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Bibliometric analysis of peer-reviewed literature on augmented reality with an emphasis on education versus physics education

Nadi Suprapto *, Universitas Negeri Surabaya, Physics Department, Jalan Ketintang, Surabaya 60231, Indonesia, https://orcid.org/0000-0002-8990-7412

Binar Kurnia Prahani, Universitas Negeri Surabaya, Physics Department, Jalan Ketintang, Surabaya 60231, Indonesia, https://orcid.org/0000-0002-5606-6629

Utama Alan Deta, Universitas Negeri Surabaya, Physics Department, Jalan Ketintang, Surabaya 60231, Indonesia, https://orcid.org/0000-0002-2881-7843

Iqbal Ainur Rizki, Universitas Negeri Surabaya, Physics Department, Jalan Ketintang, Surabaya 60231, Indonesia, https://orcid.org/0000-0001-8618-5592

Fauzi Bakri, Universitas Negeri Jakarta, Physics Department, Jalan Rawamangun Muka No. 1, Jakarta 13220, Indonesia, https://orcid.org/0000-0002-5734-4782

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Abstract

Analysing peer-reviewed literature on augmented reality (AR) is vital for future research and development. The objective of the current study was to assess research activity on AR with an emphasis on education and physics education. A bibliometric method was applied using SciVerse Scopus. The study period was from 1978 to 2021. The search query found 3,393 documents in the AR-related education literature and 97 in the AR-related physics education literature. The bibliometric analysis result shows that the similarity of the results of the visualisation of AR in education networks with AR in physics education is that research focuses on students, and the majority is integrated with virtual reality. This research has implications for providing insight to the next researcher in finding gap research and novelty in the field of AR in education and physics education.

Keywords: Augmented Reality; Bibliometric; Education; Physics Education.

* ADDRESS FOR CORRESPONDENCE: Nadi Suprapto, Universitas Negeri Surabaya, Surabaya, Indonesia
E-mail address: nadisuprapto@unesa.ac.id / Tel.: +6281 332 334 242

1. An overview of Augmented Reality (AR) technology

Augmented reality, or AR technology, sounds like a future term, meaning it does not apply in everyday life. In fact, people are competing to develop technology. So do not be surprised if we live in the AR era as it is today. AR is a technology that achieves real-time integration of digital computer-generated content with the real world (Bicen & Bal, 2016; Chen et al., 2019). AR allows users to see 2D or 3D virtual objects projected onto the real world. So, in essence, AR is a technology that can insert information into the virtual world and display it in the real world with the help of computer webcams, cameras and even special glasses. AR can be displayed on various devices, such as mobile phones, cameras, screens, webcams and special glasses. These devices will function as output devices. It will display information in the form of images, videos, animations and 3D models that need to be used.

Users can see the results in both artificial and natural light. AR uses simultaneous localisation and mapping technology, sensors and depth meters. For example, collecting sensor data to determine a location and calculating the distance from the previous location to the destination location. Additionally, AR has several types and methods depending on the application. The first is marker-based AR (Digital Promise, 2022). Some people call it image recognition because this type requires a special visual object and a camera to scan it. Visual objects can take any form, from printed QR codes to special symbols. This AR device also calculates the position and orientation of the marker to position the content. That way, the marker will display a digital animation that the user can see.

The second is markerless AR (Digital Promise, 2022; Sonia Schechter, 2014). This type makes AR widely used. Markerless AR uses GPS technology, a speed meter, a digital compass and an accelerometer built into the device to provide data based on your location. The markerless AR technology found on your smartphone device has the availability of a location detection feature. This type is commonly used for mapping directions and other location-based mobile applications.

The third is projection-based AR (Digital Promise, 2022). It works by projecting artificial light onto an entire surface. In some cases, it allows the user to interact with it. It is like the holograms we see in sci-fi movies like Star Wars. AR can detect the interaction between the user and the projection through its changes. The last is superimposition-based AR. It can replace the original appearance with an augmented one, either fully or partially. This is where object recognition plays an important role.

