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Binar Kurnia Prahani <binarprahani@unesa.ac.id>

[tused] Editor Decision

2 messages

Ümmühan Ormancı <ummuhan45@gmail.com> Thu, Sep 15, 2022 at 6:45 PM
To: "Dr, Binar Kurnia Prahani" <binarprahani@unesa.ac.id>, Hanandita Veda Saphira <hanandita.19049@mhs.unesa.ac.id>, Firmanul Catur Wibowo <firmanulwibowo@ia-education.com>, Misbah Misbah <misbah@ia-education.com>, Nurul Fitriyah Sulaeman <nurulfitriyahsulaeman@ia-education.com>

Dr, Binar Kurnia Prahani, Hanandita Veda Saphira, Firmanul Catur Wibowo, Misbah Misbah, Nurul Fitriyah Sulaeman:

We have reached a decision regarding your submission to Journal of Turkish Science Education, "Virtual & Augmented Reality in Physics Learning: Research, Trend, and Contribution in the 20 Last Years ".

Our decision is: Revisions Required

Reviewer B:

I consider this study important because it is a research that will guide researchers who will conduct research in the field of AR and VR in their future studies. However, I think it would be useful to make corrections in the article in line with my suggestions below:

1. The article must be proof-reading in terms of language (English). Some sentences are incomprehensible and there are word mistakes.

2. Why did the researcher intensify the examination of AR and VR publications, especially in the field of physics education? It would be helpful to explain the reason for this.

3. The resolution of some images is not good. should be made more readable and understandable.

4. Errors in the layout, content and headings of some tables should be corrected.

5. Findings and discussion are presented together. This seems to have prevented an in-depth discussion of the research findings. I believe that the findings of the research need to be discussed in depth, especially in terms of physics education.

6. The bibliography should be revised according to the spelling rules. There are errors.

7. Limitations of the research should be stated and suggestions for future research can be given wider place.

8. Some other minor points are mentioned on the article file.

Recommendation: Revisions Required

Reviewer D:

The article is well organized and has a few issues that should be overcome.

Findings and discussion are given together. The discussion should be done in more detail.

Some implications for future researchers are also done in more detail.

Recommendation: Accept Submission

Journal of Turkish Science Education

2 attachments

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Binar Kurnia Prahani <binarprahani@unesa.ac.id> Sat, Sep 17, 2022 at 3:59 PM
To: Ümmühan Ormancı <ummuhan45@gmail.com>

Dear Editor
Dr. Ümmühan Ormancı

We have revised according to the suggestions of editors and reviewers.

Hopefully it will be published in 2022.
Thank you very much

Best Regards,
Dr. Binar Kurnia Prahani
Univesitas Negeri Surabaya, Indonesia

2 attachments

2 Changes made on Manuscript 17-9-22-Prahani et al TUSED.doc
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Trend and Visualization of Virtual Reality & Augmented Reality in Physics Learning From 2002-2021

Binar Kurnia PRAHANI[1], Hanandita Veda SAPHIRA[2], Firmanul Catur WIBOWO[3], MISBAH[4], Nurul Fitriyah SULAEMAN[5]

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ABSTRACT
Augmented Reality (AR) & Virtual Reality (VR) are now wide open to all fields. The objectives of this study are to analyze the comparison of trend research on the top 200 cited AR and VR publications in all areas~~;~~, ~~To~~ to identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research~~;~~, ~~To~~ to ~~identify the~~ compare ~~of~~ the top 10 most productive author of the AR and VR in Physics learning research~~;~~, ~~To~~ to determine ~~the comparison of~~ the top-cited author, subject areas and affiliation of the AR and VR in Physics learning research~~;~~, ~~T~~ to analyze the comparison of the distribution of AR and VR publications in Physics learning research~~;~~. The metadata gathered is ~~by~~ from the Scopus database and investigated by VOSViewer. This research shows that the trend of research in AR and VR in all fields is increasing each year. The top keywords used in AR and VR to Physics learning are 'AR' and 'VR', with total link strengths of 479 and 1,882. AR ~~or~~ and VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

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Virtual Reality

Introduction

~~E~~Using emerging technology in the education process nowadays is necessary. Technology is changing much faster than ever, so ~~technology~~ technology-related skills need to be developed early in education (Hashim, 2018; Kuppusamy, 2020; Putranta et al., 2021; Tilhou et al., 2020~~; Putranta et al.,~~

~~2021~~). Technology and education are necessary elements of the academic system (Dzuranin et al., 2018; Grippa et al., 2018; Van de Oudeweetering & Voogt, 2018; Williams, 2019). Integrating practices and technologies ~~that~~ can impact the future development of education, ~~namely:~~such as Augmented reality (AR) technology, student achievement analysis, educational applications of machine learning/artificial intelligence ~~to educational application~~, open education resources, and adaptive learning technology (Yan, 2021).

Virtual reality (VR) and AR are now wide open to all fields. VR and AR are not new technologies (Elmqaddem, 2019). AR and VR are active areas of research and education as a technology that enables educators and teaching-learning processes (Gudoniene & Rutkauskiene, 2019; ~~K. T.~~ Huang et al., 2019). While AR extends the current perception of reality, VR replaces the real world with a simulated world (Blazauskas & Gudoniene, 2020; Martin et al., 2018; Motejlek & Alpay, 2019). The use of ~~AR and/or VR in education provide if~~ AR and/or VR in education provides an immersive multimodal environment enhanced by multiple sensory traits, providing effective tools for enhancing learning and useful for helping K-12 students (Zhou et al., 2020).

AR is a technology that can superimpose computer-generated virtual visualization output indirectly and/or directly on a real environment in real-time (Aggarwal & Singhal, 2019; Baker et al., 2020; Lee, 2012) and real-world (Chen et al., 2019). Since then, there have been many approaches and various have been used to design AR ~~-~~for educational purposes (Wu et al., 2013). Meanwhile, the simplest definition of VR is the replacement of experiences of more than one physical with a virtual thrill (Coburn et al., 2017) or simulation environment (Nomura & Sawada, 1999). VR has existed since the 1960s (~~F. C.~~ Huang et al., 2015). VR has become one of the extensive technologies discussed all around fields in terms of applications, uses, and various types, and can bring tremendous benefits in the real world (Saeed et al., 2017).

In the education field, ~~some research~~studies show a variety of topics of interest: ~~intercultural~~ Intercultural learning through VR technology (Akdere et al., 2021); Immersed VR in a virtual laboratory in the subject of digital engineering (Khairudin et al., 2019); VR reinforces student learning through hands-on activity and educates students about innovative learning models used in technology (Kustandi et al., 2020) and also fostering students' critical thinking skills through the VR laboratory (Ikhsan et al., 2020). While in the AR research, namely meta-Analysis ~~to~~ of Education in 2018 (Hantono et al., 2018); Mapping of WOS (López-Belmonte et al., 2020); Trends ~~in~~ from 2006 to 2016 (Altinpulluk, 2019). Not only the education field, AR and also VR technology researches are widely abroad to field such as industry (Gattullo et al., 2019), tourism (Cranmer et al., 2020), health science, and medical anatomy (Moro et al., 2017), dentistry (~~T. K.~~ Huang et al., 2018), business (El-Seoud & Taj-Eddin, 2019) and also other fields. Based on the findings, many researchers identified AR, and there is potential for future work (Arslan et al., 2020; Hedberg et al., 2018).

Although research publications on AR and VR tend to increase every year, the trend of these research ~~remind~~ remain unclear. Therefore, it takes research to find out how AR and VR are used in each area of research to find future novelty and research ideas. In addition, the use of AR and VR in the field of education also needs to be known to be an opportunity for research studies and learning innovations in the future. Previous publications tend to immerse AR and VR in the general learning process. Despite this, researchers tend to conduct bibliometric research to compare AR and VR trends research through Scopus over the past 20 years and the contribution of AR and VR in Physics education to specify the previous research. This research is focused on Physics education because in physics learning many abstract, microscopic, and macroscopic concepts are found. So ~~that~~ VR and AR can be physics learning aids that are currently being discussed.

Research Objectives

This research analyzes bibliometrics on 'AR' and 'VR' keywords as general fields and specifies it to implement AR and VR in Physics education and compare them. ~~Publication~~ The publications ~~that~~ indexed by Scopus ~~is~~ are used to collect the metadata and the VOSViewer application will be an assistant tool. This research is expected to compare trends, patterns, novelty, and future research in AR and VR

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Commented [A9]: Smth like this sentence would be better in the abstract through all-around fields and in the Physics education field during the past twenty years (2002-2021). Specifically, the objectives of this research are as follows:

1. To compare trend research on the top 200 cited to represent the AR and VR publications in all fields during 2002-2021.
2. To analyze the comparison of the subject areas, countries, and top affiliations that have contributed to the top 200 cited AR and VR publications in all fields during 2002-2021.
3. To identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research during 2002-2021.
4. To identify the comparison of the top 10 most productive authors of ~~the~~ AR and VR in Physics learning research during 2002-2021.
5. To identify the comparison of the top-cited author, subject areas, and affiliation of ~~the~~ AR and VR in Physics learning research during 2002-2021.
6. To analyze the comparison of the distribution of AR and VR publications in Physics learning research during 2002-2021.
7. To analyze the top 10 cited publications in AR and VR in Physics learning research during 2002-2021.

Methods

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This research is bibliometric research using descriptive analysis. This research used Scopus as a structured database to analyze the published data (Aria & Cuccurullo, 2017; Goli & Haghighinasab, 2022; Mongeon & Paul-Hus, 2016; Shubina et al., 2021; Thu et al., 2021). Scopus has become the largest database and has more than 77.8 million core records from different various fields with various metadata and document types, either non-academic or academic fields (Hernández et al., 2021; Nurdin et al., 2021; Pham-Duc et al., 2021; Pranckutė, 2021; Singh et al., 2021; Thu et al., 2021). Also, Scopus has a loading of sources 70% greater than Web of Science (López-Illescas et al., 2008; Supriadi et al., 2021). Bibliometrics consists of four phases, namely: (1) defining a study design, (2) collecting data through the criteria, (3) data analysis, and (4) interpreting and visualizing data (Kamarrudin et al., 2022; Lorenzo et al., 2022; Marulanda-Grisales & Vera-Acevedo, 2022). In this research, two filterings were performed on data criteria. Finally, the process of this research to determine the use of AR and VR in general fields is as in **Figure 1**. Then, Researchers specify the keyword to know AR and VR impact or contribution to Physics learning as in **Figure 2** during the past twenty years.

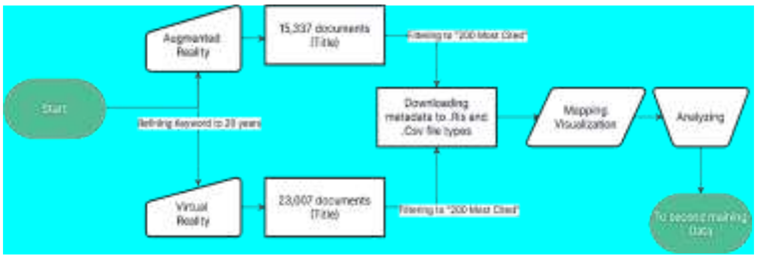
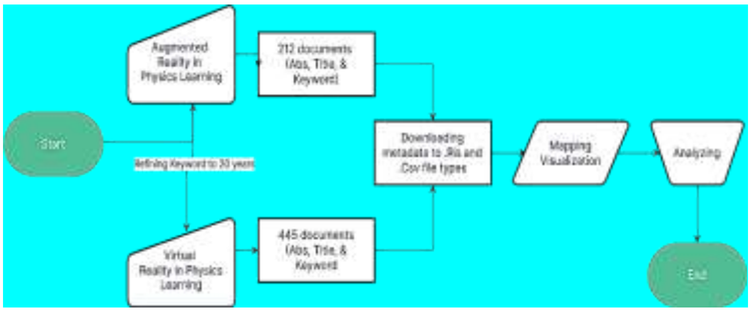


Figure 1. Research flowchart to the general keywords



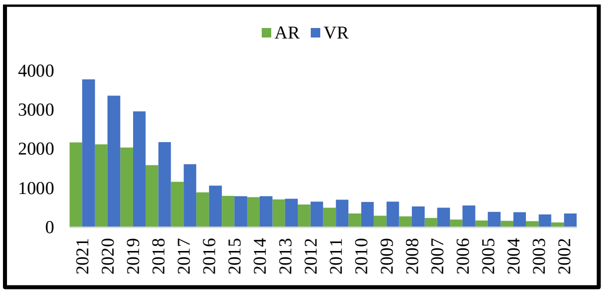
Figure~~-~~ 2. Research flowchart to the specified keywords

Data mining was ~~collected~~ done on March 30, 2022. The results obtained are sorted by "number of citations" from high to low. Then, the data were downloaded ~~them~~ in .csv and .ris file formats. After that, data ~~was~~ were uploaded to the VOSViewer software to show the details of the transcription of the data and visualize the bibliometric assignments (Abdullah, 2022; Jayadinata et al., 2021; Nandiyanto & Al Husaeni, 2021; van Eck & Waltman, 2010, 2017; Wong, 2018). For the final stage, data are analyzed descriptively to answer the research objectives.

Findings and Discussion

Comparison of Trend Research AR and VR in All Fields During 2002-2021

Based on metadata filtering and analysis, there are known annual trends in AR and VR publications in all research fields from 2002 to 2021. The trend shows the interest of researchers to research the subject of the study. AR and VR in all fields from 2002 to 2021 it is depicted in **Figure 3**.



Figure~~-~~ 3. Comparison of AR and VR trend researches in all fields during 2002-2021

Based on **Figure 3**, research trends on both AR and VR in all fields during the past twenty years tend to increase each year (Cavalcanti et al., 2021; Ed & Hutchison, 2013; Papakostas et al., 2021). However, VR publications are more numerous than AR and this shows that interest in AR and VR continues to increase and becomes an interesting topic to be used as research material. And, it can be realized that AR and VR are ~~an~~ interesting trends every year with the increase in research trends from 2002 to 2021. The use of AR and VR integrase in various fields of work is indeed a hot topic discussed (Bottani & Vignali, 2019), especially in educational sciences. This is because AR and VR are considered capable of becoming learning medium that covers many aspects of learning, especially in 21st-century learning (~~C. H.~~ Chen et al., 2020; Elmqaddem, 2019; Sanabria & Arámburo-Lizárraga, 2017).

Hence, after being analyzed using VosViewer, it can be known keywords that are often used in AR and VR publications from 2002 to 2021 in all fields. Keywords that are often used in AR and VR publications in all fields from 2002 to 2021 are as in **Figure 4.**

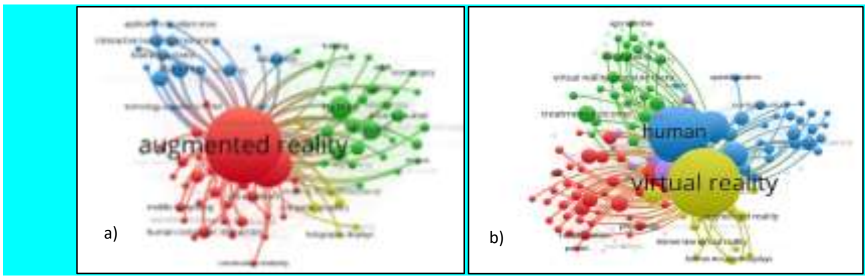


Figure.~~–~~ 4. a) Keywords that are used in AR publications; b) Keywords that used in VR publications

Figure 4 is an illustration of keywords that is widely used in AR and VR publications in all fields in the past twenty years. In AR, the most common keywords are 'Augmented Reality' (n=13,086), 'Virtual Reality' (n=3,908), 'Human' (n=1,182) and 'Mobile Augmented Reality' (n=1,011). While in VR publications, the most widely used keywords in publications are 'Virtual Reality' (19,483), 'Human' (n=5,368), 'Humans' (n=4,159) and 'Article' (n=3,534).

