The Comparison of the Top 100 Cited Publications of Augmented Reality and Virtual Reality for the Last Thirty Years

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Abstract—The development of technology like mobile devices, computers, and other smart devices is developing rapidly, especially AR and VR technologies. This study describes a comparison among 100 cited papers in AR and VR studies. Research data covering the top one hundred cited publications for the last thirty years were obtained from the Scopus database. The article is most publication document type. Most of these top-cited papers were published in 2005 for VR and 2013 for AR. The journal Computer and Education is the primary source of the Elsevier, which governs the publication of the most influential AR-VR studies. Most research articles have multiple authors. Slater and Feiner are recognized as the most productive author. The United States dominates the production of highly cited AR-VR papers. Future research should focus on other disciplines, use one or more keywords, and collaborate with Google Scholar, the Web of Science data, for in-depth analysis.

Keywords— augmented reality, bibliometric, virtual reality, VOSViewer

1 Introduction

1.1 Background

In the 21st century, the development of technology, especially mobile, computer, and other smart devices that use the internet, is growing so fast [1]. It can be seen from many users of devices and human activity, especially industries that integrated technology to start the activity. Therefore, integrating technology in each human activity can make human activity easier. According to [2] and [3], technology can integrate irrigation and fertilization activity so farmers can manage and monitor it by phone. The development technologies contribute to constructing knowledge, especially on research trends. Several studies have been conducted on one of the most popular interactive technologies, significantly augmented reality and virtual reality [4]. For

example, The Computers and Education Journal has publications related to virtual reality and augmented reality since 1976.

Currently, bibliometric analysis is the most literature research in the pandemic era.

Bibliometric focuses on analyzing quantifiable published data that can be used to produce objective and reproducible results and provides insight into the relationships between documents are analyzed [5][6]. In bibliometric research, researchers can use citation analysis to measure systematic relevance and use it to uncover the maxims of impactful research in a field [7]. Articles that receive more citations must be good research quality and influence expertise in a particular field [7]. Similarly, [8] researched bibliometric analysis of 356 publication papers on virtual reality in health care in the Web of Science using BibExcel, HistCite, and VOSViewer between 1994 and 2021. Thus, [9] analyzed virtual reality in higher education from a bibliometric analysis. In this research, 1073 papers published in Scopus between 1994 to 2020 have been included in the analysis. Another study [10] identifies the 215 papers from Scopus databases between 2003 and 2018 on augmented reality. So bibliometric analysis methods related to AR and VR research have been used, especially in the last thirty years.

In addition, [11] analyzes a large-scale network and cluster for both VR and AR in all scientific disciplines. In contrast to these studies, this research purpose of providing and comparing a current and comprehensive visualization of VR and AR research in the top one hundred cited papers in the last thirty years via a bibliometric analysis. So. this study contributes to future research on VR and AR by measuring, comparing, and mapping the trends research of literature on this topic.

1.2 Research objective

This study reviewed the trends research between augmented reality (AR) and virtual reality (VR) in terms of the top hundred cited papers to compare and identify the status of AR and VR research so this study can help future researchers. The research objective is to explore the top one hundred cited papers on VR and AR for the last thirty years. There are several research objectives were discussed in this research:

1. To identify and compare the document types of the top one hundred cited papers among AR and VR research.
2. To study and compare the most productive author of the top one hundred cited papers among AR and VR research.
3. To identify and compare the year-wise distribution of the top one hundred cited papers among AR and VR research.
4. To identify and compare the sources publishing of the top one hundred cited papers among AR and VR research.
5. To discover and compare the countries most interested in AR and VR research and collaboration among them.
6. To analyze each trends research AR and VR research for the last thirty years.
7. To analyze the differences and similarities between AR and VR.
8. To analyze the advantages and disadvantages of AR and VR.

2 Methods

This research uses quantitative descriptive using bibliometric analysis [7][12][13]. Therefore, bibliometric analysis is a statistical method for quantitative data analysis of scientific literature, significant articles, conference papers, books, book chapters, and other publications that can prove and find novelty and research trends [12][14][15][16]—the flowchart research in Figure 1.