Furthermore, the following are the categories of devices that support AR (Sonia Schechter, 2014): (1) mobile devices (smartphones and tablets) is the most widely used and suitable for AR mobile apps that start from business, sports, games and social networking. (2) Special AR devices are specifically designed for better AR experiences. An example is the head-up display, which sends data with a transparent display to a view that the user can accept. (3) AR glasses – we must have heard of this one device. It is like Google Glass, Laster See-Thru and Meta 2 Glasses. This device can display notifications from our smartphones. (4) Virtual retinal displays – these produce an image with a laser beam into the human eye. It aimed to display a bright image (high contrast) and high resolution. This system is still being built for trial use. AR can be applied to various fields, such as social media, games, medical, broadcasts or movies. Games that use the AR concept are Harry Potter, Jurassic Park and Pokemon Go.

One of the AR features that we often use on social media is Instagram. Almost everyone can use filters because of the availability of several interesting and entertaining filters, of course. These filters are created using AR as a 3D object and also use a touch of Artificial Intelligence (AI) technology as the logic. In addition, AR is often used for medical training (Dhar et al., 2021) in the form of both applications and other operating equipment. Medical students use AR headsets to learn the intricacies of anatomy. Meanwhile, visual AR is common on our television screens from weather broadcasts to sporting events.

If we often find quality events in terms of visual objects, then that is the use of AR technology. One example of a film that uses AR is Star Wars.

2. Research on AR

Since Milgram and Kishino (1994) defined 'Milgram's Reality-Virtuality Continuum, research on AR broadly developed'. Accordingly, AR is closer to the real situation, while augmented virtuality is closer to the virtual environment (Carmigniani et al., 2011). Several authors have conducted research on AR in the world. Researchers from Asia dominated in this area. The following are the samples of researchers from Malaysia (Majid & Salam, 2021; Omar et al., 2019), Thailand (Nasongkhla et al., 2019; Nuanmeesri, 2018; Techakosit & Nilsook, 2016), Indonesia (Muali et al., 2020; Suprapto et al., 2020a, 2021a) and China (Chen et al., 2019; Sun et al., 2019; Zhao, 2018). Meanwhile, there are also some researchers from Kazakhstan (Nurbekova & Baigusheva, 2020), Middle East (Aldalalah et al., 2019; Alkhattabi, 2017), Turkey (Karagozlu et al., 2019; Tezer et al., 2019), Australia (Dey et al., 2018; Smith et al., 2016), Europe (López Belmonte et al., 2020; Troyanskaya et al., 2021) and African (Eldokhny & Drwish, 2021; Elmqaddem, 2019). Indeed, the *International Journal of Emerging Technologies* in learning (a journal that focuses on the exchange of relevant trends and research results of technology-enhanced learning) found 45 articles of this topic until May 2022. Among research of AR in the education domain, some of them emphasised physics education. Specifically, research on AR in physics education has been conducted by some authors (Bakri et al., 2020; Daineko et al., 2022; Gopalan et al., 2020; Muali et al., 2020; Suprapto et al., 2020a). The use of AR in physics education has a very important role because many physics materials are microscopic so that students often experience misconceptions, such as electromagnetism (Bestiantono et al., 2019), thermodynamics (Foroushani, 2018), light and optics (Widiyatmoko & Shimizu, 2019) and modern physics (Halim et al., 2021). Therefore, it is substantial to explore more the use of AR in both education and physics education.

3. Research Objectives

This research reviews the research trends of AR with an emphasis on education and physics education. The research's main objective is to analyse the trends of AR related to education and physics education research from beginning to 2021. The following specific objectives are discussed:

1. To illustrate the year-wise distribution of documents in AR related to education and physics education.
2. To classify the language used in AR related to education and physics education.
3. To identify the sources publishing of documents in AR related to education and physics education.
4. To illustrate the authorship pattern and prolific author of documents in AR related to education and physics education.
5. To identify the country of origin of the papers, affiliations and collaboration among them.
6. To analyse the co-occurrence keywords in AR related to education and physics education.
7. To identify the top citations of the documents in AR related to education and physics education.
8. To analyse the network and overlay visualisation of research in AR related to education and physics education.