These keywords show a strong relationship between both AR and VR as immersive human and mobile AR. Moreover, the results point to increasing interest in research on the use of VR in Humanee and article research. For example research of Grandi et al., (2018) conducted the design of a handheld-based interface for collaborative manipulations of 3D objects in mobile AR as Human-Centered Computing (HCC)-Interaction (HCI). Both AR and VR keywords are related to each other, ~~It~~ so it is not surprising that managers find it hard to distinguish similar-sounding, IT-based concepts such as AR and VR (Farshid et al., 2018).

Comparison of Subject Areas, Countries, and Top Affiliation of Top 200 Cited AR and VR Publications in All Fields During 2002-2021

Table 1

Comparison of AR and VR to top countries, subject areas, and affiliations in all fields during these past twenty years

AR			VR		
Countries	**Subject Areas**	**Affiliation**	**Countries**	**Subject Areas**	**Affiliation**
United States	Computer Science	Technical University of Munich	United States	Computer Science	University of Southern California
Germany	Engineering	Technische Universitat Graz	China	Engineering	IRCCS Istituto Auxologico Italiano
China	Mathematics	University of South Australia	Germany	Medicine	CNRS Centre National de la Recherche Scientifique
South Korea	Social Sciences	Beijing Institute of Technology	United Kingdom	Social Sciences	Università Cattolica del Sacro Cuore
Japan	Medicine	National University of Singapore	Italy	Mathematics	Universitat de Barcelona

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According to **Table 1**, ~~it can be seen that~~ the United States of America is the country with the most publications on AR (n=2,702) and VR (n=5,080). F~~, but f~~or AR, the country with the second most publications is Germany (n=1,374), while for VR is China (n=2,887). In subject areas, AR and VR have the same result again, namely the top subject areas owned by 'Computer Science' followed by 'Engineering', the difference is in the third top subject areas, namely for AR in 'Mathematics' (n = 2,417), while VR in 'Medicine' (n = 5,117). At top Affiliation, the Technical University of Munich is the top affiliate in AR, while the University of Southern California is the top affiliate in VR.

In line with previous bibliometric research on AR and also VR, the United States has become the top country in publications on AR and VR. These findings also show that the USA has become the most influential country, based on the number of publications over the twenty years. Meanwhile, the top subject areas are the specific areas of instruction in which courses are offered within academic organizations. Computer science, engineering, medicine, and/or mathematics have become the top subject areas of AR and VR research. This finding showed that most AR and VR publications are related to a technical science in line with the top affiliation in AR which is the Technical University of Munich (Germany) and assisting abstract or imagining objects such as mathematics and formula of medicine.

The mapping of visualization of top countries in AR and VR publications from 2002 to 2021 can be described in **Figure 5** and **Figure 6**. This result was generated with Datawrapper.

Figure. 5. Top ~~Countries~~ countries in AR publications from 2002 to 2021

Figure. 6. Top ~~Countries~~ countries in VR publications from 2002 to 2021

Based on **Table 1**, it can be analyzed that there has been no difference in the first order of top countries, subject areas, and affiliations in AR and VR publications in all fields over the past twenty years. **Figure 5** and **Figure 6** show that the top 3 countries in AR and VR publications are the United States, China, and Germany. Other countries have an average of fewer than 100 publications, but indeed some countries have more than 500 publications and fewer than 1,000 publications from 2002 to 2022. These findings are related to previous research that found the USA, China, and Germany as the most influential countries in the publication of AR and VR in all fields (Garzón, 2021; Karakus et al., 2019).

Comparison of Trend Mapping Visualization of AR and VR in Physics Learning During 2002-2021

The most occurrence keywords are analyzed before mapping out the visualization of AR and VR in Physics Learning research during the past twenty years, as shown in **Table 2.**

Table 2

Top 15 Keywords Used in AR And VR To Physics Learning Research During the Past Twenty Years

AR			VR		
Keyword	**Total Link Strength**	**Occurrence**	**Keyword**	**Total Link Strength**	**Occurrence**
Augmented Reality	479	146	Virtual Reality	1,882	334
Students	257	55	E-Learning	848	139
Virtual Reality	129	31	Students	699	99
E-Learning	126	26	Education	609	80
Education Computing	110	20	Teaching	385	54
Education	103	22	Physics	320	45
Physics Learning	89	19	Engineering Education	302	44
Computer-Aided Instruction	87	17	Learning Systems	280	51
Engineering Education	86	17	Augmented Reality	251	52
Teaching	69	14	Human	237	23
Laboratories	63	13	Computer-Aided Instruction	229	35
Learning Systems	60	13	Humans	225	20
Learning Environments	58	11	Article	215	21
Physics Education	55	13	Learning	206	26
Augmented Reality Technology	45	11	Virtual Laboratories	204	27

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From **Table 2**, it can be seen that the highest total link strength and the most frequently occurring keywords are "Augmented Reality" (n=479) to AR, and "Virtual Reality" (n=1,882) to VR. Hence, it is clear that every keyword is related to AR and VR itself. The second order of the keywords is "Students" (n=257) for AR and "E-Learning" (n=848) for VR. Followed by "Virtual Reality" (n=129) to AR and "Students" (n=699) to VR. From Table 2, we can also conclude that AR is still related to the VR keyword and vice versa. Based on this pattern, it can be found that the trends of both AR and VR in Physics Learning research in 2002-2021 are: 1) Related to Education; 2) Implementation of e-learning

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Commented [A15]: I would wonder if the connection between those two loosen over time as the difference becomes more clear with every publication activities for students and teachers; 3) Technology integration in learning; 4) Computer-aided instruction; 5) Physics learning and education. Specifically, trends in AR can be Augmented reality technology, whereas VR can be Virtual laboratories.

Based on this finding, AR and VR are contributed to students and e-learning in physics learning. Emerging AR and VR to Physics concepts are now wide open since Physics is one abstract and difficult subject (Zamil et al., 2021). The development of student worksheet-AR based is very suitable to be used as a learning tool in physics practicum activities in Senior High School in 10th grade (Bakri et al., 2020). Integrating AR into physics classrooms can enhance students' physics learning self-efficacy, guide students to be more inclined to higher-level conceptions of learning physics, and stimulates students' motivation to learn more deeply (Cai et al., 2021). Also, a review of problem-based AR made learning more meaningful (Wulandari et al., 2021). Technological innovations, such as augmented reality (AR), have the potential to fundamentally change education by making difficult concepts available and accessible to beginners (Church & Marasoiu, 2019). Meanwhile, VR technology provides a promising media for educational researchers (Budi et al., 2021; Sarıoğlu & Girgin, 2020). VR environment in terms of learners' perceptions and their conceptual learning in Physics learning increased (Georgiou et al., 2020; Tsivitanidou et al., 2021). The use of virtual reality technology in the e-learning environment had a positive effect on students (Abdüsselam & Erten, 2022; Rogers et al., 2017; Wiederhold et al., 2018; F. Yang & Wu, 2010).

Therefore, to find a novelty of the research based on the mapping results, we can look at the relationships between smaller keywords or fewer keywords. It is shown in **Figure 7**.

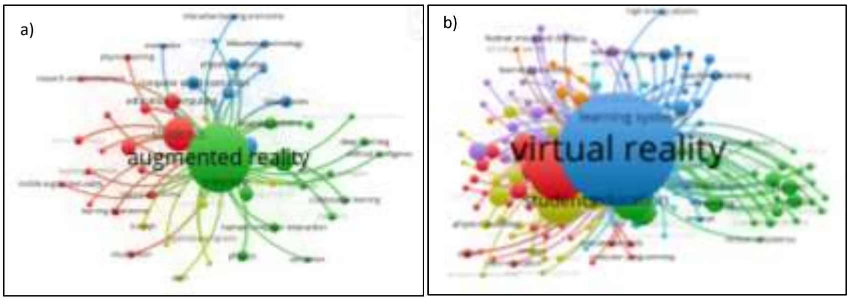

Figure.~~–~~ 7. Trends keywords mapping in Physics learning to a) AR; b) VR during 2002-2021

To find the novelty of previous research, the mapping of metadata keywords (~~X.~~ Chen et al., 2021; Gamage et al., 2022; Goerlandt et al., 2021; Pournader et al., 2021). ~~Comparison~~ A comparison of visualizations of keyword co-occurrences in AR and also VR research in Physics learning during 2002-2021 are shown in **Figure 7.** These are analyzed to find the novelty between these researches. **Figure 7** of mapping visualization are shown that there are 4 main clusters for AR, namely: 1) Cluster 1 with red nodes (n=16 items); 2) Cluster 2 with green nodes (n=15 items); 3) Cluster 3 with blue nodes (n=11 items); and 4) Cluster 4 with yellow nodes (n=10 items). Meanwhile, ~~comparing~~ compared to VR, there are 7 main clusters, namely: 1) Cluster 1 with red nodes (n=31 items); 2) Cluster 2 with green nodes (n=30 items); 3) Cluster 3 with blue nodes (n=28 items); 4) Cluster 4 with yellow nodes (25 items); 5) Cluster 5 with purple nodes (n=23 items); 6) Cluster 6 with turquoise (n=22 items); and 7) Cluster 7 with orange nodes (n=8 items). Some examples of specific keyword mapping visualization results on AR are AR, students, AR technology, simulation, deep learning, and artificial intelligence. Also, for VR are VR, e-learning, students, STEM, high energy physics, and computer sciences.

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If future researchers want to explore AR and VR in Physics learning on top trends, there is still ~~open~~ an opportunity to explore more about AR and VR in Physics learning research because the top trends still have a wide range and various fields of terms. AR and VR in Physics learning can still improve and assist educators in many aspects. Whereas, fewer trends such as can be used as an alternative future research field, especially to investigate AR on simulation, deep learning, and artificial intelligence. Meanwhile, there are still chances for VR for example STEM, high energy physics, and computer sciences.

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Comparison of Top 10 Most Productive Authors to AR and VR in Physics Learning Research

The metadata results on Scopus can show the author of the publication of AR and VR in Physics learning research in the past twenty years. **Table 3** shows the top 10 most productive authors of LMS research from 2002-2021.

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Table 3

The top 10 Most Productive Authors

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AR		VR	
Author	**Total Publications**	**Author**	**Total Publications**
Muliyati, D.	12	Parker, J.	6
Bakri, F.	11	Wasfy, T. M.	6
Kuhn, J.	7	Guetl, C.	5
Kapp, S.	6	Terzopoulos, D.	5
Thees, M.	6	Wasfy, H.M.	5

Table 3 shows that Muliyati, D. is the most prolific author with 12 publications in AR, followed by Bakri, F. who has 11 publications, and Kuhn, J. became the third most productive author with 7 publications in total. Meanwhile, Parker, J. is the most prolific author with 6 publications in VR, followed by Wasfy, T. M. with 6 publications, and Guetl, C. with 5 publications in third place.

Comparison of Top Cited Author, Subject Areas, and Sources Titles of The AR and VR in Physics Learning Research

Table 4 shows top-cited authors, subject areas, and affiliation to AR and VR in Physics learning research from 2002-2021.

Table 4

Top research citations, subject areas, and affiliation on AR and VR in physics learning research ~~During~~ between 2002-2021

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AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
Potkonjak , V., et al.	Computer Science	Universitas Negeri Jakarta	Journal Of Physics Conference Series	Potkonjak , V., et al.	Computer Science	Technische Universitat Graz	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture

AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
							Notes In Bioinformatics
Enyedy, N., et al.	Social Sciences	Technische Universität Kaiserslautern	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	Lindgren, R., et al.	Engineering	Curtin University	ACM International Conference Proceeding Series
Cai, S., et al.	Physics and Astronomy	Institut Pendidikan Indonesia	AIP Conference Proceedings	Miles, H.C., et al.	Social Sciences	International Information Technology University	Journal Of Physics Conference Series
Saidin, N.F., et al.	Engineering	Harvard University	Ceur Workshop Proceedings	Chan, S., et al.	Mathematics	Advanced Science and Automation Corp.	Proceedings Of SPIE The International Society For Optical Engineering
Dünser, A., et al.	Mathematics	Indiana University Bloomington	ACM International Conference Proceeding Series	Saidin, N.F., et al.	Physics and Astronomy	The Ohio State University	ASEE Annual Conference And Exposition Conference Proceedings
Fidan, M., & Tuncel, M.	Materials Science	Beijing Normal University	Communications In Computer And Information Science	Dünser, A., et al.	Medicine	Instituto Superior de Engenharia do Porto	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics

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Based on the top-cited authors in **Table 4**, AR and VR in Physics learning research ~~is~~ are Potkonjak, V., et al. with the most citations. The top subject areas in both AR and VR Publications in Physics learning are Computer science with top affiliation respectively Universitas Negeri Jakarta and Technische Universitat Graz. Meanwhile, the top source titles are "Journal of Physics Conference Series" and "Lecture Notes in Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics".

In line with the top subject areas in all field publications of AR and VR, the top subject areas in Physics learning are still Computer Science, social sciences, and engineering. These findings have still shown that AR and VR even in Physics learning tend to contribute to computer science subjects. In line with the top author, the findings of metadata show that Mulyati, D. and Bakri, F. with the affiliation of Universitas Jakarta has published an AR-based development electric book (Permana et al., 2019), electromotive force concept (Bakri et al., 2019b) and Lorentz force (Bakri et al., 2019a) in Journal of Physics Conference Series.

Comparison of Distribution of AR and VR Publications in Physics Learning Research

Table 5 shows the distribution of publications on AR and VR in Physics learning research over the past twenty years.

Table 5

Comparison of Distribution of AR and VR in Physics Learning

Year	AR				VR					Citable Years
	Paper	Cited	ACPP	ACPPY	Paper	Cited	ACPP	ACPPY	Paper	
2002	0	0	0.00	0.00	3	0	0.00	0.00	3	20
2003	0	0	0.00	0.00	3	0	0.00	0.00	3	19
2004	0	0	0.00	0.00	4	14	0.00	0.00	4	18
2005	0	0	0.00	0.00	8	15	0.00	0.00	8	17
2006	2	45	22.50	1.41	11	23	2.09	0.13	11	16
2007	0	0	0.00	0.00	19	87	0.00	0.00	19	15
2008	2	18	9.00	0.64	16	50	3.13	0.22	16	14
2009	2	0	0.00	0.00	18	19	1.06	0.08	18	13
2010	6	51	8.50	0.71	23	103	4.48	0.37	23	12
2011	3	22	7.33	0.67	23	141	6.13	0.56	23	11
2012	6	234	39.00	3.90*	27	254	9.41	0.94	27	10
2013	3	55	18.33	2.04	16	140	8.75	0.97	16	9
2014	4	41	10.25	1.28	15	13	0.87	0.11	15	8
2015	8	193	24.13	3.45	14	118	8.43	1.20	14	7
2016	11	431*	39.18*	6.53	22	574*	26.09*	4.35*	22	6
2017	15	177	11.80	2.36	30	110	3.67	0.73	30	5
2018	21	155	7.38	1.85	26	57	2.19	0.55	26	4
2019	39	212	5.44	1.81	39	83	2.13	0.71	39	3
2020	40	217	5.43	2.71	60	68	1.13	0.57	60	2
2021	49*	68	1.39	1.39	68*	55	0.81	0.81	68*	1
Total	211	1919	209.65	30.74	445	1924	80.35	12.31	445	-

Description: *=the highest number
ACPPY= Average Citation Per Paper Per Year
ACPP= Average Citation Per Paper

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Table 5 shows, that AR 2002-2005, 2007 had no published documents. And 2021 became the year with the most publications. Furthermore, the years with the highest citation were 2016 (4,310 citations) fewest citations were 2002-2005, and 2007 because they did not have published documents. Whereas, in VR, all years have publications, with most publications in the year 2021. The highest citation was in 2016 (574 citations) and the fewest citation was in the year 2002 and 2003.

Review of Top 10 Cited Publications on AR and VR in Physics Learning Research

Table 6 is a review of the top 10 publications cited as impactful studies on AR and VR in Physics learning research from 2002-2021.