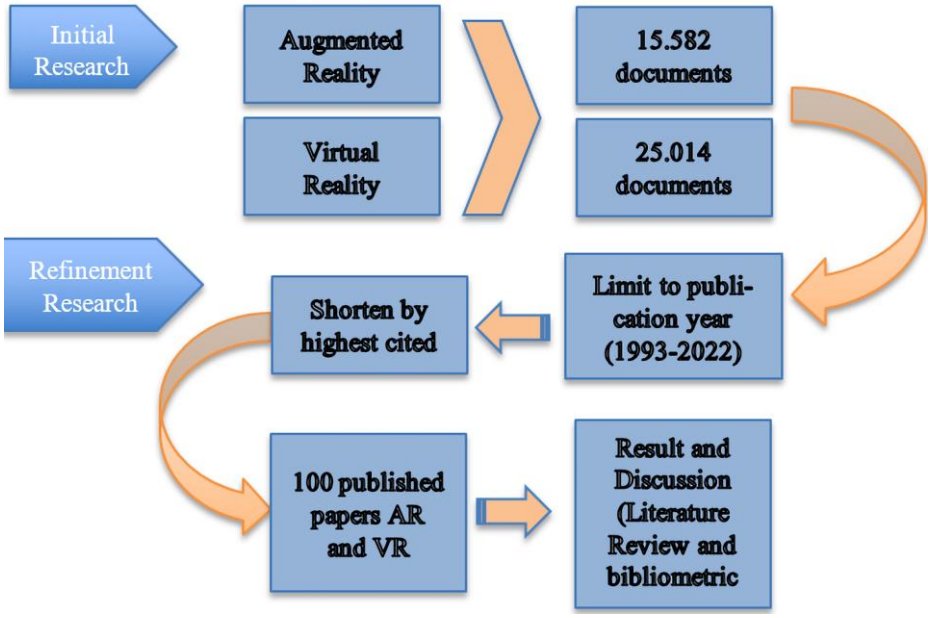


Fig. 1. The flowchart research procedure

The database sources are from Scopus, which was collected on January 27, 2022. Researchers used the Scopus database because it is one of the world's largest sources of peer-reviewed scientific literature [17]. In addition, Scopus updates its data daily, with 32% of all Scopus indexed content consisting of social science literature [18]. In addition, because Scopus is the largest data source of its kind, there are many prioritized studies (over other databases such as Web of Science, Dimensions) for bibliometric studies [19]. Bibliometric analysis has five steps such as keyword determination, initial search results, search refinement, initial data statistics, and data analysis creation [20][21].

The database does not limit the type of language and publication type then sorted by highest cited. Then each data of the top hundred cited papers is downloaded in *.ris* or *.csv* file format, which will then be uploaded to the VOSViewer software. In this study, two analytical techniques were used to perform bibliometric analysis. The first analysis technique uses VOSViewer to reveal the network visualization of the keywords obtained from the *.ris* file metadata. The second analytical technique, de-

scriptive analysis, analyzes the year of publication, country, affiliation, language, and others obtained from the analyzed *.csv* metadata using *Microsoft Excel* and word cloud generator for visualization [7].

3 Discussions

3.1 Document type

Table 1 shows the number of publication-type documents in each top one hundred cited papers. There are no top-cited papers about AR in the form of a note. Besides, VR studies do not have top-cited papers in the form of a book chapter. AR has 63 papers in the form of articles, 23 conference papers, 12 papers in the form of review, and one paper for book chapters and books. Besides, VR has 67 papers in the form of articles, 24 review papers, six conference papers, two papers in a book, and one paper for note. The total citation rate of articles in each study is the highest number.

Nevertheless, the average cited rate and median in VR is higher than in AR. However, the standard deviation of AR research, especially in article papers, is high in 277,28. The language used in the top one hundred cited papers related to AR and VR over the last thirty years has been English.