4. Theoretical Framework

The theoretical framework underlies AR's use in education and physics education is content/material, technology, teachers and students and learning theory, as shown in Figure 1. A AR mobile application that enables students to view the provided augmentations is more likely to be used in educational content, given the use of AR, than a traditional online learning platform (Kazanidis et al., 2021). In physics, not all material can be augmented and must be adapted to its needs. It is recommended for materials that are easy to practice directly, such as kinematics, dynamics, torque and equilibrium are not required augmentations, but materials of an abstract and microscopic nature, such as electromagnetism, thermodynamics and modern physics need augmentation. The media type of the provided augmentation (e.g., text, link, video, image, sound and 3D object) is related to the AR visualisation, which can also serve as a leading indicator for the quality level of the AR content. The technology aspect has a crucial role because this aspect is the main aspect in making media for AR (Bourhim & Akhiate, 2022). This media can be created using the Software Development Kit, such as Vuforia, Wikitude, ARKit, ARCore and ARToolkit. Meanwhile, the teacher and student aspect is the subject of AR users in education, so the two interact directly in the use of AR in learning (Cabero-Almenara et al., 2019). In addition, the development of AR also requires a theoretical foundation of learning, such as the multi-representation theory, the constructivism theory, experiential learning and the dual coding theory so that the creation of AR can be theoretically rational (Arends, 2011; Kolb, 2014).

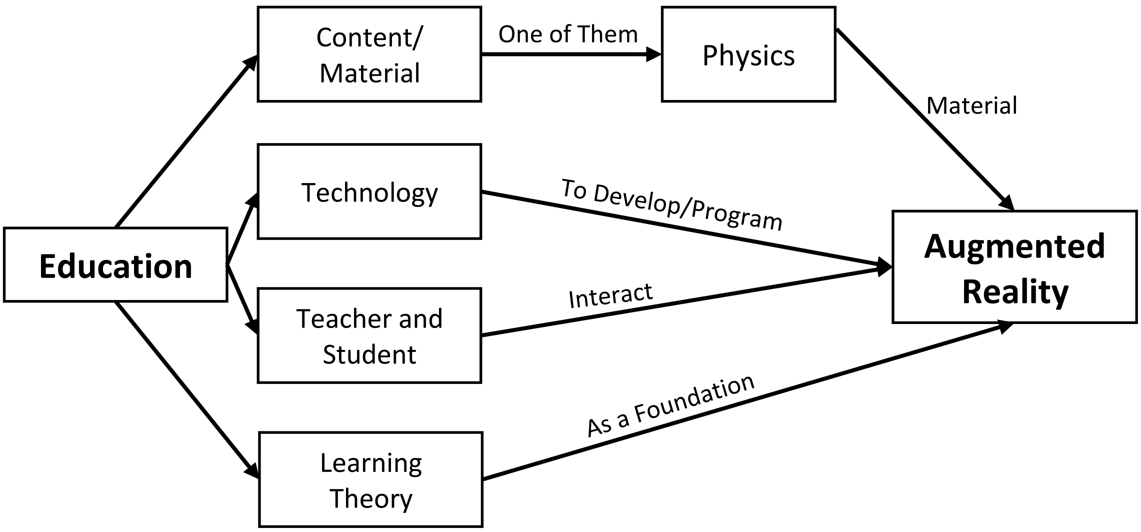

Figure 1. Theoretical Framework of AR in Education and Physics Education

5. Methodology

5.1. Database

The research adopted the bibliometric method (Nurhasan et al., 2022; Suprapto et al., 2021b, 2021c, 2021d; Yanuarti & Suprapto, 2021; Zakhiyah et al., 2021). The first step in this method is to decide on the appropriate database. The *SciVerse* Scopus was used to accomplish the study's objective because 'it is larger than the Web of Science and the data export from Scopus to other programmes is easy to perform' (Zakhiyah et al., 2021).

5.2. Research Process and Metadata Collection

In the current study, the authors reviewed many articles published as 'systematic reviews' or 'bibliometric method' to build a search query for AR in education and physics education. The keywords used and included are shown in Figure 2. 'Validation of the search queries was based on two approaches' (Nurhasan et al., 2022; Suprapto et al., 2021b). In the first approach, all documents in AR literature were reviewed to make sure that they fit within the target of the study. This approach was adopted to eliminate false-positive results by excluding irrelevant documents focusing on AR in education versus physics education. The second approach was based on comparing the actual number of articles for each author and journal targeted, obtained from the author's personal Scopus profile.