Table 6

Review of top 10 cited articles in AR And VR in physics learning research

Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
				AR		
Enyedy N., et al. (Enyedy et al., 2012)	146	2.39 (Q1)	9.1	98th	LPP technology and activities to learn strength and mobility concepts at an earlier age than expected. Toddlers do not have to be limited to remembering scientific facts or unstructured searches just because they cannot design controlled experiments for research.	Further discussion of this research is the depth of conceptual understanding that students develop through augmented reality and participatory modeling, and the role that these types of education can play. Building blocks for later learning concepts, and student modeling skills development.
Cai S., et al. (Cai et al., 2016)	91	0.92 (Q1)	5.1	93rd	AR-based motion detection software can improve student attitudes and learning outcomes. This research provides a discussion of the application of AR technology in secondary school physics education.	The stability of AR-based motion detection software may need to be improved.
Dunser et al. (Dünser et al., 2012)	76	0 (Not assigned yet)	-	80th	AR has the potential to become an important tool for teaching challenging 3D ideas.	Although the built-in interactions appear to be restricted, they currently enable the creation of pretty strong effects for instructive books, such as shifting scenes or activating, halting, or modifying animations.
Fidan & Tunel (Fidan & Tuncel, 2019)	68	3.03 (Q1)	14.4	99th	AR technology has the potential to become an important and efficient tool for eliciting positive feelings in kids during the PBL process.	The combination of AR and PBL may be applied to other Physics subjects and try to explore in other STEAM fields.
Cai et al. (Cai et al., 2013)	49	0.55 (Q1)	14.4	99th	An embedded AR educational environment that combines reality and virtuality would considerably excite students' learning interests and increase their level of engagement, implying that	Although there is inadequate information to evaluate if the AR tools improved students' conceptual knowledge, they did present students with alternative chances for scientific learning.

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Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
					this learning implementation has enormous potential in practice.	
			VR			
Yang, K. H., et al. (K. Y. Yang & Heh, 2007)	73	1.03 (Q1)	4.3	90th	The IVPL could assist 10th graders to enhance their physics instructional fulfillment and technology system skills	Further research needs to address the fundamental implications of each online interactive learning behavior and online learning process to improve human learning as soon as possible.
Aloetti, J., et al. (Aleotti & Caselli, 2011)	35	0.89 (Q1)	7.5	86th to Computer Graphics and Computer-Aided Designs	Inference at the physical level allows learning systems to discover task similarities across multiple demonstrations.	Optimization based on priority relation and geometric clustering has been proposed.
McGrath et al. (McGrath et al., 2010)	29	0.54 (Q2)	1.5	38th to General Physics and Astronomy	Students regarded the VR simulation in Physics' special relativity course to be a favorable learning experience, and they described the subject area as less abstract after using it.	Exploring additional disciplines where a visual approach might help students learn, we've started working on a simulation of quantum physics ideas.
Vrellis et al. (Vrellis et al., 2010)	24	0 (Not assigned yet)	-	97th	Multi-user virtual environments show that satisfying, engaging, and productive collaborative learning activities may be implemented in second life.	Improvement of non-verbal capability using real-time motion capture to improve social presence and cooperation efficiency throughout participants.
(Greenwald et al., 2018)	19	0.28 (Q2)	2.0	54th (General Computer Science)	The VR learning benefit exhibited here may be the top of a very vast iceberg, one that others indicated in the Related Research have also begun to find.	Advancing such information and norms further is undoubtedly a lucrative and intriguing subject.

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In **Table 6**, each article was analyzed based on the citation, Scimago Journal and Country Rank (SJR) accessed on www.scimagojr.com (Ianoş & Petrişor, 2020; Kasper, 2021; Sun, 2019; Torres-Samuel et al., 2018), CiteScore accessed on www.scopus.com (per April 2, 2022), also findings and recommendations in the publication. The review and analysis results in the top 10 cited publications in the **Table 6** tend to examine the effect and comparison of AR and VR in physics learning: The use of AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability. These publications become fundamental for future research, so they have great citations and impact on AR and VR in the development of Physics learning subjects. Based on data taken as of April 2, 2022, most of the top 10 cited publications are listed in the rank journal Quartile 1 (Q1) has CiteScore 9.1~~–~~ and percentile~~—~~ 98th to Education for AR in Physics learning research and VR has Quartile 1 (Q1) and CiteScore 4.3 and 90th to Education. This shows that publications that become the top 10 cited are publications with undoubted credibility. Because the publisher of the publication has a good reputation. Analysis of SJR, indicator assigns a different score to citations based on the importance of the citation source journal. Hence, citations from influential journals will be more valuable and the journals receiving them will gain more fame (Stephen, 2020).

Conclusion and Implications

This research is the first research that conduct a review and analysis of bibliometrics compared to AR and VR in general fields and Physics learning during the past twenty years from 2002 to 2021. This subject has become one of the research fields that has undergone significant development and improvement and technological development and its contribution to education, especially to Physics learning impact. Finally, this research has seven conclusions: 1) The trend research in AR and VR to all fields are ~~tent~~ in an ~~increase~~ increasing trend over the~~each~~ years; 2) Both of AR and VR research has United States as top countries in publications and Computers Science as subject areas, meanwhile AR has Technical University of Munich for top affiliation and VR has University of Southern Californias as top affiliation; 3) Top keyword that used in AR and VR to Physics learning are 'AR' and 'VR', with total link strength are respectively 479 and 1,882; 4) The top most productive authors to AR and VR in Physics learning research are Muliyati, D for AR and Pirker, J. for VR with total 12 and 6 documents each; 5) Top cited authors, in repectively AR and VR in Physics learning research are Potkonjak, V., et al. with the most citations; 6) The distribution of Publications on AR and VR in Physics learning publications has 2016 as highest citation and 2021 as the most publications, for the fewest years citation are 200-2005 and 2007 because they did not have published documents for AR. Whereas, for VR, the highest citation was in 2016 with 574 citations and the fewest citations were in 2002 and 2003; 7) The use of AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

This research is limited to the Scopus database. Hence, the implication of this research tends to find research novelties to AR and VR research, trend, and contribution to Physics learning during twenty years (2002-2021) through the results of the mapping, visualization patterns, and also literature review. Future researchers are expected to define a profile with other metadata, such as Google Scholar and WebScience, and combine them. The researchers can find the topics most relevant to Physics learning and the authors who have had the most significant impact and identify the main research lines of scientists in each defined period. Therefore, it also helps to narrow down the following trends that can be developed in this field of research, especially in Physics learning or Physics education field. Future researchers can explore AR and VR in Physics learning on top trends. There is still any chance to explore more about AR and VR in Physics learning research because the top trends still have a wide

Commented [A23]: Please add your discussion in this section and add some more suggestions for future work.

Commented [A24]: The question here is: "So what?" Why did I read this article? How can I use it for my future research? How does this paper help the field? What are the real trends in AR and VR research? What should I study next? Please try to answer these questions here in this section at least as deeply as your analysis.

Commented [A25]: This cannot be the conclusion of such a deep article! Please show us deep insights of your findings and what you have found that is really important for the field range and various fields of terms. AR and VR in Physics learning can still improve and assist educators in many aspects. In comparison, fewer trends can be used as an alternative future research field, especially to investigate AR on simulation, deep learning, and artificial intelligence. Meanwhile, there are still chances for VR, for example, STEM, high energy physics, and computer sciences.

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Trend and Visualization of Virtual Reality & Augmented Reality in Physics Learning From 2002-2021

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ABSTRACT
Augmented Reality (AR) & Virtual Reality (VR) are now wide open to all fields. The objectives of this study are to analyze the comparison of trend research on the top 200 cited AR and VR publications in all areas; To identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research; To identify the compare of top 10 most productive author of the AR and VR in Physics learning research; To determine the comparison of the top-cited author, subject areas and affiliation of the AR and VR in Physics learning research; To analyze the comparison of the distribution of AR and VR publications in Physics learning research; The metadata gathered is by Scopus database and investigated by VOSViewer. This research shows that the trend of research in AR and VR in all fields is increasing each year. The top keywords used in AR and VR to Physics learning are 'AR' and 'VR', with total link strengths of 479 and 1,882. AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

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Introduction

Emerging technology in the education process nowadays is necessary. Technology is changing much faster than ever, so skills need to be developed early in education (Hashim, 2018; Kuppusamy, 2020; Tilhou et al., 2020). Technology and education are necessary elements of the academic system (Dzuranin et al., 2018; Grippa et al., 2018; Van de Oudeweetering & Voogt, 2018; Williams, 2019). Integrating practices and technologies that can impact the future development of education, namely: Augmented reality (AR) technology, student achievement analysis, machine learning/artificial intelligence to educational application, open education resources, and adaptive learning technology (Yan, 2021).

Virtual reality (VR) and AR are now wide open to all fields. VR and AR are not new technologies (Elmqaddem, 2019). AR and VR are active areas of research and education as a technology that enables educators and teaching-learning processes (Gudoniene & Rutkauskiene, 2019; K. T. Huang et al., 2019). While AR extends the current perception of reality, VR replaces the real world with a simulated world (Blazauskas & Gudoniene, 2020; Martin et al., 2018; Motejlek & Alpay, 2019). The use of AR and/or VR in education provide if AR and/or VR in education provides an immersive multimodal environment enhanced by multiple sensory traits, providing effective tools for enhancing learning and useful for helping [16] K-12 students (Zhou et al., 2020).

AR is a technology that can superimpose computer-generated virtual visualization output indirectly and/or directly on a real environment in real-time (Aggarwal & Singhal, 2019; Baker et al., 2020; Lee, 2012) and real-world (Y. Chen et al., 2019). Since then, there have been many approaches and various have been used to design AR for educational purposes (Wu et al., 2013). Meanwhile, the simplest definition of VR is the replacement of experiences of more than one physical with a virtual thrill (Coburn et al., 2017) or simulation environment (Nomura & Sawada, 1999). VR has existed since the 1960s (F. C. Huang et al., 2015). VR has become one of the extensive technologies discussed all around fields in terms of applications, uses, and various types, and can bring tremendous benefits in the real world (Saeed et al., 2017).

In the education field, some research show intercultural learning through VR technology (Akdere et al., 2021); Immersed VR in a virtual laboratory in the subject of digital engineering (Khairudin et al., 2019); VR reinforces student learning through hands-on activity and educates students about innovative learning models used in technology (Kustandi et al., 2020) and also fostering students' critical thinking skills through the VR laboratory (Ikhsan et al., 2020). While in the AR research, namely meta-Analysis to Education in 2018 (Hantono et al., 2018); Mapping of WOS (López-Belmonte et al., 2020); Trends in 2006 to 2016 (Altinpulluk, 2019). Not only education field, AR and also VR technology researches are widely abroad to field such as industry (Gattullo et al., 2019), tourism (Cranmer et al., 2020), health science, and medical anatomy (Moro et al., 2017), dentistry (T. K. Huang et al., 2018), business (El-Seoud & Taj-Eddin, 2019) and also other fields. Based on the findings, many researchers identified AR, and there is potential for future work (Hedberg et al., 2018).

Research publications on AR and VR tend to increase every year. Therefore, it takes research to find out how AR and VR are used in each area of research to find future novelty and research ideas. In addition, the use of AR and VR in the field of education also needs to be known to be an opportunity for research studies and learning innovations in the future. Previous researches are tend to immerse AR and VR in the general learning process. Despite this, researchers tend to conduct bibliometric research to **compare** AR and VR trends researches through Scopus over the past 20 years and the contribution of AR and VR to Physics education to specify the previous research. This research is focused on Physics education because in physics learning many abstract, microscopic, and macroscopic concepts are found. So that VR and AR can be physics learning aids that are currently being discussed.

Research Objectives

This research analyzes bibliometrics on 'AR' and 'VR' keywords as general fields and specifies it to implement AR and VR in Physics education and compare them. Scopus is used to collect the metadata and the VOSViewer application will be an assist tool. This research is expected to compare trends, patterns, novelty, and future research in AR and VR through all-around fields and in the Physics education field during the past twenty years (2002-2021). Specifically, the objectives of this research are as follows:

1. To compare trend research on the top 200 cited to represent the AR and VR publications in all fields during 2002-2021.
2. To analyze the comparison of the subject areas, countries, and top affiliations that have contributed to the top 200 cited AR and VR publications in all fields during 2002-2021.

3. To identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research during 2002-2021.
4. To identify the comparison of the top 10 most productive authors of the AR and VR in Physics learning research during 2002-2021.
5. To identify the comparison of the top-cited author, subject areas, and affiliation of the AR and VR in Physics learning research during 2002-2021.
6. To analyze the comparison of the distribution of AR and VR publications in Physics learning research during 2002-2021.
7. To analyze the top 10 cited publications in AR and VR in Physics learning research during 2002-2021.

Methods

This research is bibliometric research using descriptive analysis. This research used Scopus as a structured database to analyze the published data (Aria & Cuccurullo, 2017; Goli & Haghighinasab, 2022; Mongeon & Paul-Hus, 2016; Shubina et al., 2021; Thu et al., 2021). Scopus has become the largest database and has more than 77.8 million core records from different various fields with various metadata and document types, either non-academic or academic fields (Hernández et al., 2021; Nurdin et al., 2021; Pham-Duc et al., 2021; Pranckutė, 2021; Singh et al., 2021; Thu et al., 2021). Also, Scopus has a loading of sources 70% greater than Web of Science (López-Illescas et al., 2008; Supriadi et al., 2021). Bibliometrics consists of four phases, namely: (1) defining a study design, (2) collecting data through the criteria, (3) data analysis, and (4) interpreting and visualizing data (Lorenzo et al., 2022). In this research, two filterings were performed on data criteria. Finally, the process of this research to determine the use of AR and VR in general fields is as in **Figure 1**. Then, Researchers specify the keyword to know AR and VR impact or contribution to Physics learning as in **Figure 2** during the past twenty years.

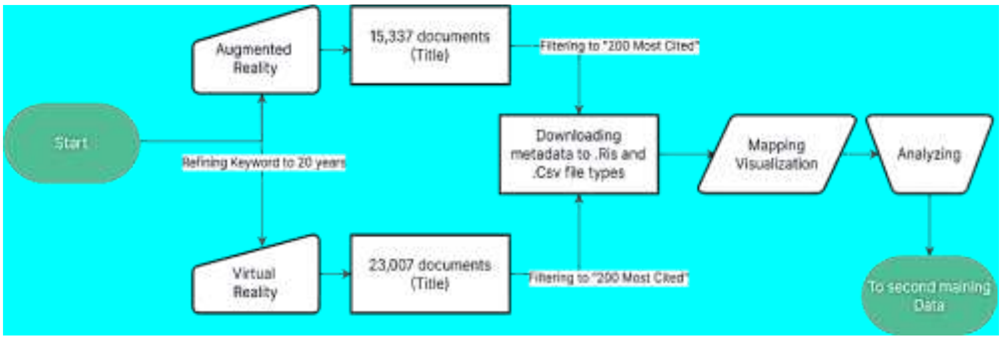

Figure 1. Research flowchart to the general keywords

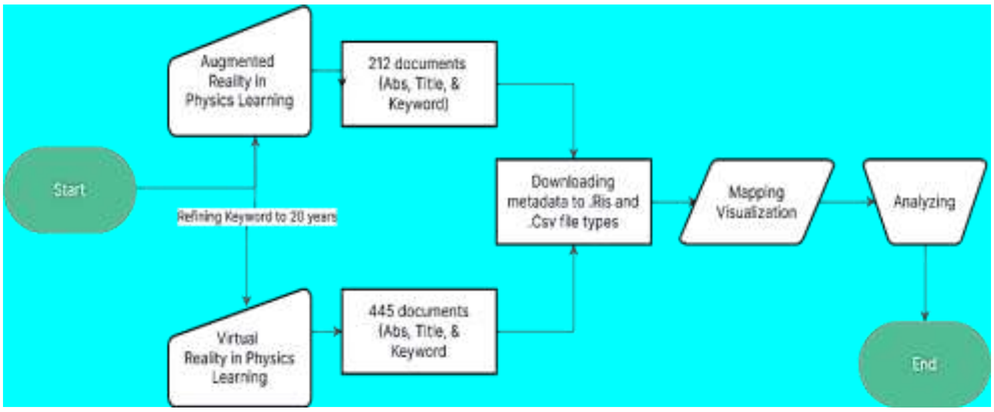

Figure 2. Research flowchart to the specified keywords

Data mining was collected on March 30, 2022. The results obtained are sorted by "number of citations" from high to low. Then, downloaded them in .csv and .ris file formats. After that, data was uploaded to the VOSViewer software to show the details of the transcription of the data and visualize the bibliometric assignments (Jayadinata et al., 2021; Nandiyanto & Al Husaeni, 2021; van Eck & Waltman, 2010, 2017; Wong, 2018). For the final stage, data are analyzed descriptively to answer the research objectives.