Table 1. Document type of top hundred cited papers

Document Type	Augmented Reality					Virtual Reality				
	f	***Total Cited***	***Mean***	***Median***	***SD***	***F***	***Total Cited***	***Mean***	***Median***	***SD***
Article	63*	19649*	311,88*	235*	277,28*	67*	25196*	376,05	294	237,36
Book	1	570	570	570	-	2	1000	500	500*	98,99
Book Chapter	1	290	290	290	-					
Conference Paper	23	8563	372,30	240	338,09	6	4829	804,83*	435	685,28*
Review	12	7660	638,33	243,5	1253,05	24	9286	386,91	322,50	154,38
Note						1	398	398	398	-
Total	100	36732	436,50	315,70	373,68	100	40709	493,16	389,90	235,20

f= frequency, *SD*= Standard Deviation, * the highest number

3.2 Top ten authors

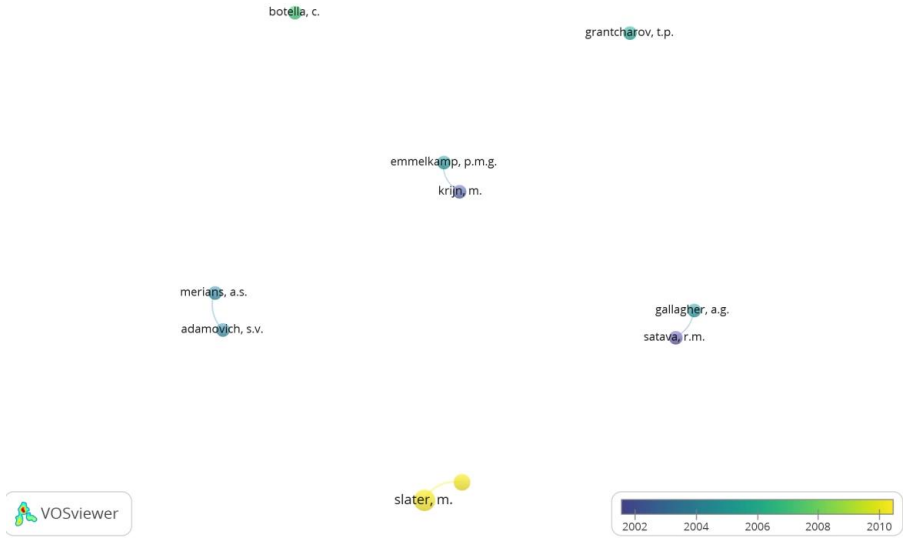
Table 2 describes the top ten authors, the number of most cited papers, the author's region, and the AR and VR study affiliation. There are top ten authors who have published three or more of the top-cited papers. Sanchez-vives and Slater from Spain are the authors that have published many papers about AR and the highest link strength (4). Therefore, Gallagher from the United States received the most paper citations about AR. Besides, Feiner from the United States as the author that has published many papers about VR and the highest link strength (6). The most number of paper citations about VR is Nee from Singapore.