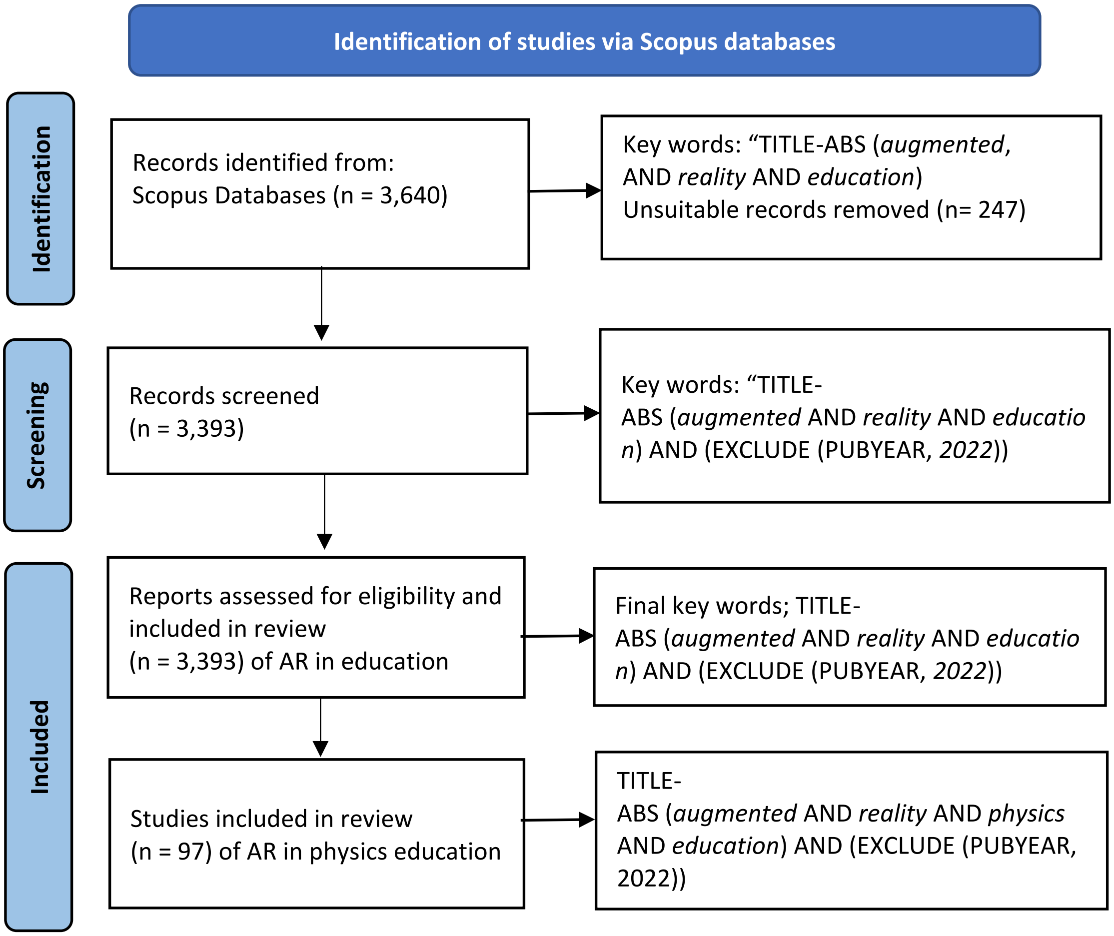

Figure 2. PRISMA Flow Diagram for Research Process and Metadata Collection (adapted from Suprapto, Prahani, et al., 2021)

5.3. Data Analysis

Data in the retrieved literature were exported to Microsoft Excel. The exported data included 'the annual growth of publications, types of documents, languages, countries, authors, institutions and citations' (Suprapto et al., 2021b, 2021d; Zakhiyah et al., 2021). The retrieved literature was also exported to VOSviewer programme (van Eck & Waltman, 2010) to create network visualisation maps. The strength of international research collaboration was presented as Total Link Strength, which

VOSviewer automatically gives upon mapping the research activity of selected countries (Sweileh, 2020).