Findings and Discussion

Comparison of Trend Research AR and VR in All Fields During 2002-2021

Based on metadata filtering and analysis, there are known annual trends in AR and VR publications in all research fields from 2002 to 2021. The trend shows the interest of researchers to research the subject of the study. AR and VR in all fields from 2002 to 2021 it is depicted in **Figure 3**.

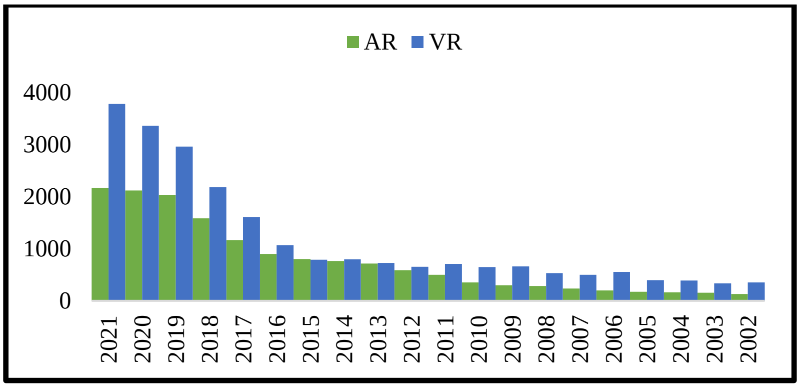

Figure 3. Comparison of AR and VR trend researches in all fields during 2002-2021

Based on **Figure 3**, research trends on both AR and VR in all fields during the past twenty years tend to increase each year (Cavalcanti et al., 2021; Ed & Hutchison, 2013; Papakostas et al., 2021). However, VR publications are more numerous than AR and this shows that interest in AR and VR continues to increase and becomes an interesting topic to be used as research material. And, it can be realized that AR and VR are an interesting trend every year with the increase in research trends from 2002 to 2021. The use of AR and VR integrase in various fields of work is indeed a hot topic discussed (Bottani & Vignali, 2019), especially in education science. This is because AR and VR are considered capable of becoming learning medium that covers many aspects of learning, especially in 21st-century learning (C. H. Chen et al., 2020; Elmqaddem, 2019; Sanabria & Arámburo-Lizárraga, 2017).

Hence, after being analyzed using VosViewer, it can be known keywords that are often used in AR and VR publications from 2002 to 2021 in all fields. Keywords that are often used in AR and VR publications in all fields from 2002 to 2021 are as in **Figure 4.**

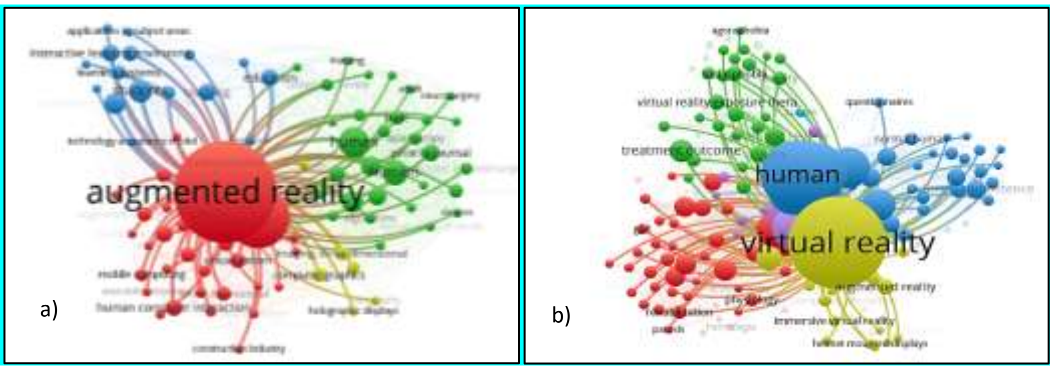

Figure. 4. a) Keywords that are used in AR publications; b) Keywords that used in VR publications

Figure 4 is a keyword that is widely used in AR and VR publications in all fields in the past twenty years. In AR, the most common keywords are 'Augmented Reality' (n=13,086), 'Virtual Reality' (n=3,908), 'Human' (n=1,182) and 'Mobile Augmented Reality' (n=1,011). While in VR publications, the most widely used keywords in publications are 'Virtual Reality' (19,483), 'Human' (n=5,368), 'Humans' (n=4,159) and 'Article' (n=3,534).

These keywords show a strong relationship between both AR and VR as immersive human and mobile AR. Moreover, the results point to increasing interest in research on the use of VR in Humanee and article research. For example research of Grandi et al., (2018) conducted the design of a handheld-based interface for collaborative manipulations of 3D objects in mobile AR as Human-Centered Computing (HCC)-Interaction (HCI). Both AR and VR keywords are related to each other, It is not surprising that managers find it hard to distinguish similar-sounding, IT-based concepts such as AR and VR (Farshid et al., 2018).

Comparison of Subject Areas, Countries, and Top Affiliation of Top 200 Cited AR and VR Publications in All Fields During 2002-2021

Table 1

Comparison of AR and VR to Top Countries, Subject Areas, and Affiliation in All Fields During These Past Twenty Years

AR			VR		
Countries	**Subject Areas**	**Affiliation**	**Countries**	**Subject Areas**	**Affiliation**
United States	Computer Science	Technical University of Munich	United States	Computer Science	University of Southern California
Germany	Engineering	Technische Universitat Graz	China	Engineering	IRCCS Istituto Auxologico Italiano
China	Mathematics	University of South Australia	Germany	Medicine	CNRS Centre National de la Recherche Scientifique
South Korea	Social Sciences	Beijing Institute of Technology	United Kingdom	Social Sciences	Università Cattolica del Sacro Cuore
Japan	Medicine	National University of Singapore	Italy	Mathematics	Universitat de Barcelona

According to **Table 1**, it can be seen that the United States is the country with the most publications on AR (n=2,702) and VR (n=5,080), but for AR, the country with the second most publications is Germany (n=1,374), while VR is China (n=2,887). In subject areas, AR and VR have the same result again, namely the top subject areas owned by 'Computer Science' followed by 'Engineering', the difference is in the third top subject areas, namely for AR in 'Mathematics' (n = 2,417), while VR in 'Medicine' (n = 5,117). At top Affiliation, the Technical University of Munich is the top affiliate in AR, while the University of Southern California is the top affiliate in VR.

In line with previous bibliometric research on AR and also VR, the United States has become the top country in publications on AR and VR. These findings also show that the USA has become the most influential country, based on the number of publications over the twenty years. Meanwhile, the top subject areas are the specific areas of instruction in which courses are offered within academic organizations. Computer science, engineering, medicine, and/or mathematics have become the top subject areas of AR and VR research. This finding showed that most AR and VR publications are related to a technical science in line with the top affiliation in AR which is the Technical University of Munich (Germany) and assisting abstract or imagining objects such as mathematics and formula of medicine.

The mapping of visualization of top countries in AR and VR publications from 2002 to 2021 can be described in **Figure 5** and **Figure 6**. This result was generated with Datawrapper.

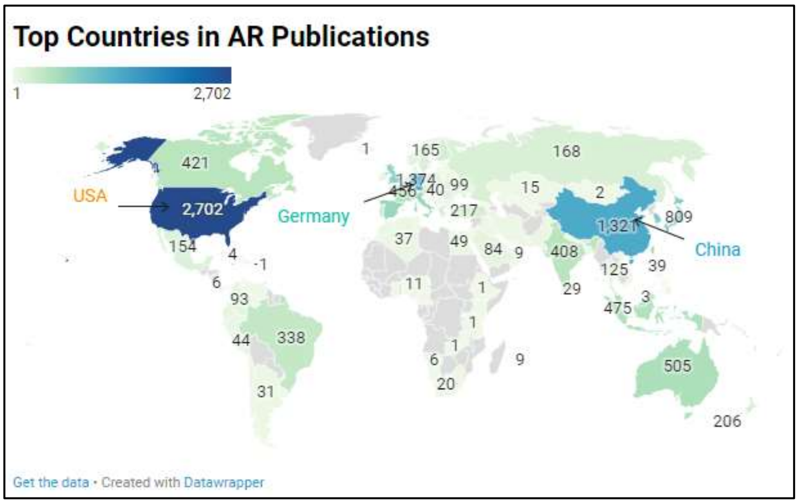

Figure. 5. Top Countries in AR publications from 2002 to 2021

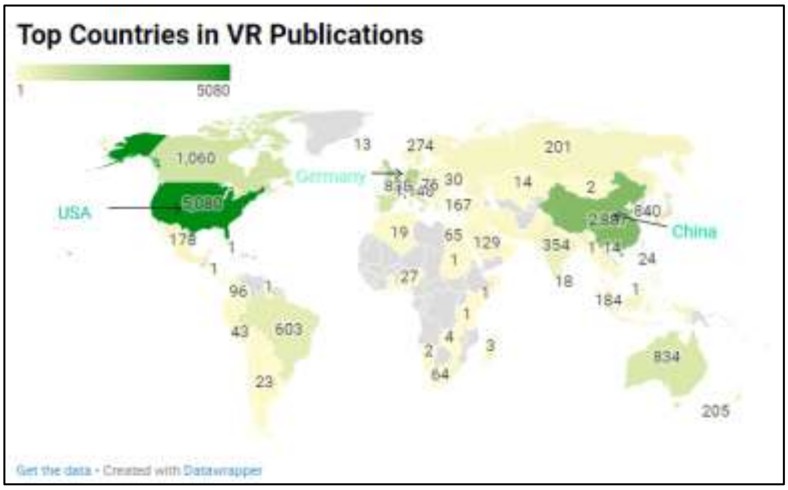

Figure. 6. Top Countries in VR publications from 2002 to 2021

Based on **Table 1**, it can be analyzed that there has been no difference in the first order of top countries, subject areas, and affiliations in AR and VR publications in all fields over the past twenty years. **Figure 5** and **Figure 6** show that the top 3 countries in AR and VR publications are the United States, China, and Germany. Other countries have an average of fewer than 100 publications, but indeed some countries have more than 500 publications and fewer than 1,000 publications from 2002 to 2022. These findings are related to previous research that found the USA, China, and Germany as the most influential countries in the publication of AR and VR in all fields (Garzón, 2021; Karakus et al., 2019).

Comparison of Trend Mapping Visualization of AR and VR in Physics Learning During 2002-2021

The most occurrence keywords are analyzed before mapping out the visualization of AR and VR in Physics Learning research during the past twenty years, as shown in **Table 2.**

Table 2

Top 15 Keywords Used in AR And VR To Physics Learning Research During the Past Twenty Years

AR			VR		
Keyword	**Total Link Strength**	**Occurrence**	**Keyword**	**Total Link Strength**	**Occurrence**
Augmented Reality	479	146	Virtual Reality	1,882	334
Students	257	55	E-Learning	848	139
Virtual Reality	129	31	Students	699	99
E-Learning	126	26	Education	609	80
Education Computing	110	20	Teaching	385	54
Education	103	22	Physics	320	45
Physics Learning	89	19	Engineering Education	302	44
Computer-Aided Instruction	87	17	Learning Systems	280	51
Engineering Education	86	17	Augmented Reality	251	52
Teaching	69	14	Human	237	23
Laboratories	63	13	Computer-Aided Instruction	229	35
Learning Systems	60	13	Humans	225	20
Learning Environments	58	11	Article	215	21
Physics Education	55	13	Learning	206	26
Augmented Reality Technology	45	11	Virtual Laboratories	204	27

From **Table 2** it can be seen that the highest total link strength and the most frequently occurring keywords are "Augmented Reality" (n=479) to AR, and "Virtual Reality" (n=1,882) to VR. Hence, it is clear that every keyword is related to AR and VR itself. The second order of the keywords is "Students" (n=257) for AR and "E-Learning" (n=848) for VR. Followed by "Virtual Reality" (n=129) to AR and "Students" (n=699) to VR. From Table 2, we can also conclude that AR is still related to the VR keyword and vice versa. Based on this pattern, it can be found that the trends of both AR and VR in Physics Learning research in 2002-2021 are: 1) Related to Education; 2) Implementation of e-learning activities for students and teachers; 3) Technology integration in learning; 4) Computer-aided instruction; 5) Physics learning and education. Specifically, trends in AR can be Augmented reality technology, whereas VR can be Virtual laboratories.

Based on this finding, AR and VR are contributed to students and e-learning in physics learning. Emerging AR and VR to Physics concepts are now wide open since Physics is one abstract and difficult subject (Zamil et al., 2021). The development of student worksheet-AR based is very suitable to be used as a learning tool in physics practicum activities in Senior High School in 10th grade (Bakri et al., 2020). Integrating AR into physics classrooms can enhance students' physics learning self-efficacy, guide students to be more inclined to higher-level conceptions of learning physics, and stimulates students' motivation to learn more deeply (Cai et al., 2021). Also, a review of problem-based AR made learning more meaningful (Wulandari et al., 2021). Technological innovations, such as augmented reality (AR), have the potential to fundamentally change education by making difficult concepts available and accessible to beginners (Church & Marasoiu, 2019). Meanwhile, VR technology provides a promising media for educational researchers (Budi et al., 2021). VR environment in terms of learners' perceptions and their conceptual learning in Physics learning increased (Georgiou et al., 2020; Tsivitanidou et al., 2021). The use of virtual reality technology in the e-learning environment had a positive effect on students (Abdüsselam & Erten, 2022; Rogers et al., 2017; Wiederhold et al., 2018; F. Yang & Wu, 2010).

Therefore to find a novelty of the research based on the mapping results, we can look at the relationships between smaller keywords or fewer keywords. It is shown in **Figure 7**.

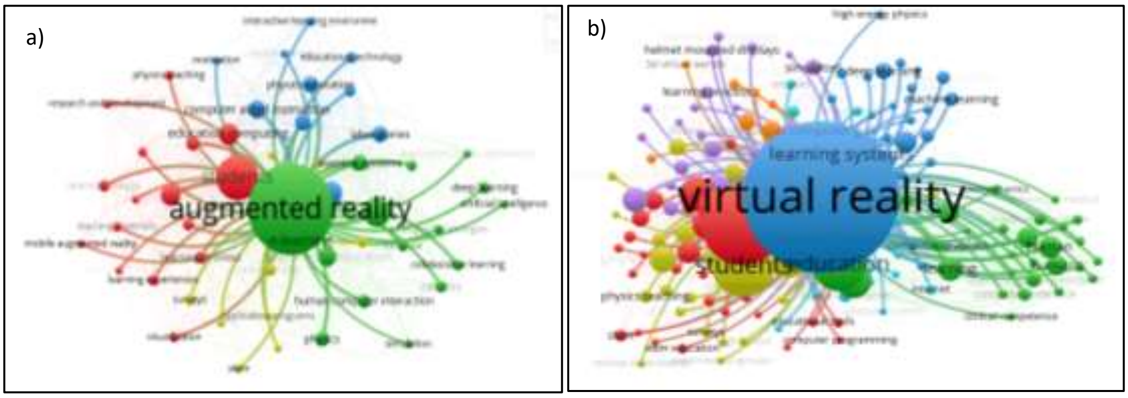

Figure. 7. Trends keywords mapping in Physics learning to a) AR; b) VR during 2002-2021

To find the novelty of previous research, the mapping of metadata keywords (X. Chen et al., 2021; Gamage et al., 2022; Goerlandt et al., 2021; Pournader et al., 2021). Comparison of visualizations of keyword co-occurrences in AR and also VR research in Physics learning during 2002-2021 are shown in **Figure 7.** These are analyzed to find the novelty between these researches. **Figure 7** of mapping visualization are shown that there are 4 main clusters for AR, namely: 1) Cluster 1 with red nodes (n=16 items); 2) Cluster 2 with green nodes (n=15 items); 3) Cluster 3 with blue nodes (n=11 items); and 4) Cluster 4 with yellow nodes (n=10 items). Meanwhile, comparing to VR, there are 7 main clusters, namely: 1) Cluster 1 with red nodes (n=31 items); 2) Cluster 2 with green nodes (n=30 items); 3) Cluster 3 with blue nodes (n=28 items); 4) Cluster 4 with yellow nodes (25 items); 5) Cluster 5 with purple nodes (n=23 items); 6) Cluster 6 with turquoise (n=22 items); and 7) Cluster 7 with orange nodes (n=8 items). Some examples of specific keyword mapping visualization results on AR are AR, students, AR technology, simulation, deep learning, and artificial intelligence. Also, for VR are VR, e-learning, students, STEM, high energy physics, and computer sciences.