Table 2. Top ten authors

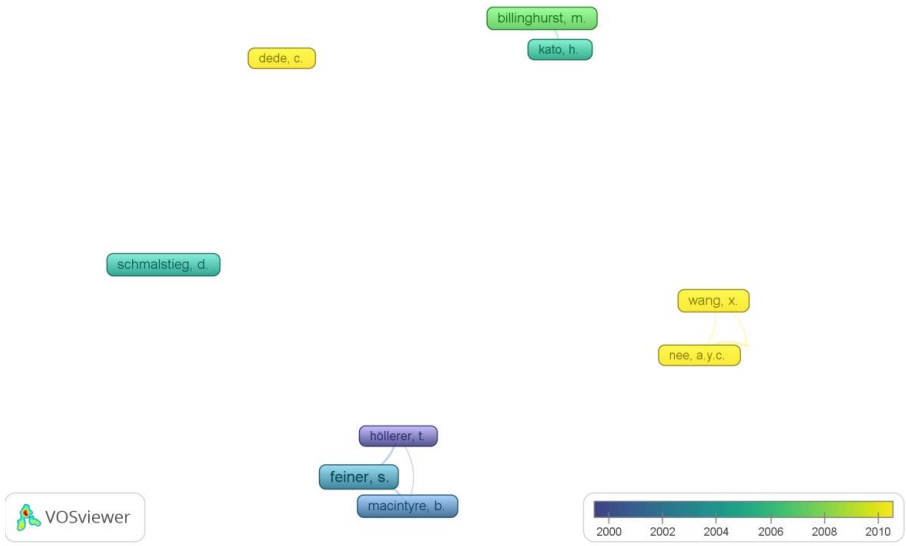
Augmented Reality						Virtual Reality					
Authors	***TP***	***TC***	***LS***	***Region***	***Affiliation***	***Authors***	***TP***	***TC***	***LS***	***Region***	***Affiliation***
Sanchez-vives, m.v.	4	2054	4*	Spain	Univ. Miguel Hernandez	Feiner, s.	8*	4919	6*	United States	Colombia University
Slater, m.	7*	2883	4*	Spain	Univ. de Barcelona	Hollerer, t.	3	756	4	United States	Colombia University
Ada-movich, s. v.	3	1224	3	United States	Univ. Heights	Macintyre, b.	5	3370	4	United States	Colombia University
Merians, a. s.	3	1224	3	United States	Univ. of Med of New Jersey	Nee, a. y. c.	3	11737*	4	Singa-pore	National Univ. of Singapore
Em-melkamp, p. m. g.	3	1088	2	Nether-lands	Univ of Amster-dam	Ong, s. k.	3	3553	4	Singa-pore	National Univ. of Singapore
Gal-lagher, a. g.	3	3105*	2	United States	Emory Univ. School of Medicine	Billinghurst, m.	5	3396	2	New Zealand	Univ. of Canter-bury
Krijn, m.	3	1053	2	Nether-lands	Univ of Amster-dam	Kato, h.	3	2180	2	Japan	Hiroshima City University
Satava, r. m.	3	3072	2	United States	Emory Univ. School of Medicine	Wang, x.	5	1390	2	Singa-pore	National Univ. of Singapore
Botella, c.	3	1100	0	Spain	Univ. Politenica de Valen-cia	Dede, c.	3	1183	0	United States	Harvard Graduate School of Education
Grant-charov, t. p.	3	1529	0	Den-mark	Aarhus University	Schmalstieg, d.	4	1087	0	Austria	Vienna Univ. of Technolo-gy

TP=total papers, *TC*=total citation, *LS*=link strength, * the highest number

Top authors clusters and the number of an author over time are shown in Figure 2. In the VR study, there are 6 clusters, and Slater's cluster is the enormous author cluster with top-cited papers. Then, in the AR study, there are 5 clusters. The most prominent author clusters with top-cited papers are Feiner, Macintyre, and Hollerer clusters.



(a)



(b)

Fig. 2. Overlay top ten author in (a) AR study and (b) VR study

3.3 Year-wise distribution of top 100 cited papers

The top one hundred cited papers of AR-VR research have been published for the last thirty years, which 2013 is the year with the highest number of AR papers (13) and 2005 for VR papers (10). Thus, 1997 with 4 AR papers was the most significant

published year, 2005 with ten VR papers. The AR research has to mean citations per paper was the highest at 1364 in 1997, and the mean citations per paper per year was the highest at 65 for 2019. The VR research has to mean citations per paper was the highest at 681 in 1993, and the mean citations per paper per year was the highest at 129 for 2020. The highest average citation was reached by VR research at 1565.

