2020). The link/lines of various colors amongst the keywords show the connection between each keyword; for example, the keyword 'virtual reality' remains constant (from 1994–2020) and is used with terms such as 'virtual worlds', 'virtual reality simulation', 'immersion', and 'communication'. Virtual Reality was very important and was the most frequently used keyword throughout the 27 years (1994–2020), followed by e-learning, virtual worlds, and education. Computer science education, Web 2.0, and visualization disappeared after 2004 (Figure 7).

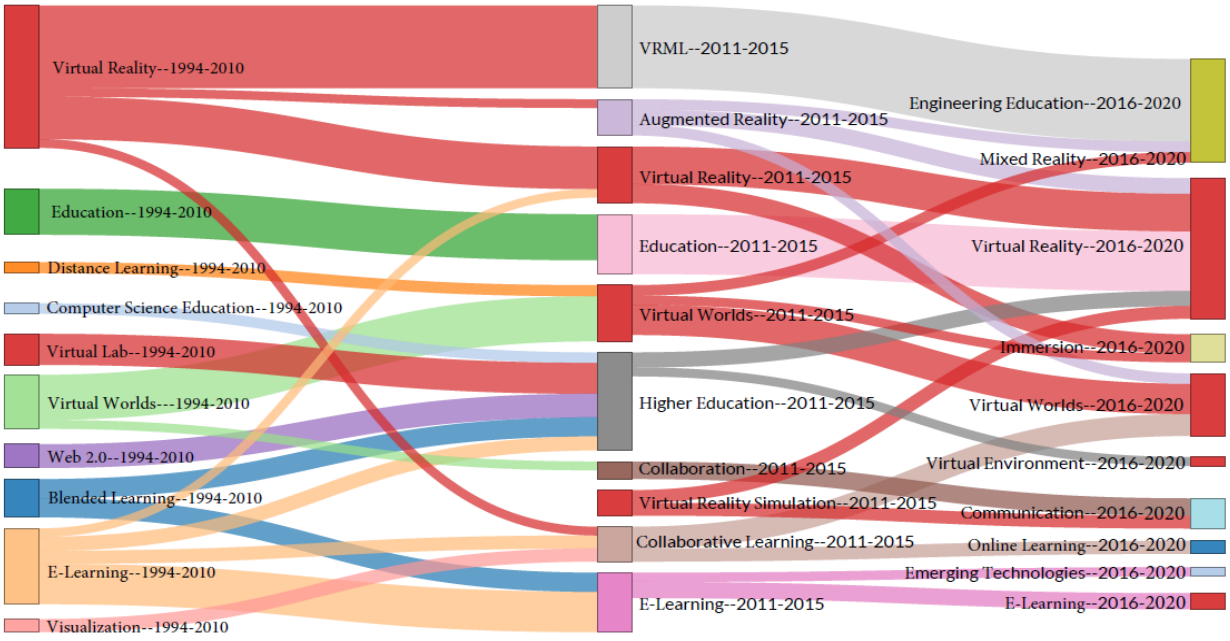


Figure 7. Thematic evolution of the author keywords.

4. Discussion

The overall findings reveal that VR research is gaining currency in terms of applicability, publications and citations. This is evident by the increasing number of articles and citations in the VR domain in the context of higher education (in various fields) in the last decade [61–63]. The major findings of the study reveal that the top researchers, countries, organizations, and journals in VR research belong to developed countries. Similarly, the top research collaborations were found among developed countries. This could be viewed through the lens of diffusion/adoption of technologies across countries. The perspective highlights that the focus of researchers in the high-income economies (developed countries) is on the research and development (R&D) processes, whereas researchers in the low-income economies adopt technologies already developed in the technologically advanced countries [64]. Based on this perspective, it may be assumed that future research may emerge from developing countries in the VR domain. Another major finding of the study is the interdisciplinary nature of the VR domain. VR research is not confined to the computer sciences discipline [65] only; rather, VR related research has also been conducted in the fields of education, computer science, technology, engineering, leadership, management sustainability, and human behavior. Alongside this, VR is currently used in medicine [66], journalism and psychology [67], and marketing [68], showing that VR research is not confined to any specific discipline. Despite the multidisciplinary nature of the VR results, the highest number of citations in the current research are from journals in the field of computer science and education. This could be due to the focus of the current study on VR research in the higher education sector.

Multiple authorship patterns were observed in the data in terms of publications, as most of the papers were collaborations including more than one author. Most of the publications (the highest number of publications, in fact) were publications with three authors. Already, multiple authors' papers are trending in academia [69,70] in other disciplines as well. There are well defined reasons behind the rising trend of multiple authorships; for instance, the increasing tendency to collaborate with other international researchers leads to more specialization, financial support, and division of labor [71]. Another factor behind the rising trend is the growing prevalence of the "publish or perish" phenomenon in academia [72]. At the same time, multiple authorships have led to the misconduct and misbehavior related to the authorship disagreements [73] and unethical practices in academic research [74].

From the keyword perspective, with relation to higher education, virtual reality, virtual worlds, augmented reality, simulations, e-learning, and second life are the top keywords in the VR research. All these keywords relate to the characterization of something based on immersion (multisensory), presence, and interactivity [67]. Similarly, Heim views VR as having various essential components, such as interaction, simulation, immersion, artificiality, and network communications [75]. The thematic evolution of the keyword also shows the importance of 'Virtual Reality' as a keyword throughout the 27-year span (1994–2020). Moreover, the commonly used keywords in the early period (1994–2000) were distance education, pre-secondary education, active learning, practice based learning, and virtual reality. In the period (2011–2020), virtual reality, augmented reality, virtual worlds, collaborative learning, e-learning, educational technology, and technology were common keywords. Similarly, in the latest period (2011–2020), virtual reality was once again a commonly used keyword, along with some new keywords, such as experiential learning, simulation, and higher education. The disappearance of computer science education as a keyword after 2004 could be due to the extension of VR research from computer graphics to several disciplines [65].

5. Conclusions

The main objective of the present bibliometric study was to examine overall research trends, productivity, international collaborations, top universities and authors, citations and journals impact, keywords, and thematic evolution of the VR domain in the field of VR in higher education over the last 27 years (1994–2020). This bibliometric study helps to examine the publishing trends and patterns in order to understand the nature and level of productivity of the discipline and to guide the researchers in deciding what to publish and where to publish, keeping in view the subject productivity, highly relevant journals, authors, thematic evolution, etc. Publications and citation numbers have gradually increased during the last decades. Furthermore, VR is now a vibrant research domain which is not owned by any one specific discipline. The main beauty of VR research is that it is not only researched by the researchers in the field of computer science but also those from other disciplines as well, such as marketing, medical sciences, engineering, psychology, education, and pharmacy. The adoption of technology in all industries and sectors of life could be the main reason behind this. Furthermore, the authorship patterns found in the VR domain tend to feature research conducted by multiple authors, with research conducted by three authors being the most dominant of these.

Overall, the study concludes with arguments that VR is no longer an illusion or imaginary technology, but is instead very practical and a necessity of the current time. There is still great potential in the field of VR for exploration, understanding, and testing. Its multidisciplinary nature makes it even more attractive for the authors from various disciplines, countries, and specializations to work on.

The limitations of the study are its reliance on the Scopus database. Although we justify the selection of Scopus database, the scope of this research may be limited; therefore, data collected from Web of Science, ERIC, Google Scholar, and EBSCO may provide opportunities for future research. Another limitation is the focus on only one level of education, the higher education sector. Future research may explore VR research trends at primary and secondary levels of education. VR trends in the educational context of developing countries will also add value.

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