If future researchers want to explore AR and VR in Physics learning on top trends, there is still any chance to explore more about AR and VR in Physics learning research because the top trends still have a wide range and various fields of terms. AR and VR in Physics learning can still improve and assist educators in many aspects. Whereas, fewer trends such as can be used as an alternative future research field, especially to investigate AR on simulation, deep learning, and artificial intelligence. Meanwhile, there are still chances for VR for example STEM, high energy physics, and computer sciences.

Comparison of Top 10 Most Productive Authors to AR and VR in Physics Learning Research

The metadata results on Scopus can show the author of the publication of AR and VR in Physics learning research in the past twenty years. **Table 3** shows the top 10 most productive authors of LMS research from 2002-2021.

Table 3

The top 10 Most Productive Authors

AR		VR	
Author	**Total Publications**	**Author**	**Total Publications**
Muliyati, D.	12	Parker, J.	6
Bakri, F.	11	Wasfy, T.M.	6
Kuhn, J.	7	Guetl, C.	5
Kapp, S.	6	Terzopoulos, D.	5
Thees, M.	6	Wasfy, H.M.	5

Table 3 shows that Muliyati, D. is the most prolific author with 12 publications in AR, followed by Bakri, F. who has 11 publications, and Kuhn, J. became the third most productive author with 7 publications in total. Meanwhile, Parker, J. is the most prolific author with 6 publications in VR, followed by Wasfy, T.M. with 6 publications, and Guetl, C. with 5 publications in third place.

Comparison of Top Cited Author, Subject Areas, and Sources Titles of The AR and VR in Physics Learning Research

Table 4 shows top-cited authors, subject areas, and affiliation to AR and VR in Physics learning research from 2002-2021.

Table 4

Top Research Citations, Subject Areas, and Affiliation on AR and VR in Physics Learning Research During 2002-2021

AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
Potkonjak , V., et al.	Computer Science	Universitas Negeri Jakarta	Journal Of Physics Conference Series	Potkonjak , V., et al.	Computer Science	Technische Universitat Graz	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In

AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
							Bioinformatic s
Enyedy, N., et al.	Social Sciences	Technische Universität Kaiserslaute rn	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	Lindgren, R., et al.	Engineering	Curtin University	ACM International Conference Proceeding Series
Cai, S., et al.	Physics and Astronomy	Institut Pendidikan Indonesia	AIP Conference Proceedings	Miles, H.C., et al.	Social Sciences	Internationa l Information Technology University	Journal Of Physics Conference Series
Saidin, N.F., et al.	Engineering	Harvard University	Ceur Workshop Proceedings	Chan, S., et al.	Mathematic s	Advanced Science and Automation Corp.	Proceedings Of SPIE The International Society For Optical Engineering
Dünser, A., et al.	Mathematics	Indiana University Bloomingto n	ACM International Conference Proceeding Series	Saidin, N.F., et al.	Physics and Astronomy	The Ohio State University	ASEE Annual Conference And Exposition Conference Proceedings
Fidan, M., & Tuncel, M.	Materials Science	Beijing Normal University	Communication s In Computer And Information Science	Dünser, A., et al.	Medicine	Instituto Superior de Engenharia do Porto	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatic s

Based on top-cited authors in **Table 4**, respectively, AR and VR in Physics learning research are Potkonjak, V., et al. with the most citations. Top subject areas in both AR and VR Publications in Physics learning are Computer science with top affiliation respectively Universitas Negeri Jakarta and Technische Universitat Graz. Meanwhile, the top source titles are Journal of Physics Conference Series and Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics.

In line with the top subject areas in all field publications of AR and VR, the top subject areas in Physics learning are still Computer Science, social sciences, and engineering. These findings have still shown that AR and VR even in Physics learning tend to contribute to computer science subjects. In line with the top author, the findings of metadata show that Mulyati, D. and Bakri, F. with the affiliation of Universitas Jakarta has published an AR-based development electric book (Permana et al., 2019), electromotive force concept (Bakri et al., 2019b) and Lorentz force (Bakri et al., 2019a) in Journal of Physics Conference Series.

Comparison of Distribution of AR and VR Publications in Physics Learning Research

Table 5 shows the distribution of publications on AR and VR in Physics learning research over the past twenty years.

Table 5

Comparison of Distribution of AR and VR in Physics Learning

Year	AR				VR					Citable Years
	Paper	Cited	ACPP	ACPPY	Paper	Cited	ACPP	ACPPY	Paper	
2002	0	0	0.00	0.00	3	0	0.00	0.00	3	20
2003	0	0	0.00	0.00	3	0	0.00	0.00	3	19
2004	0	0	0.00	0.00	4	14	0.00	0.00	4	18
2005	0	0	0.00	0.00	8	15	0.00	0.00	8	17
2006	2	45	22.50	1.41	11	23	2.09	0.13	11	16
2007	0	0	0.00	0.00	19	87	0.00	0.00	19	15
2008	2	18	9.00	0.64	16	50	3.13	0.22	16	14
2009	2	0	0.00	0.00	18	19	1.06	0.08	18	13
2010	6	51	8.50	0.71	23	103	4.48	0.37	23	12
2011	3	22	7.33	0.67	23	141	6.13	0.56	23	11
2012	6	234	39.00	3.90*	27	254	9.41	0.94	27	10
2013	3	55	18.33	2.04	16	140	8.75	0.97	16	9
2014	4	41	10.25	1.28	15	13	0.87	0.11	15	8
2015	8	193	24.13	3.45	14	118	8.43	1.20	14	7
2016	11	431*	39.18*	6.53	22	574*	26.09*	4.35*	22	6
2017	15	177	11.80	2.36	30	110	3.67	0.73	30	5
2018	21	155	7.38	1.85	26	57	2.19	0.55	26	4
2019	39	212	5.44	1.81	39	83	2.13	0.71	39	3
2020	40	217	5.43	2.71	60	68	1.13	0.57	60	2
2021	49*	68	1.39	1.39	68*	55	0.81	0.81	68*	1
Total	211	1919	209.65	30.74	445	1924	80.35	12.31	445	-

Description: *=the highest number
ACPPY= Average Citation Per Paper Per Year
ACPP= Average Citation Per Paper

Table 5 shows, that AR 2002-2005, 2007 had no published documents. And 2021 became the year with the most publications. Furthermore, the years with the highest citation were 2016 (4,310 citations) fewest citations were 2002-2005, and 2007 because they did not have published documents. Whereas, in VR, all years have publications, with most publications in the year 2021. The highest citation was in 2016 (574 citations) and the fewest citation was in the year 2002 and 2003**.**

Review of Top 10 Cited Publications on AR and VR in Physics Learning Research

Table 6 is a review of the top 10 publications cited as impactful studies on AR and VR in Physics learning research from 2002-2021.

Table 6

Review of Top 10 Cited Articles in AR And VR In Physics Learning Research

Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
				AR		
Enyedy N., et al. (Enyedy et al., 2012)	146	2.39 (Q1)	9.1	98th	LPP technology and activities to learn strength and mobility concepts at an earlier age than expected. Toddlers do not have to be limited to remembering scientific facts or unstructured searches just because they cannot design controlled experiments for research.	Further discussion of this research is the depth of conceptual understanding that students develop through augmented reality and participatory modeling, and the role that these types of education can play. Building blocks for later learning concepts, and student modeling skills development.
Cai S., et al. (Cai et al., 2016)	91	0.92 (Q1)	5.1	93rd	AR-based motion detection software can improve student attitudes and learning outcomes. This research provides a discussion of the application of AR technology in secondary school physics education.	The stability of AR-based motion detection software may need to be improved.
Dunser et al. (Dünser et al., 2012)	76	0 (Not assigned yet)	-	80th	AR has the potential to become an important tool for teaching challenging 3D ideas.	Although the built-in interactions appear to be restricted, they currently enable the creation of pretty strong effects for instructive books, such as shifting scenes or activating, halting, or modifying animations.
Fidan & Tunel (Fidan & Tuncel, 2019)	68	3.03 (Q1)	14.4	99th	AR technology has the potential to become an important and efficient tool for eliciting positive feelings in kids during the PBL process.	The combination of AR and PBL may be applied to other Physics subjects and try to explore in other STEAM fields.
Cai et al. (Cai et al., 2013)	49	0.55 (Q1)	14.4	99th	An embedded AR educational environment that combines reality and virtuality would considerably excite students' learning interests and increase their level of engagement, implying that	Although there is inadequate information to evaluate if the AR tools improved students' conceptual knowledge, they did present students with alternative chances for scientific learning.

Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
					this learning implementation has enormous potential in practice.	
			VR			
Yang, K. H., et al. (K. Y. Yang & Heh, 2007)	73	1.03 (Q1)	4.3	90th	The IVPL could assist 10th graders to enhance their physics instructional fulfillment and technology system skills	Further research needs to address the fundamental implications of each online interactive learning behavior and online learning process to improve human learning as soon as possible.
Aloetti, J., et al. (Aleotti & Caselli, 2011)	35	0.89 (Q1)	7.5	86th to Computer Graphics and Computer-Aided Designs	Inference at the physical level allows learning systems to discover task similarities across multiple demonstrations.	Optimization based on priority relation and geometric clustering has been proposed.
McGrath et al. (McGrath et al., 2010)	29	0.54 (Q2)	1.5	38th to General Physics and Astronomy	Students regarded the VR simulation in Physics' special relativity course to be a favorable learning experience, and they described the subject area as less abstract after using it.	Exploring additional disciplines where a visual approach might help students learn, we've started working on a simulation of quantum physics ideas.
Vrellis et al. (Vrellis et al., 2010)	24	0 (Not assigned yet)	-	97th	Multi-user virtual environments show that satisfying, engaging, and productive collaborative learning activities may be implemented in second life.	Improvement of non-verbal capability using real-time motion capture to improve social presence and cooperation efficiency throughout participants.
(Greenwald et al., 2018)	19	0.28 (Q2)	2.0	54th (General Computer Science)	The VR learning benefit exhibited here may be the top of a very vast iceberg, one that others indicated in the Related Research have also begun to find.	Advancing such information and norms further is undoubtedly a lucrative and intriguing subject.

In **Table 6**, Each article was analyzed based on the citation, Scimago Journal and Country Rank (SJR) accessed on www.scimagojr.com (Ianoş & Petrişor, 2020; Kasper, 2021; Sun, 2019; Torres-Samuel et al., 2018), CiteScore accessed on www.scopus.com (per April 2, 2022), also findings and recommendations in the publication. The review and analysis results in the top 10 cited publications in the **Table 6** tend to examine the effect and comparison of AR and VR in physics learning: The use of AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability. These publications become fundamental for future research, so they have great citations and impact on AR and VR in the development of Physics learning subjects. Based on data taken as of April 2, 2022, most of the top 10 cited publications are listed in the rank journal Quartile 1 (Q1) has CiteScore 9.1 and percentile 98th to Education for AR in Physics learning research and VR has Quartile 1 (Q1) and CiteScore 4.3 and 90th to Education. This shows that publications that become top 10 cited are publications with undoubted credibility. Because the publisher of the publication has a good reputation. Analysis of SJR, indicator assigns a different score to citations based on the importance of the citation source journal. Hence, citations from influential journals will be more valuable and the journals receiving them will gain more fame (Stephen, 2020).

Conclusion and Implications

This research is the first who conduct a review and analysis of bibliometrics compared to AR and VR in general fields and Physics learning during the past twenty years from 2002 to 2021. This subject has become one of the research fields that has undergone significant development and improvement and technological development and its contribution to education, especially to Physics learning impact. Finally, this research has seven conclusions: 1) The trend research in AR and VR to all fields are tent increase each years; 2) Both of AR and VR research has United States as top countries in publications and Computers Science as subject areas, meanwhile AR has Technical University of Munich for top affiliation and VR has University of Southern Californias as top affiliation; 3) Top keyword that used in AR and VR to Physics learning are 'AR' and 'VR', with total link strength are respectively 479 and 1,882; 4) The top most productive authors to AR and VR in Physics learning research are Muliyati, D for AR and Pirker, J. for VR with total 12 and 6 documents each; 5) Top cited authors, in repectively AR and VR in Physics learning research are Potkonjak, V., et al. with the most citations; 6) The distribution of Publications on AR and VR in Physics learning publications has 2016 as highest citation and 2021 as the most publications, for the fewest years citation are 200-2005 and 2007 because they did not have published documents for AR. Whereas, for VR, the highest citation was in 2016 with 574 citations and the fewest citations were in 2002 and 2003; 7) The use of AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

This research is limited to Scopus database. Hence, the implication of this research tends to find research novelties to AR and VR research, trend, and contribution to Physics learning during twenty years (2002-2021) through the results of the mapping, visualization patterns, and also literature review. Future researchers are expected to define a profile with other metadata, such as Google Scholar and WebScience, and combine them. The researchers can find the topics most relevant to Physics learning and the authors who have had the most significant impact and identify the main research lines of scientists in each defined period. Therefore, it also helps to narrow down the following trends that can be developed in this field of research, especially in Physics learning or Physics education field. Future researchers can explore AR and VR in Physics learning on top trends. There is still any chance to explore more about AR and VR in Physics learning research because the top trends still have a wide range and various fields of terms. AR and VR in Physics learning can still improve and assist educators in many aspects. In comparison, fewer trends can be used as an alternative future research field, especially to investigate AR on simulation, deep learning, and artificial intelligence. Meanwhile, there are still chances for VR, for example, STEM, high energy physics, and computer sciences.

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Dear Editor-in-Chief,

Thanks to editors and reviewers for having spent a great deal of time and care to provide positive recommendations for our articles. Researchers welcome all positive recommendations with pleasure because reviewer feedback has greatly helped improve the quality of our articles. The following changes have been made on the Manuscript "**Trend and Visualization of Virtual Reality & Augmented Reality in Physics Learning From 2002-2021**" in accordance with reviewers' comments. Our great hope is our article can be received at The Journal of Turkish Science Education. Thank you very much.