Table 3. Year wise distribution of top one hundred cited papers

Year	Augmented Reality				Virtual Reality				Citable Years
	Papers	***TC***	***ACPP***	***ACPPY***	***Papers***	***TC***	***ACPP***	***ACPPY***	
1993	1	546	546	18,82	3	2045	681,67*	23,50	29
1995	1	1013	1013	37,52	5	1983	396,60	14,68	27
1996	2	445	222,50	8,55	1	262	262	10,07	26
1997	4	5459*	1364,75*	54,59	3	1067	355,67	14,23	25
1998	2	418	209	8,70					24
1999	2	1965	982,50	42,71	4	1269	317,25	13,79	23
2000	2	525	262,50	11,93	4	1189	297,25	13,51	22
2001	2	2435	1217,50	57,97	4	1741	435,25	20,72	21
2002	6	1581	263,5	13,17	5	3224	644,80	32,24	20
2003	3	908	302,67	15,92	3	2537	845,67	44,51	19
2004	3	617	205,67	11,42	6	2615	435,83	24,21	18
2005	1	570	570	33,53	10*	5187*	518,70	30,51	17
2006	*3*	851	283,67	17,72	3	906	302	18,87	16
2007	2	550	275	18,33	5	2147	429,40	28,62	15
2008	5	1682	336,40	24,03	7	2447	349,57	24,96	14
2009	4	1345	336,25	25,86	3	969	323	24,84	13
2010	3	743	247,67	20,64	6	2422	403,67	33,63	12
2011	4	1331	332,75	30,25	5	1797	359,40	32,67	11
2012	4	1265	316,25	31,63	3	831	277	27,70	10
2013	13*	3733	287,15	31,90	3	801	267	29,67	9
2014	10	3047	304,7	38,08	2	876	438	54,75	8
2015	4	927	231,75	33,10	3	915	305	43,57	7
2016	4	874	218,50	36,42	1	398	398	66,33	6
2017	7	1933	276,14	55,23	6	1748	291,33	58,26	5
2018	6	1385	230,83	57,71	3	792	264	66	4
2019	2	392	196	65,33*	1	282	282	94	3
2020					1	259	259	129,5*	2
Mean	3,84	1405,385	424,33	30,81	3,84	1565,73	389,96	37,51	

TC=total citation; *ACPP*=average citation per paper; *ACPPY*= average citation per paper per year
* the highest number

3.4 Top ten sources and publishers

Seventy sources, either journal or conference proceedings, have published the most cited AR papers. Furthermore, top-cited papers about VR have been 73 sources. The

"Computer and Education" that have published the top-cited papers on each study (AR and VR) were four papers with 1132 citations for VR study and eight papers with 2434 citations. The "Computers and Education" Journal has been published in Elsevier from 1976 to the present.