Best Regards

Dr. Binar Kurnia Prahani

Universitas Negeri Surabaya

B-Reviewers

Reviewer's comments	Changes made	Page (see highlights)
Dil ve imla kurallarına uygun yazılmalı. (The article must be proof-reading in terms of language (English). Some sentences are incomprehensible and there are word mistakes.)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking the grammar and spelling rules.	All
Which system	Researchers receive positive advice from reviewers and add discussion about the detail of the systems.	1
Unknown citation place	Researchers receive positive advice from reviewers and add discussion about the the unknown citation.	2
araştırmacı özellikle fizik eğitimi alanında AR ve VR yayınlarının incelemesini neden yoğunlaştırmıştır? Bunun gerekçesi açıklanmalı (Why did the researcher intensify the examination of AR and VR publications, especially in the field of physics education? It would be helpful to explain the reason for this)	Researchers receive advice from the reviewer and have adding the reason to intensify the review of AR and VR publications, especially in the field of physics education.	2
Neden en çok atıf alan 200 makale? (Why the 200 most cited articles?)	Researchers receive advice from the reviewer and have adding the reason to choosing the 200 most cited articles.	2
Görsellerin çözünürlüğü arttırılmalı. (The resolution of some images is not good. should be made more readable and understandable)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done increasing the resolution of the images.	3-4
Errors in the layout, content and headings of some tables should be corrected.	Researchers receive advice from the reviewer and have checking errors in the layout, content and headings of some tables should be corrected.	All
Bulgular ve tartışma bir arada verilmiştir. Bu durum araştırma bulgularının derinlemesine tartışılmasının önüne geçmiş gibi görünüyor. Araştırmanın bulgularının özellikle de fizik eğitimi açısından derinlemesine tartışılmaya ihtiyacı olduğu kanısındayım. (Findings and discussion are presented together. This seems to have prevented an in-depth discussion of the research	Thanks to the reviewer has given a positive recommendation for our article. Researchers done adding the depth discussion along the Findings and discussion section.	4-14

findings. I believe that the findings of the research need to be discussed in depth, especially in terms of physics education)		
Grammatical error	Researchers receive advice from the reviewer and have changing the grammatical error.	5
görsellerdeki yazılar okunmuyor ve anlaşılmıyor. (The texts in the images are unreadable and incomprehensible)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done changing the size of the images.	5
tablo numarası ve adı? Yazım formu düzeltilmeli (Table number and name? Spelling form should be corrected)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done changing the table number and name.	5-13
Grammatical error	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking the grammatical error.	8
Grammatical error	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking the grammatical error.	8
Grammatical error	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking the grammatical error	8
Yayın sayısı mı? (Is it the number of publications?)	Researchers receive advice from the reviewer and yes, it is the number of publications. Researchers have adding the detail to the table.	9
Tablo 3 te bu yazar yok! (Table 3 does not have this author!)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking and changing the author of the Table 3.	9
Bu tabloda 10 makale var. Tablo başlığı gözden geçirilmeli. (There are 10 articles in this table. Table title should be revised)	Thanks to the reviewer has given a positive recommendation for our article. Researchers done changing the detail of the table title on Table 6.	12
Grammatical error	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking the grammatical error	12
Consistency title of the table 6	Researchers receive advice from the reviewer and have changing the consistency of the top 10 cited publications	14

The bibliography should be revised according to the spelling rules. There are errors.	Thanks to the reviewer has given a positive recommendation for our article. Researchers done checking on the bibliography with APA 7 styles.	All
Limitations of the research should be stated and suggestions for future research can be given wider place.	Thanks to the reviewer has given a positive recommendation for our article. Researchers done adding the limitation and suggestions for future research.	14
Some other minor points are mentioned on the article file.	Researchers receive advice from the reviewer and have checking to minor points on the article file.	All

D-Reviewers

Reviewer's comments	Changes made	Page (see highlights)
The article is well organized and has a few issues that should be overcome.	Thanks to the reviewer has given a positive recommendation for our article.	All
Findings and discussion are given together.	Thanks to the reviewer has given a positive recommendation for our article. Researchers done giving the findings and discussion together.	4-14
The discussion should be done in more detail.	Thanks to the reviewer has given a positive recommendation for our article. Researchers done adding the depth discussion along the Findings and discussion section.	4-14
Some implications for future researchers are also done in more detail.	Thanks to the reviewer has given a positive recommendation for our article. Researchers done adding the implications, limitations and suggestions for future research.	14

E-Reviewers

Reviewer's comments	Changes made	Page (see highlights)
Nothing Comments	-	-

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Virtual & Augmented Reality in Physics Learning: Research, Trend, and Contribution in the 20 Last Years

ABSTRACT

The use of Augmented Reality (AR) and Virtual Reality (VR) are now wide open to all fields. The objectives of this study are to analyze the comparison of trend research on the top 200 cited AR and VR publications in all fields; To identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research; To identify the comparison of top 10 most productive author of the AR and VR in Physics learning research; To identify the comparison of the top-cited author, subject areas and affiliation of the AR and VR in Physics learning research; To analyze the comparison of the distribution of AR and VR publications in Physics learning research; The metadata gathered is by Scopus database and analyzed by VOSViewer. This research shows that the trend of research in AR and VR in all fields are tent increasing each year. The top keywords that are used in AR and VR to Physics learning are 'AR' and 'VR', with total link strength are respectively 479 and 1,882. The use of AR or VR can be integrated into the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

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Introduction

Emerging technology in education process nowadays is necessary. Technology is changing much faster than ever, so skills need to be developed early in education (Hashim, 2018; Kuppusamy, 2020; Tilhou et al., 2020). Technology and education are one of the necessary elements of the system (Dzuranin et al., 2018; Grippa et al., 2018; Van de Oudeweetering & Voogt, 2018; Williams, 2019). Integrating practices and technologies that can impact the future development of education, namely: Augmented reality (AR) technology, student achievement analysis, machine learning/artificial intelligence to educational application, open education resources, and adaptive learning technology (Yan, 2021).

Virtual reality (VR) and AR are now widely open to all fields. VR and AR are not new technologies (Elmqaddem, 2019). AR (Garzón, 2021) and VR is an active area of research and education as a technology that enables educational and teaching-learning processes (Gudoniene & Rutkauskiene, 2019; K. T. Huang et al., 2019). While AR extends the current perception of reality, VR replaces the real world with a simulated world (Blazauskas & Gudoniene, 2020; Martin et al., 2018; Motejlek & Alpay, 2019). The use of AR and/or VR in education provide if AR and/or VR in education provides an immersive multimodal environment enhanced by multiple sensory traits, providing effective tools for enhancing learning and useful for helping [16] K-12 students (Zhou et al., 2020).

AR is a technology that can superimpose computer-generated virtual visualization output indirectly and/or directly on a real environment in real-time (Aggarwal & Singhal, 2019; Baker et al., 2020; Lee, 2012) and real-world (Y. Chen et al., 2019). Since then, there have been many approaches and various have been used to design the AR for educational purposes (Wu et al., 2013). Meanwhile, the simplest definition of VR is the replacement experiences of more than one physical with a virtual thrill (Coburn et al., 2017) or simulation environment (Nomura & Sawada, 1999). VR has existed since the

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1960s (Huang et al., 2015). VR has become one of the extensive technologies discussed all around fields in terms of applications, uses, various types, and can bring tremendous benefits in the real world (Saeed et al., 2017).

In the education field, some research show intercultural learning through the VR technology (Akdere et al., 2021); Immersed VR to virtual laboratory in subject of digital engineering (Khairudin et al., 2019); VR reinforces student learning hands-on activity and educates students about innovative learning models used in technology (Kustandi et al., 2020) and also fostering students' critical thinking skills through the VR laboratory (Ikhsan et al., 2020). While in the AR research, namely meta-Analysis to Education in 2018 (Hantono et al., 2018); Mapping of WOS (López-Belmonte et al., 2020); Trends in 2006 to 2016 (Altinpulluk, 2019). Not only education field, AR and also VR technology researches are widely abroad to field such as industry (Gattullo et al., 2019), tourism (Cranmer et al., 2020), health science and medical anatomy (Moro et al., 2017), dentistry (Huang et al., 2018), business (El-Seoud & Taj-Eddin, 2019) and also other fields. Based on the findings, many researchers identified on AR, and there are potential to future work (Hedberg et al., 2018).

Research publications on AR and VR are tend to increase every year. Therefore, it takes a research to find out how AR and VR are used in each area of research to find future novelty and research ideas. In addition, the use of AR and VR in the field of education also needs to be known to be an opportunity for research studies and learning innovations in the future. Previous researches are tend to immerging AR and VR in general learning process. In spite of this, researcher tend to conduct a bibliometric research to compare an AR and VR trends researches through Scopus over the past 20 years and the contribution of AR and VR to Physics learning to specify the previous researches.

Commented [MOU4]: araştırmacı özellikle fizik eğitimi alanında AR ve VR yayınlarının incelemesini neden yoğunlaştırmıştır? Bunun gerekçesi açıklanmalı.

Research Objectives

This research analyzes bibliometrics on 'AR' and 'VR' keywords as general fields and specify it to implement of AR and VR to Physics education and compare them. Scopus are used to collect the metadata and VOSViewer application will be an assist tool. This research is expected to compare trends, patterns, novelty, and future research in the AR and VR through all-round fields and in the Physics education field during the past twenty years (2002-2021). Specifically, the objectives of this research are as follows:

1. To compare trend research on the top 200 cited AR and VR publications in all fields during 2002-2021.
2. To analyze the comparison of the subject areas, countries, and top affiliation that have contributed to top 200 cited AR and VR publications in all fields during 2002-2021.
3. To identify the comparison of trend mapping visualization on AR and VR publications in Physics learning research during 2002-2021.
4. To identify the comparison of top 10 most productive author of the AR and VR in Physics learning research during 2002-2021.
5. To identify the comparison of top-cited author, subject areas and affiliation of the AR and VR in Physics learning research during 2002-2021.
6. To analyze the comparison of distribution of AR and VR publications in Physics learning research during 2002-2021.
7. To analyze the top 4 cited publications in AR and VR in Physics learning research during 2002-2021.

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Methods

This research is bibliometric research using descriptive analysis. This research used Scopus as a structured data-base to analyze the published data (Aria & Cuccurullo, 2017; Goli & Haghighinasab, 2022; Mongeon & Paul-Hus, 2016; Shubina et al., 2021; Thu et al., 2021). Scopus has become the largest database and has more than 77.8 million core records from different various of fields with various metadata and document types, either non-academic or academic field (Hernández et al., 2021; Nurdin et al., 2021; Pham-Duc et al., 2021; Pranckutė, 2021; Singh et al., 2021; Thu et al., 2021). Also, Scopus has loading of sources 70% greater than Web of Science (López-Illescas et al., 2008; Supriadi et al., 2021). Bibliometrics consists of four phases, namely: (1) defining a study design, (2) collecting data through the criteria, (3) data analysis, (4) interpreting and visualizing data (Lorenzo et al., 2022). In this research, two filtering were performed on data criteria. Finally, the process of this research to determine the use of AR and VR in general fields is as in **Figure 1**. Then, Researchers specify the keyword to know AR and VR impact or contribution to Physics learning as in **Figure 2** during the past twenty years.

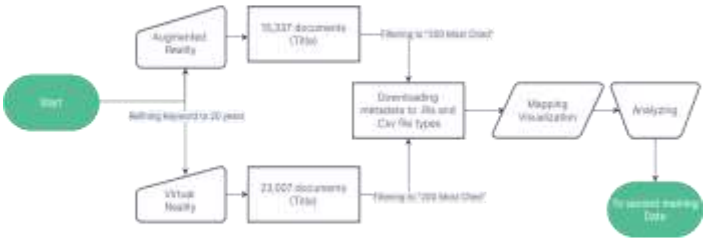

Figure 1. Research flowchart to the general keywords

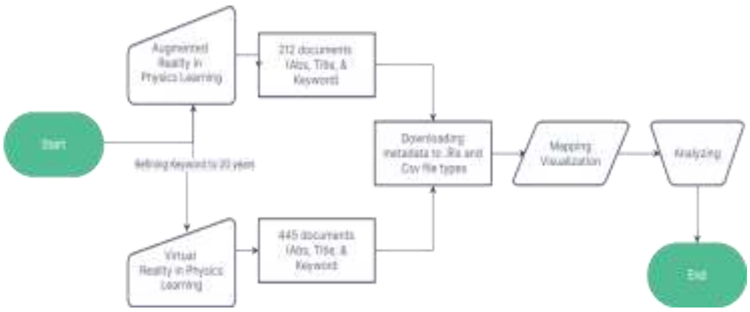

Figure 2. Research flowchart to the specify keywords

Data mining was collected on March 30, 2022. The results obtained are sorted by "number of citations" from high to low. Then, downloaded them in .csv and .ris file formats. After that, data was being uploaded to the VOSViewer software to show the details of the transcription of the data and visualize the bibliometric assignments (Jayadinata et al., 2021; Nandiyanto & Al Husaeni, 2021; van Eck & Waltman, 2010, 2017; Wong, 2018). For the final stage, data are analyzed descriptively to answer the research objectives.

Findings and Discussion

Comparison of Trend Research AR and VR in All Fields During 2002-2021

Based on metadata filtering and analysis, there are known annual trends in AR and VR publications in all research fields from 2002 to 2021. The trend shows the interest of researchers to research the subject of the study. On AR and VR in all fields from 2002 to 2021 it is depicted as in **Figure 3**.

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Commented [MOU7]: Bulgular ve tartışma bir arada verilmiştir. Bu durum araştırma bulgularının derinlemesine tartışılmasının önüne geçmiş gibi görünüyor. Araştırmanın bulgularının özellikle de fizik eğitimi açısından derinlemesine tartışılmaya ihtiyacı olduğu kanısındayım.

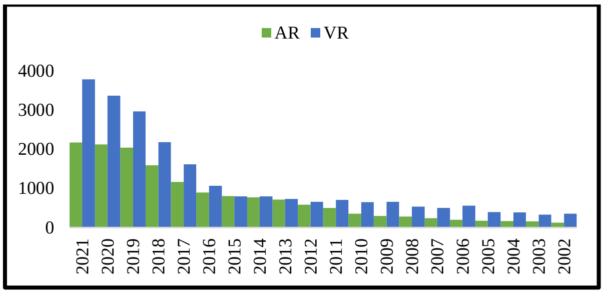

Figure 3. Comparison of AR and VR trend researches in all fields during 2002-2021

Based on **Figure 3**, research trends on both AR and VR in all fields during this past twenty years tend to increase each year (Cavalcanti et al., 2021; Ed & Hutchison, 2013; Papakostas et al., 2021). However, VR publications are more numerous than AR and this shows that interest in AR and VR continues to increase and becomes an interesting topic to be used as research material. And, it can be realized that AR and VR are an interesting trend every year with the increase in research trends every year from 2002 to 2021. The use of AR and VR integrase in various fields of work is indeed a hot topic discussed (Bottani & Vignali, 2019), especially in education science. This is because AR and VR are considered capable of becoming a learning medium that covers many aspects of learning, especially in 21st century learning (C. H. Chen et al., 2020; Elmqaddem, 2019; Sanabria & Arámburo-Lizárraga, 2017).

Then, after being analyzed using VosViewer, it can be known keywords that are often used in AR and VR publications from 2002 to 2021 in all fields. Keywords that are often used in AR and VR publications in all fields from 2002 to 2021 are as in **Figure 4.**

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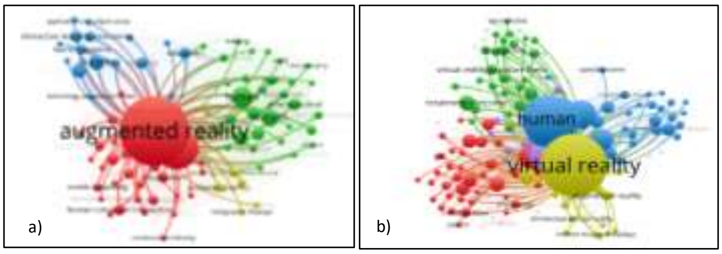

Figure. 4. a) Keywords that used in AR publications; b) Keywords that used in VR publications

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Figure 4 is a keyword that is widely used in AR and VR publications in all fields in the past twenty years. In AR, the most common keywords are 'Augmented Reality' (n=13,086), 'Virtual Reality' (n=3,908), 'Human' (n=1,182) and 'Mobile Augmented Reality' (n=1,011). While in VR publications, the most widely used keywords in publications are 'Virtual Reality' (19,483), 'Human' (n=5,368), 'Humans' (n=4,159) and 'Article' (n=3,534).