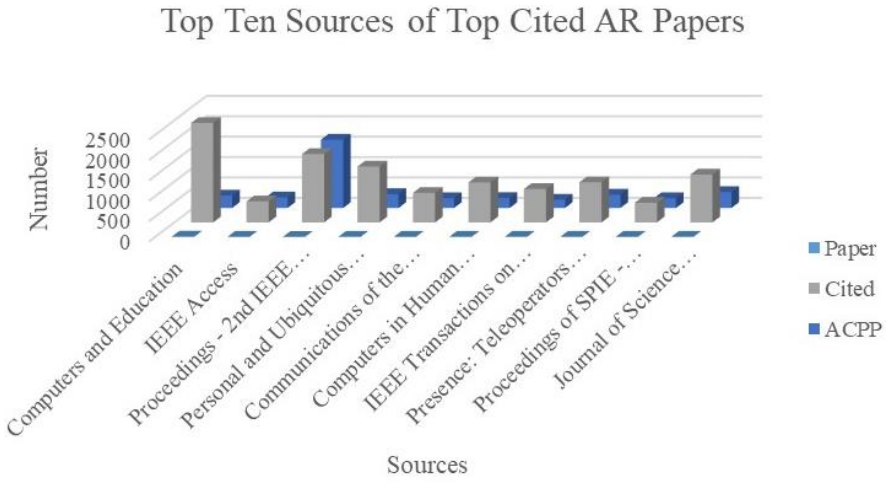


Fig. 3. (a) Top ten sources of top cited AR papers

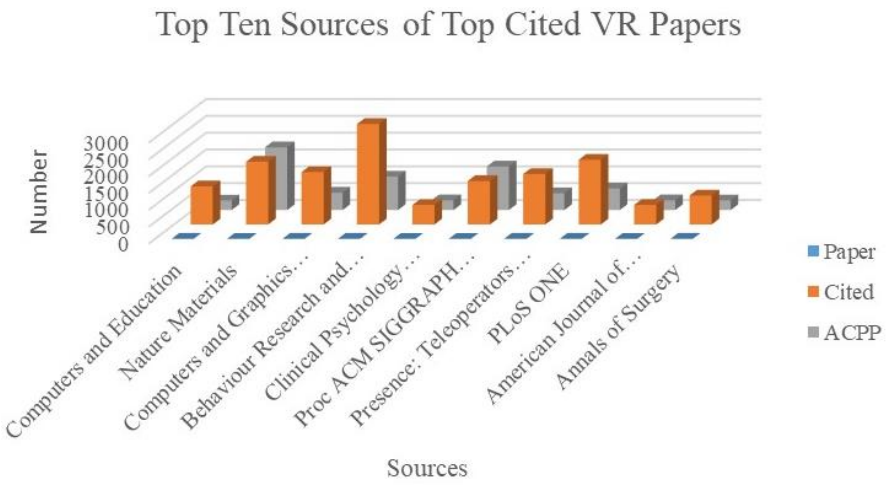


Fig. 3. (b) Top ten sources of top cited VR papers

3.5 Country

The database obtained from Scopus were then sorted by author affiliation and country. Only the first author was considered when calculating the country of publications. Seventeen countries contributed to VR studies such as the United States (42

papers), United Kingdom (8 papers), Canada, Spain, and Germany (6 papers), Denmark and Netherlands (five papers), France (4 papers), Australia, Italia, and Hong Kong (3 papers), Israel, Ireland, and Sweden (2 papers); Taiwan, Singapore, and South Korea (1 paper). Besides, AR research has 25 countries that productive published papers. There are United States (40 papers), Spain and United Kingdom (6 papers), Taiwan and Austria (5 papers), Singapore (4 papers), New Zealand, France, Germany, and Australia (3 papers), Canada, Turkey, Japan, China, South Korea, Finland, Greece, and Hong Kong (2 papers), Venezuela, Poland, South Africa, Netherlands, and Italia (1 paper).

Based on Figure 4 and Table 4, the United States is the most productive country in AR and VR study. United States has published 40 papers with total citations were 19448 for AR research and 42 papers with total citations of 19783 for VR research. Thus, the United Kingdom is a top 5 country that has publication in AR and VR study.