These keywords show a strong relationship between both AR and VR as immersive human and mobile AR. Moreover, the results point to increasing interest in research on the use VR in Humanee and article research. As in example research of Grandi et al., (2018) conducting the design of a handheld-based interface for collaborative manipulations of 3D objects in mobile AR as Human Centered Computing (HCC)-Interaction (HCI). Both of AR and VR keyword are related to each other, It is not surprising that managers find it hard to distinguish similar-sounding, IT-based concepts such as AR and VR (Farshid et al., 2018).

Comparison of Subject Areas, Countries, and Top Affiliation of Top 200 Cited AR and VR Publications in All Fields During 2002-2021

Table 1

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Comparison of AR and VR to top countries, subject areas and affiliation in all fields during these past twenty years

AR			VR		
Countries	**Subject Areas**	**Affiliation**	**Countries**	**Subject Areas**	**Affiliation**
United States	Computer Science	Technical University of Munich	United States	Computer Science	University of Southern California
Germany	Engineering	Technische Universitat Graz	China	Engineering	IRCCS Istituto Auxologico Italiano
China	Mathematics	University of South Australia	Germany	Medicine	CNRS Centre National de la Recherche Scientifique
South Korea	Social Sciences	Beijing Institute of Technology	United Kingdom	Social Sciences	Università Cattolica del Sacro Cuore
Japan	Medicine	National University of Singapore	Italy	Mathematics	Universitat de Barcelona

According to **Table 1**, it can be seen that the United States is the country with the most publications on AR (n=2,702) and VR (n=5,080), but for AR, the country with the second most publications is Germany (n=1,374), while VR is China (n=2,887). In subject areas, AR and VR have the same result again, namely the top subject areas owned by 'Computer Science' followed by 'Engineering', the difference is in the third top subject areas, namely for AR in 'Mathematics' (n = 2,417), while VR in 'Medicine' (n = 5,117). At top Affiliation, the Technical University of Munich is the top affiliate in AR, while the University of Southern California is the top affiliate in VR.

In line with previous bibliometric research on AR and also VR, United States has become the top countries in publications of AR and VR. This findings also shown that USA has become most influential country, based on the mount of publications through the twenty years. Meanwhile, the top subject areas are the specific areas of instruction in which courses are offered within academic organizations. Computer science, engineering, medicine and/or mathematics has become the top subject areas on AR and VR research. This finding shown that most AR and VR publications are related to techincal science in line with top affiliation in AR which is Tehcnical University of Munich (Germany) and assisting of an abstarct or imaginaning objects such as mathematics and formula of medicine.

The mapping of visualization of top countries in AR and VR publications from 2002 to 2021 can be described th in **Figure 5** and **Figure 6**. This results was generated with Datawrapper.

Figure. 5. Top Countries in AR publications during 2002 to 2021

Figure. 6. Top Countries in VR publications during 2002 to 2021

Based on **Table 1**, it can be analyzed that there has been no difference in the first order of top countries, subject areas, and affiliations in AR and VR publications in all fields over the past twenty years. **Figure 5** and **Figure 6** show that the top 3 countries in AR and VR publications are the United States, China and Germany. Other countries have an average of less than 100 publications, but indeed some countries have more than 500 publications and fewer than 1,000 publications during the span of 2002 to 2022. This findings are related to previous researches that found USA, China and Germany as most influential countries in publication of AR and VR in all fields (Garzón, 2021; Karakus et al., 2019).

Comparison of Trend Mapping Visualization of AR and VR in Physics Learning During 2002-2021

The most occurrence keywords are analyzed before mapping out the visualization of AR and VR in Physics Learning research during the past twenty years, as shown in **Table 2.**

Table 2

Top 15 keywords used in AR and VR to physics learning research during the past twenty years

AR			VR		
Keyword	**Total Link Strength**	**Occurrence**	**Keyword**	**Total Link Strength**	**Occurrence**
Augmented Reality	479	146	Virtual Reality	1,882	334
Students	257	55	E-Learning	848	139
Virtual Reality	129	31	Students	699	99
E-Learning	126	26	Education	609	80
Education Computing	110	20	Teaching	385	54
Education	103	22	Physics	320	45
Physics Learning	89	19	Engineering Education	302	44
Computer-Aided Instruction	87	17	Learning Systems	280	51
Engineering Education	86	17	Augmented Reality	251	52
Teaching	69	14	Human	237	23
Laboratories	63	13	Computer-Aided Instruction	229	35
Learning Systems	60	13	Humans	225	20
Learning Environments	58	11	Article	215	21
Physics Education	55	13	Learning	206	26
Augmented Reality Technology	45	11	Virtual Laboratories	204	27

From the **Table 2** it can be seen that the highest total link strength and the most frequently occurring keywords are "Augmented Reality" (n=479) to AR, and "Virtual Reality" (n=1,882) to VR. Hence, it is clear that for every keyword are related to AR and VR itself. The second order of the keyword are "Students" (n=257) to AR and "E-Learning" (n=848) to VR. Followed by "Virtual Reality" (n=129) to AR and "Students" (n=699) to VR. From Table 2, we can also conclude that AR is still related to VR keyword, and vice versa. Based on this pattern, it can be found that the trends of both AR and VR in Physics Learning research in the 2002-2021 are: 1) Related to Education; 2) Implementation of e-learning activities for students and teachers; 3) Technology integration in learning; 4) Computer-aided instruction; 5) Physics learning and education. Specifically, trends on AR can be Augmented reality technology, whereas VR can be Virtual laboratories.

Based on this finding, AR and VR are contributed to students and e-learning in physics learning. Emerging AR and VR to Phyiscs concepts are now widely open, since Physics is one of abstract and difficult subject (Zamil et al., 2021). The developement of student worksheet-AR based is very suitable to be used as a learning tool in physics practicum activities in Senior High School in 10th grade (Bakri et al., 2020). Integrating AR into physics classrooms can enhance students' physics learning self-efficacy, guide students to be more inclined to higher-level conceptions of learning physics and stimulates students' motivation to learn more deeply (Cai et al., 2021). Also, a review of problem-based AR made learning more meaningful (Wulandari et al., 2021). Technological innovations, such as augmented reality (AR), have the potential to fundamentally change education by making difficult concepts

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available and accessible to beginners (Church & Marasoiu, 2019). Meanwhile, VR technology provides a promising media for educational researchers (Budi et al., 2021). VR environment in terms of learners' perceptions and their conceptual learning in Physics learning increased (Georgiou et al., 2020; Tsivitanidou et al., 2021). , the use of virtual reality technology in the e-learning environment had a positive effect on students' (Abdüsselam & Erten, 2022; Rogers et al., 2017; Wiederhold et al., 2018; F. Yang & Wu, 2010).

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Therefore to find a novelty of the research based on the mapping results, we can look at the relationships between smaller keywords or fewer keywords. It is shown in **Figure 7**.

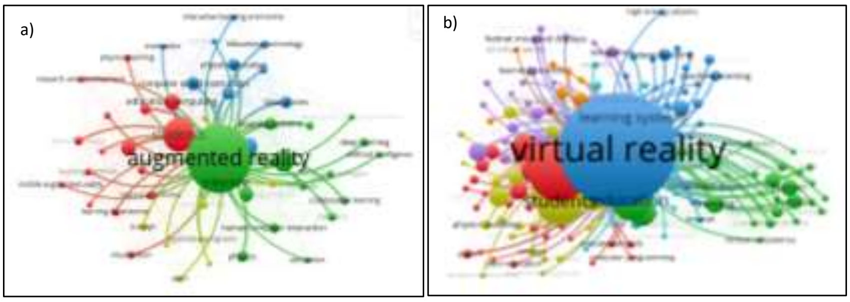

Figure. 7. Trends keywords mapping in Physics learning to a) AR; b) VR during 2002-2021

To find the novelty of previous research, the mapping of metadata keywords (X. Chen et al., 2021; Gamage et al., 2022; Goerlandt et al., 2021; Pournader et al., 2021). Comparison of visualizations of keyword co-occurrences in AR and also VR research in Physics learning during 2002-2021 are shown in **Figure 7.** This are analyzed to find the novelty and intterationship between these researches. **Figure 7** of mapping visualization are shown that there are 4 main clusters for AR, namely: 1) Cluster 1 with red nodes (n=16 items); 2) Cluster 2 with green nodes (n=15 items); 3) Cluster 3 with blue nodes (n=11 items); and 4) Cluster 4 with yellow nodes (n=10 items). Meanwhile, comparing to VR, there are 7 main clusters, namely: 1) Cluster 1 with red nodes (n=31 items); 2) Cluster 2 with green nodes (n=30 items); 3) Cluster 3 with blue nodes (n=28 items); 4) Cluster 4 with yellow nodes (25 items); 5) Cluster 5 with purple nodes (n=23 items); 6) Cluster 6 with turquoise (n=22 items); and 7) Cluster 7 with orange nodes (n=8 items). Some examples of specific keyword mapping visualization results on AR are AR, students, AR technology, simulation, deep learning and artificial intelligence. Also, for VR are VR, e-learning, students, stem, high energy physics, and computer sciences.

If future researchers want to explore AR and VR in Physics learning on top trends, there is still any chance to explore more about AR and VR in Physics learning research because the top of trends still have a wide range and various fields of terms. AR and VR in Physics learning can still improve and assist education in many aspects. Whereas, for fewer trends such as can be used as an alternative future research field, especially to investigate AR on simulation, deep learning and artificial intelligence. Meanwhile, there are still any chance for the VR for example stem, high energy physics and computer sciences.

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Comparison of Top 10 Most Productive Authors to AR and VR in Physics Learning Research

The metadata results on Scopus can show the author of the publication of AR and VR in Physics learning research in the past twenty years. **Table 3** shows the top 10 most productive authors on LMS research in the 2002-2021.

Table 3

The top 10 most productive authors

AR		VR	
Author	**Total**	**Author**	**Total**
Muliyati, D.	12	Parker, J.	6
Bakri, F.	11	Wasfy, T.M.	6
Kuhn, J.	7	Guetl, C.	5
Kapp, S.	6	Terzopoulos, D.	5
Thees, M.	6	Wasfy, H.M.	5

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Table 3 shown that**,** Muliyati, D. is the most prolific author with 12 publications in AR, followed by Bakri, F. who has 11 publications and Slater, M. became a third most productive author with 7 publications in total. Meanwhile, Parker, J. is the most prolific author with 6 publications in VR, followed by Wasfy, T.M. within 6 publications, and Guetl, C. with 5 publications in third place.

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Comparison of Top Cited Author, Subject Areas and Sources Titles of The AR and VR in Physics Learning Research

Table 4 shows top-cited authors, subject areas and affiliation to AR and VR in Physics learning research during the 2002-2021.

Table 4

Top research citations, subject areas and affiliation on AR and VR in Physics learning research during 2002-2021

AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
Potkonjak, V., et al.	Computer Science	Universitas Negeri Jakarta	Journal Of Physics Conference Series	Potkonjak, V., et al.	Computer Science	Technische Universitat Graz	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics
Enyedy, N., et al.	Social Sciences	Technische Universität Kaiserslautern	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	Lindgren, R., et al.	Engineering	Curtin University	ACM International Conference Proceeding Series
Cai, S., et al.	Physics and Astronomy	Institut Pendidikan Indonesia	Aip Conference Proceedings	Miles, H.C., et al.	Social Sciences	International Information	Journal Of Physics Conference Series

AR				VR			
Top Cited Author	**Top Subject Areas**	**Top Affiliation**	**Source Title**	**Top Cited Author**	**Top Subject Areas**	**Top Affiliation**	**Source Title**
						Technology University	
Saidin, N.F., et al.	Engineering	Harvard University	Ceur Workshop Proceedings	Chan, S., et al.	Mathematics	Advanced Science and Automation Corp.	Proceedings Of SPIE The International Society For Optical Engineering
Dünser, A., et al.	Mathematics	Indiana University Bloomington	ACM International Conference Proceeding Series	Saidin, N.F., et al.	Physics and Astronomy	The Ohio State University	ASEE Annual Conference And Exposition Conference Proceedings
Fidan, M., & Tuncel, M.	Materials Science	Beijing Normal University	Communications In Computer And Information Science	Dünser, A., et al.	Medicine	Instituto Superior de Engenharia do Porto	Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics

Based on top-cited authors in **Table 4**, in repectively AR and VR in Physics learning research are Potkonjak, V., et al. with the most citations. Top subject areas in both AR and VR Publications in Physics learning are Computer science with top affiliation respectively Universitas Negeri Jakarta and Technische Universitat Graz. Meanwhile for the top source title are Journal of Physics Conference Series and Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics.

In line with the top subject areas in all fields publications of AR and VR, the top subject areas in Physics learning are still Computer Science, social sciences and engineering. This findings still shown that AR and VR even in Phyics learning are tend to contribute in computer science subjects. In line with top author, the findings of metadata shown that Mulyati, D. and Bakri, F. with affiliation of Universitas Jakarta has publish a AR based development electric book (Permana et al., 2019), electromotive foce concept (Bakri et al., 2019b) and Lorentz force (Bakri et al., 2019a) in Journal of Physics Conference Series.

Comparison of Distribution of AR and VR Publications in Physics Learning Research

Table 5 shows the distribution of publications on AR and VR in Physics learning research over the past twenty years.

Table 5

Comparison of distribution AR and VR in Physics learning

Year	AR				VR					Citable Years
	Paper	Cited	ACPP	ACPPY	Paper	Cited	ACPP	ACPPY	Paper	
2002	0	0	0.00	0.00	3	0	0.00	0.00	3	20
2003	0	0	0.00	0.00	3	0	0.00	0.00	3	19
2004	0	0	0.00	0.00	4	14	0.00	0.00	4	18
2005	0	0	0.00	0.00	8	15	0.00	0.00	8	17
2006	2	45	22.50	1.41	11	23	2.09	0.13	11	16
2007	0	0	0.00	0.00	19	87	0.00	0.00	19	15
2008	2	18	9.00	0.64	16	50	3.13	0.22	16	14
2009	2	0	0.00	0.00	18	19	1.06	0.08	18	13
2010	6	51	8.50	0.71	23	103	4.48	0.37	23	12
2011	3	22	7.33	0.67	23	141	6.13	0.56	23	11
2012	6	234	39.00	3.90*	27	254	9.41	0.94	27	10
2013	3	55	18.33	2.04	16	140	8.75	0.97	16	9
2014	4	41	10.25	1.28	15	13	0.87	0.11	15	8
2015	8	193	24.13	3.45	14	118	8.43	1.20	14	7
2016	11	431*	39.18*	6.53	22	574*	26.09*	4.35*	22	6
2017	15	177	11.80	2.36	30	110	3.67	0.73	30	5
2018	21	155	7.38	1.85	26	57	2.19	0.55	26	4
2019	39	212	5.44	1.81	39	83	2.13	0.71	39	3
2020	40	217	5.43	2.71	60	68	1.13	0.57	60	2
2021	49*	68	1.39	1.39	68*	55	0.81	0.81	68*	1
Total	211	1919	209.65	30.74	445	1924	80.35	12.31	445	-

Description: *=the highest number
ACPPY= Average Citation Per Paper Per Year
ACPP= Average Citation Per Paper

Table 5 shown, in AR 2002-2005, and 2007 had no published documents. And 2021 became the year with the most publications. Furthermore, the years with the highest citation was in 2016 (4,310 citations) fewest citations were 2002-2005, and 2007 because they did not have published documents. Whereas, in VR, all years have publications, with most publications in the year of 2021. The highest citation was in 2016 (574 citations) and the fewest citation was in a year of 2002 and 2003**.**

Review of Top 4 Cited Publications on AR and VR in Physics Learning Research

Table 6 is a review of the top 4 publications cited as impactful studies on AR and VR in Physics learning research during the 2002-2021.