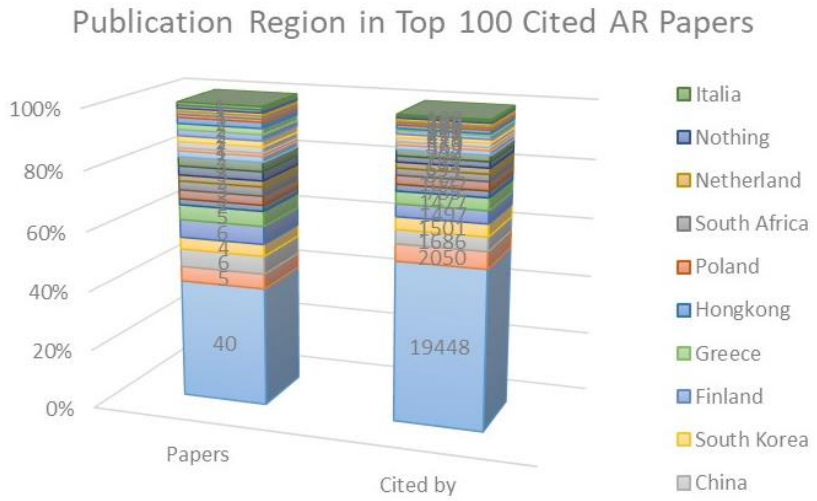


Fig. 4. (a) Publication regions of top cited AR papers

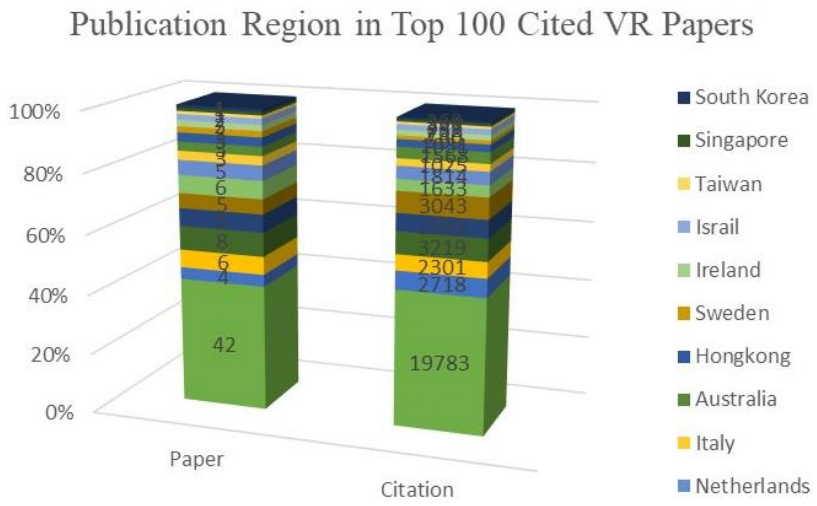


Fig. 4. (b) Publication regions of top cited VR papers

Table 4. Top 5 of most productive country

Augmented Reality			**Virtual Reality**		
Country	***Papers***	***Citations***	***Country***	***Papers***	***Citations***
United States	40*	19448*	United States	42*	19783
Taiwan	5	2050	United Kingdom	8	3306
Spain	6	1686	Denmark	5	2079
Singapore	4	1501	France	4	2785
United Kingdom	6	1497	Canada	6	2553

* the highest number

3.6 Keywords

The font size of the keywords in Figure 5 represents the frequency of the keywords used in the papers. Keywords in AR and VR research have similarities, including assembly, skills, review, augmented, virtual, reality, technology, research, sciences, students, learning. According to that, AR and VR have a strong relationship in multiple disciplines, especially education, technology, sciences, and research.

(a) (b)

Fig. 5. The most relevant keywords of top cited (a) AR papers and (b) VR papers

Then, findings are obtained from research about AR and VR. The number of repetitions of a keyword is set to a minimum of 3. From the observations on the map using the VOSViewer, there are 3 cluster in AR study were presented in Figure 6.

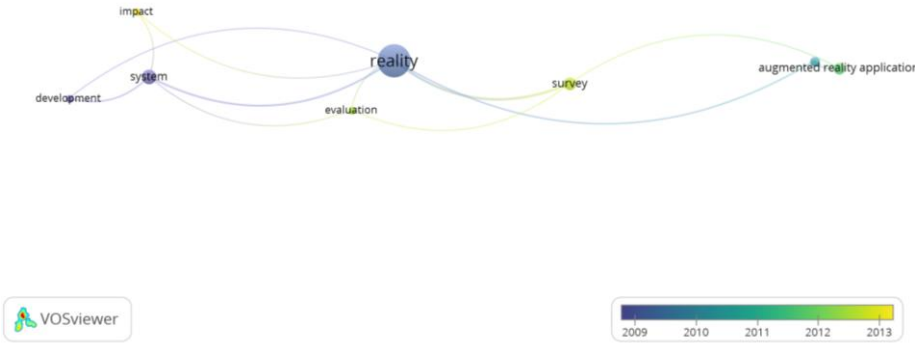


Fig. 6. Visualization of the AR research for the last thirty years

The first cluster contains development, impact, and system. The second cluster contains evaluation, reality, and survey. Third clusters contain augmented reality application maintenance. The keyword "augmented reality applications" have high relevance in 2,39, "reality" has high occurrences in 54, and link strength in 13. Figure 6 explains that "reality" is related to augmented reality applications and surveys. There are several augmented reality applications in top one hundred cited papers, especially "A survey of augmented reality" by [22]. This research describes that augmented reality can be applied in visualization, medical, military, manufacturing, and entertainment using 3-d virtual objects in real-time. On other hand, augmented reality has been applied in design and manufacturing. Research by [23] reports AR applications, including CNC simulation, assembly, robot path planning, maintenance, and plant layout. Thus, there are studies about AR in education and pedagogical studies conducted by [24][25][26][27][28][29][30][31].

There are 3 clusters of VR research in Figure 7. The first cluster such as application augmented reality and design. The second cluster includes laparoscopic surgery, VR simulation, VR training, and application. The third cluster such as immersive VR and presence. The keyword "immersive VR" and "presence" have the highest relevance at 1,85. The highest occurrences were reached by "presence" and "application." Thus the highest link strength was reached by laparoscopic surgery. According to the keyword pattern, there are studies about applied VR in daily life, especially in medical, education, business, and industry. Immersion represents the technical capabilities of the system. There is a subjective correlation of immersiveness [32].