Table 6

Review of top 4 cited articles in AR and VR in Physics learning research

Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
				AR		
Enyedy N., et al. (Enyedy et al., 2012)	146	2.39 (Q1)	9.1	98th	LPP technology and activities to learn strength and mobility concepts at an earlier age than expected. Toddlers do not have to be limited to remembering scientific facts or unstructured searches just because they cannot design controlled experiments for research.	We will further discuss the depth of conceptual understanding that students develop through augmented reality and participatory modeling, and the role that these types of education can play. Building blocks for later learning concepts, and student modeling skills development.
Cai S., et al. (Cai et al., 2016)	91	0.92 (Q1)	5.1	93rd	AR-based motion detection software can improve student attitudes and learning outcomes. This research provides a discussion of the application of AR technology in secondary school physics education.	The stability of AR-based motion detection software may need to be improved.
Dunser et al. (Dünser et al., 2012)	76	0 (Not assigned yet)	-	80th	AR has the potential to become an important tool for teaching challenging 3D ideas.	Although the built-in interactions appear to be restricted, they currently enable for the creation of pretty strong effects for instructive books, such as shifting scenes or activating, halting, or modifying animations.
Fidan & Tunel (Fidan & Tuncel, 2019)	68	3.03 (Q1)	14.4	99th	AR technology has the potential to become an important and efficient tool for eliciting positive feelings in kids during the PBL process.	The combination of AR and PBL may be applied to other Physics subjects and try to explore in other STEAM fields.
Cai et al. (Cai et al., 2013)	49	0.55 (Q1)	14.4	99th	An embedded AR educational environment that combines reality and virtuality would considerably excite students' learning interests and increase their level of engagement, implying that	Although there is inadequate information to evaluate if the AR tools improved students' conceptual knowledge, they did present students with alternative chances for scientific learning.

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Author(s)	Citation	SJR	CiteScore (2020)	Percentile (to Education)	Findings	Recommendations
					this learning implementation has enormous potential in practice.	
			VR			
Yang, K. H., et al. (K. Y. Yang & Heh, 2007)	73	1.03 (Q1)	4.3	90th	The IVPL had capability to assist 10th graders enhance their physics instructional fulfillment and technology system skills	Further research needs to address the fundamental implications of the each online interactive learning behavior and online learning process in order to improve human learning as soon as possible.
Aloetti, J., et al. (Aleotti & Caselli, 2011)	35	0.89 (Q1)	7.5	86th to Computer Graphics and Computer-Aided Designs	Inference at the physical level allows learning systems to discover task similarities across multiple demonstrations.	Optimization based on priority relation and geometric clustering has been proposed.
McGrath et al. (McGrath et al., 2010)	29	0.54 (Q2)	1.5	38th to General Physics and Astronomy	Students regarded the VR simulation in Physics' special relativity course to be a favorable learning experience, and they described the subject area as less abstract after using it.	Exploring at additional disciplines where a visual approach might help students learn, and we've started working on a simulation of quantum physics ideas.
Vrellis et al. (Vrellis et al., 2010)	24	0 (Not assigned yet)	-	97th	Multi-user virtual environments show that satisfying, engaging, and productive collaborative learning activities may be implemented in second life.	Improvement of non-verbal capability using real-time motion capture in order to improve social presence and cooperation efficiency throughout participants.
(Greenwald et al., 2018)	19	0.28 (Q2)	2.0	54th (General Computer Science)	The VR learning benefit exhibited here may be the top of a very vast iceberg, one that others indicated in the Related Research have also begun to find.	Advancing such information and norms further is undoubtedly a lucrative and intriguing subject.

On the **Table 6**, Each article was analyzed based on the citation, Scimago Journal and Country Rank (SJR) accessed on www.scimagojr.com (Ianoş & Petrişor, 2020; Kasper, 2021; Sun, 2019; Torres-Samuel et al., 2018), CiteScore accessed on www.scopus.com (per April 2, 2022), also findings and recommendations in the publication. The review and analyze results in the top 4 cited publications on the **Table 6** tend to examine the effect and comparison of AR and VR in physics learning: The use of AR or VR can be integrated in the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability. These publications become fundamental for future research, so they have great citations and impact in AR and VR in development of Physics learning subjects. Based on data taken as of April 2, 2022, most of the top 10 cited publications are listed in the rank journal Quartile 1 (Q1) has CiteScore 9.1 and percentile 98th to Education for AR in Physics learning research and VR has Quartile 1 (Q1) and CiteScore 4.3 and 90th to Education. This shows that, publications that become top 10 cited are publications with undoubted credibility. Because, the publisher of the publication has a good reputation. Analysis from SJR, indicator assigns a different score to citations based on the importance of the citation source journal. Hence, citations from influential journals will be more valuable and the journals receiving them will gain more fame (Stephen, 2020).

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Conclusion and Implications

This research is the first who conduct a review and analysis of bibliometrics compared to AR and VR in general fields and in Physics learning during the past twenty years from 2002 to 2021. This subject has become one of the research fields that has undergone significant development and improvement and technological development and its contribution to education, especially to Physics learning impact. Finally, this research has seven conclusions: 1) The trend research in AR and VR to all fields are tent increase each years; 2) Both of AR and VR research has United States as top countries in publications and Computers Science as subject areas, meanwhile AR has Technical University of Munich for top affiliation and VR has University of Southern Californias as top affiliation; 3) Top keyword that used in AR and VR to Physics learning are 'AR' and 'VR', with total link strength are respectively 479 and 1,882; 4) The top most productive authors to AR and VR in Physics learning research are Muliyati, D for AR and Pirker, J. for VR with total 12 and 6 documents each; 5) Top cited authors, in repectively AR and VR in Physics learning research are Potkonjak, V., et al. with the most citations; 6) The distribution of Publications on AR and VR in Physics learning publications has 2016 as highest citation and 2021 as the most publications, for the fewest years citation are 200-2005 and 2007 because they did not have published documents for AR. Whereas, for VR, the highest citation was in 2016 with 574 citations and the fewest citations were in 2002 and 2003; 7) The use of AR or VR can be integrated in the classroom from toddler to secondary school. Implications of the review of the top 10 cited publications require more improvement and optimization of AR and VR stability.

The implication of this research are tend to find a research novelties to AR and VR research, trend and contribution to Phyiscs learning during twenty years (2002-2021) through the results of mapping, visualization patterns and also literature review. Future researchers are expected to define a profile with other metadata such as Google Scholar,WebScience and/or also combine them. The researchers can find the topics most relevant to Physics learning and the authors who have had the greatest impact, and identify the main research lines of scientists in each defined period. Therefore, it also helps to narrow down the next trends that can be developed in this fields of research especially in Physics learning or Physics education field.

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Workflow Publication

Submission Review Copyediting Production

Round 1 Round 2

Journal of Turkish Science Education

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Notifications

[tused] Editor Decision	2022-09-15 11:45 AM
[tused] Editor Decision	2022-10-20 07:07 AM
[tused] Editor Decision	2022-12-30 12:18 PM

Reviewer's Attachments Search

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Revisions Search Upload File

7145	2 Revision 17-9-22-Prahani et al TUSED.docx	September 17, 2022	Article Text
7146	2 Changes made on Manuscript 17-9-22-Prahani et al TUSED.doc	September 17, 2022	Other

Review Discussions Add discussion

Name	From	Last Reply	Replies	Closed
About Article	uormanci 2022-09-15 11:45 AM	binarkurniaprahani 2022-09-17 09:04 AM	1	

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Round 2 Status
Submission accepted.

Notifications

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7752 6. Revision 21-12-22-Prahani et al TUSED_Oregda Organizasyon Eğitim ve Danışmanlık.docx	December 21, 2022	Article Text

Review Discussions

Add discussion

Name	From	Last Reply	Replies	Closed
About Article	uormanci 2022-09-15 11:45 AM	binarkurniaprahani 2022-09-17 09:04 AM	1	

Binar Kurnia Prahani <binarprahani@unesa.ac.id>

[tused] Editor Decision

1 message

Ümmühan Ormancı <ummuhan45@gmail.com> Thu, Oct 20, 2022 at 2:07 PM
To: "Dr, Binar Kurnia Prahani" <binarprahani@unesa.ac.id>, Hanandita Veda Saphira <hanandita.19049@mhs.unesa.ac.id>, Firmanul Catur Wibowo <firmanulwibowo@ia-education.com>, Misbah Misbah <misbah@ia-education.com>, Nurul Fitriyah Sulaeman <nurulfitriyahsulaeman@ia-education.com>

Dr, Binar Kurnia Prahani, Hanandita Veda Saphira, Firmanul Catur Wibowo, Misbah Misbah, Nurul Fitriyah Sulaeman:

We have reached a decision regarding your submission to Journal of Turkish Science Education, "Virtual & Augmented Reality in Physics Learning: Research, Trend, and Contribution in the 20 Last Years ".

Our decision is to: Accept Submission

Reviewer A:

The authors have done almost all the requirements by reviewers. It should accept for publication.

Recommendation: Accept Submission

Journal of Turkish Science Education

2 attachments

B-2 Revision 17-9-22-Prahani et al TUSED.docx
2520K

B-2 Changes made on Manuscript 17-9-22-Prahani et al TUSED.doc
69K

Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Proof reading and editing services- TUSED Special Issue

18 messages

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Wed, Jun 30, 2021 at 2:03 AM
To: binarprahani@unesa.ac.id

Dear Dr. Prahani;

The proofreading and editing service for TUSED Special Issue in OrEgDa takes about three weeks after the coming fee.

Your article's fee: 300 Dollars

If this is suitable for you, we continue the process.

Sincerely,
OrEgDa Team.

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Wed, Jun 30, 2021 at 3:55 AM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Yes, please proceed.
[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Wed, Jun 30, 2021 at 4:01 AM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Author,

You can send the fee as Eft. Bank charges belong to the sender. The required information is as follows:

The name of the bank: Halk Bank
Branch name: 745 Buca/ İzmir
Account holder: Sevinc Kacar
Account number: 23002109
Iban number: TR03 0001 2009 7450 0023 0021 09
SWIT Code: TRHBTR2A
Account Holder Street Adress and City: 2040 street No:7 Pamukkale DENIZLI
Banka Adress: Uğur Mumcu Street, 85/A, 35390 Buca /İzmir

Sincereley,
OrEgDa Team

Binar Kurnia Prahani <binarprahani@unesa.ac.id>, 29 Haz 2021 Sal, 23:55 tarihinde şunu yazdı:
[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Wed, Jun 30, 2021 at 5:13 AM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Dear OrEgDa Team

Meybe by Paypal?
[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Wed, Jun 30, 2021 at 4:15 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Paypal is not suitable for us. But you can send Western Union. SİIncerely

Binar Kurnia Prahani <binarprahani@unesa.ac.id>, 30 Haz 2021 Çar, 01:13 tarihinde şunu yazdı:
[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Fri, Aug 6, 2021 at 4:31 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Dr. Prahani,

Can we get information about your process? We still have not received the fee. We are waiting for the fee to continue the process. Best regards

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>, 30 Haz 2021 Çar, 12:15 tarihinde şunu yazdı:
[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Tue, Aug 17, 2021 at 8:27 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Dr. Prahani,

Can you give information about your process?

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>, 6 Ağu 2021 Cum, 12:31 tarihinde şunu yazdı:
[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Fri, Aug 20, 2021 at 12:59 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Dear Oregda Organizasyon Eğitim ve Danışmanlık

We are very sorry, we are unable to transfer to the bank due to the effects of the Covid-19 restrictions in our area.
If there is a pay pal we will transfer it immediately.
However, if you have to transfer to an account through a bank, it will be August 24, 2021.
Thank you very much

Best Regards,

Dr. Binar Kurnia Prahani
Universitas Negeri Surabaya

[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Fri, Aug 20, 2021 at 1:01 PM

To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>
Cc: AYŞEGÜL SAĞLAM ARSLAN <asaglam-arslan@trabzon.edu.tr>

Dear Oregda Organizasyon Eğitim ve Danışmanlık

We are very sorry, we are unable to transfer to the bank due to the effects of the Covid-19 restrictions in our area.
If there is a pay pal we will transfer it immediately.
However, if you have to transfer to an account through a bank, it will be August 24, 2021.
Thank you very much

Best Regards,

Dr. Binar Kurnia Prahani
Universitas Negeri Surabaya

[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Fri, Aug 20, 2021 at 5:12 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Dr. Prahani,

Paypal is not valid in our country. However, you can use Western Union if you wish.

Since the articles will be published in August, the process must be completed urgently. Accordingly, a decision will be made about your article. We are waiting for your reply.

Best regards

Virüs bulunmuyor. www.avg.com

Binar Kurnia Prahani <binarprahani@unesa.ac.id>, 20 Ağu 2021 Cum, 09:01 tarihinde şunu yazdı:
[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Fri, Aug 20, 2021 at 5:54 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

OK

August 24, 2021 will be done

[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Mon, Aug 23, 2021 at 6:07 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Dr. Prahani,

Since a special issue will be published in August, can you give us some information about what you will do? If the payment cannot be completed within two to three days, unfortunately, your article will not be received for the duration.
Yours truly

Binar Kurnia Prahani <binarprahani@unesa.ac.id>, 20 Ağu 2021 Cum, 12:54 tarihinde şunu yazdı:
[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Mon, Aug 23, 2021 at 5:16 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Dear Oregda Organizasyon

August 24, 2021 we will transferred via bank. We apologize for thw inconvenience due to the impact of Covid-19 in our area.

Best Regards

Binar Kurnia Prahani
[Quoted text hidden]
[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Tue, Aug 24, 2021 at 2:20 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Dear Oregda Organizasyon Eğitim ve Danışmanlık

We have paid 300 USD. The bank confirmed that 3 days will arrive in the account (Sevinc Kacar).
Thank you for the opportunity.

Best Regards,

Binar Kurnia Prahani
Universitas Negeri Surabaya

[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Tue, Aug 24, 2021 at 2:21 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Dear Oregda Organizasyon Eğitim ve Danışmanlık

We have paid 300 USD. The bank confirmed that 3 days will arrive in the account (Sevinc Kacar).
Thank you for the opportunity.

Best Regards,

Binar Kurnia Prahani
Universitas Negeri Surabaya

Best Regards,

Binar Kurnia Prahani
Universitas Negeri Surabaya

IJORER : International Journal of Recent Educational Research : https://journal.ia-education.com/index.php/ijorer

[Quoted text hidden]

Payment Proofread Tused_Binar Kurnia Prahani.pdf
410K

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Mon, Dec 12, 2022 at 6:30 AM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>, Ümmühan Ormancı <ummuhan45@gmail.com>

Dear Oregda Organizasyon Eğitim ve Danışmanlık

We have paid 300 USD in August 2022. Is our paper finished? We hope it will be published in TUSED.
[Quoted text hidden]

Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com> Tue, Dec 20, 2022 at 5:54 PM
To: Binar Kurnia Prahani <binarprahani@unesa.ac.id>

Dear Author;

The final version of your article is below. Thank you for choosing us.

Sincerely

Binar Kurnia Prahani <binarprahani@unesa.ac.id>, 12 Ara 2022 Pzt, 02:30 tarihinde şunu yazdı:
[Quoted text hidden]

5. Revision 20-10-22-Prahani et al TUSED (1).docx
2543K

Binar Kurnia Prahani <binarprahani@unesa.ac.id> Wed, Dec 21, 2022 at 3:58 PM
To: Oregda Organizasyon Eğitim ve Danışmanlık <oregda@gmail.com>

Thank you very much

Best Regards,
Binar Kurnia Prahani
Universitas Negeri Surabaya

[Quoted text hidden]

Binar Kurnia Prahani <binarprahani@unesa.ac.id>

[tused] New notification from Journal of Turkish Science Education

1 message

Ümmühan Ormancı <ummuhan45@gmail.com> Wed, Dec 21, 2022 at 6:29 PM
Reply-To: Salih Çepni <editortused@gmail.com>
To: "Dr, Binar Kurnia Prahani" <binarprahani@unesa.ac.id>

You have a new notification from Journal of Turkish Science Education:

You have been added to a discussion titled "About Article - Format" regarding the submission "Virtual & Augmented Reality in Physics Learning: Research, Trend, and Contribution in the 20 Last Years ".

Link: https://www.tused.org/index.php/tused/authorDashboard/submission/2078

Salih Çepni

Journal of Turkish Science Education