Fig. 7. Visualization of the VR research for the last thirty years

3.7 Literature review top one hundred cited papers

Table 6 shows several indicators of AR and VR. According to that, AR and VR are two different things, but both are technology in the modern era. AR is a part of VR [22]. The literature review is based on top-cited one hundred papers about AR and VR study.

Table 6. Literature review top cited papers about AR and VR study

Indicators	Augmented Reality	Virtual Reality
Concept	AR combines the concept of real-time interactive real and virtual [22]	VR provide a stereo pair visualization which is created in the graphics path of the computer system and updated in real time [33].
Forms	3 D Animation [22][36][40]	As a device [33]
Scope/Disciplines	All disciplines	All disciplines
User's view	User can see the real world with the virtual objects superimposed upon or composited with real world obtained by camera and QR Code [34][36].	User can't see the real world and user include to synthetic environment obtained by computer general world [34]

Device	Smartphone or Tablet PC [40]	Helmet [35], mobile phone, and VR headset [39] [41]
Categories	- Interactive applications - Geographical position - Objects positioned in real world [34]	- Non-immersive - Fully immersive - Semi immersive - AR - Collaborative VR

Figure 8 is Milgram`s Reality-Virtuality Continuum, a continuum that extends from the real environment to virtual environments. According Figure 8, AR is closer to the real world. Furthermore, Augmented Virtual (VR) is closer to the virtual world [37]. So, AR integrate the virtual world directly into a real world, while AV is an attempt to organize a real world into a virtual world.

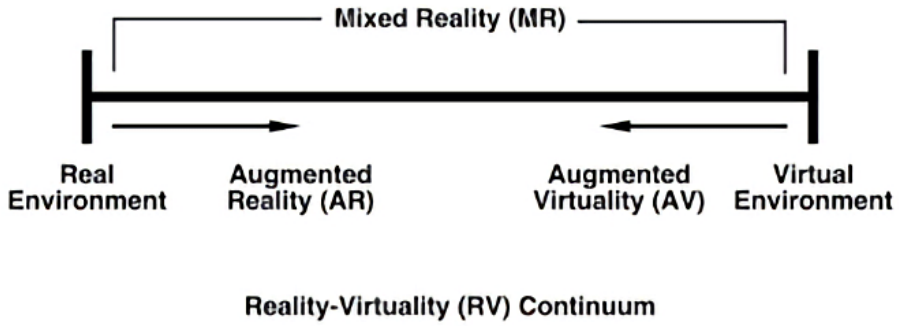


Fig. 8. Milgram and Kishino's mixed reality [37][38]

3.8 Research implications

The discussion of each study (AR and VR) can be used as an alternative to future AR and VR research. This study provides new information for librarians, researchers, and policymakers worldwide to advance virtual and augmented reality research and create a comprehensive Scopus document. The study also provides librarians, researchers, and policymakers with insight and information into search trend patterns in Scopus documents. Librarians and researchers can conduct further research on the development and cooperation between other universities to increase publications and more references/information for further research about augmented reality and virtual reality. Research related to AR and VR can also be directed to the scope/field.

4 Conclusion

It is the first comparative study of the top one hundred cited papers among AR and VR studies using bibliometric analysis. The database obtained from Scopus on the top one hundred cited publications for the last thirty years. Articles are the most published type of document. Most of these top-cited articles were published in 2005 for virtual reality and 2013 for augmented reality. The Journal of Computing and Education is

Elsevier's primary source, moderating the publication of the most influential ARVR studies. Most research articles have multiple authors. Slater and Feiner are recognized as the most productive authors. The United States dominates the production of highly cited AVRR articles. In this study, we used only Scopus databases to search relevant publications using the keywords "Augmented Reality" or "Virtual Reality". Biometric data, such as index or citation time, indicate the scope and impact of the corresponding work. However, due to the way the research works and how scientific publications work, it is not necessarily accurate and comprehensive. Future research should focus on other areas, using one or more keywords, and collaborating with Google Scholar, Web of Science data, for in-depth analysis.

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