6. Results and Discussion

6.1. The year-wise distribution of documents in AR

Figure 3 shows the number of documents on AR in the education and physics education domain from the Scopus database. Basically, the trends of document growth of both are identical. However, the use of AR in physics education has experienced fluctuations, especially from 2010 to 2016. On the other hand, starting from 2016, the number of documents on AR in education increased significantly. Meanwhile, AR in physics education started to increase rapidly in 2018. In the era of COVID-19, the use of AR in both education and physics education is still prospective. Detailed information of document growth is illustrated in Appendix A.

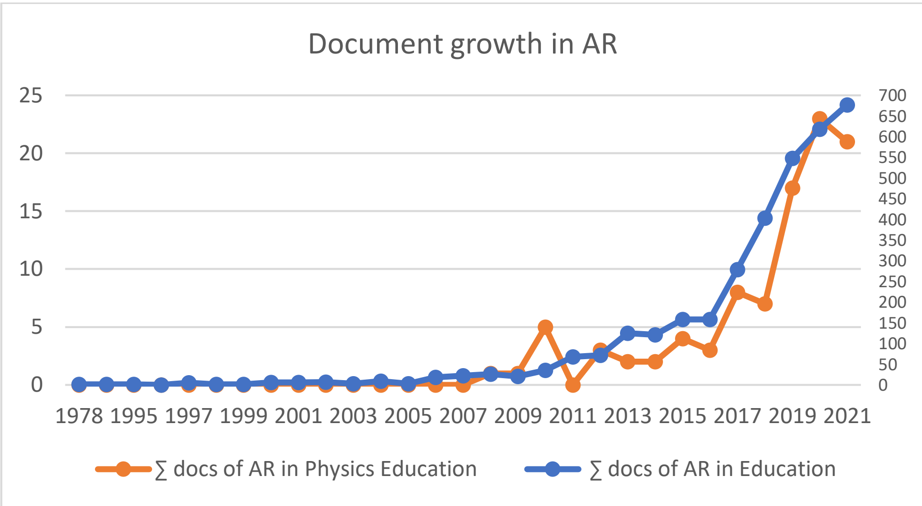

Figure 3. The Year-Wise Distribution of Documents in AR in Education Versus Physics Education

6.2. Language Used in augmented reality research

In terms of language used in the article, the whole and after filtering is shown in Table 1. English is the most widely spoken language because it can increase the reach of article publications. Furthermore, as the *lingua franca* of science, English is the language most capable of crossing national boundaries and increasing the impact of research. Furthermore, publications in international mainstream journals fulfil one of the most important requirements for research assessment (López-Navarro et al., 2015). Currently, publication in so-called mainstream journals (primarily those published in English) is the primary criterion used by most evaluation agencies to assess research productivity and performance, but this comes at the expense of having to compete for a place in a select minority of crowded journals, to the detriment of local communication (Salager-Meyer, 2014). Some other languages with fewer appearances are Spanish (77), Portuguese (27), Chinese (13), German (13), Turkish (9), Russian (6), French (4), Dutch (2) and Hungarian (2). Meanwhile, in the search results that have been filtered, the only languages are Chinese and Portuguese.

Table 1. Language Used in AR in Education and Physics Education

AR in Education			**AR in Physics Education**		
Language	**∑ docs**	**Percentage (%)**	**Language**	**∑ docs**	**Percentage (%)**
English	3246	95.66	English	95	97.93
Spanish	77	2.26	Chinese	1	1.03
Portuguese	27	0.79	Portuguese	1	1.03
Chinese	13	0.38			
German	13	0.38			
Turkish	9	0.26			
Others	14	0.38			
Total	3393	100%	Total	97	100%

6.3. The sources publishing documents in AR

Table 2 shows that the most prolific subject area in AR is the types of conference paper documents (1668), followed by article 1058), conference review (273), book chapter (200), review (147), book (17), editorial (9), note (9), erratum (5), letter (4), short survey (2) and 1 type of undefined document. Then, after filtering, the remaining documents are conference paper (60), article (21), conference review (13), book chapter (2) and note (1).

Table 2. Type of AR documents

Type of documents	**AR in Education**		**AR in Physics Education**	
	∑ docs	**Percentage (%)**	**∑ docs**	**Percentage (%)**
Conference Paper	1,668	49.16	60	61.85
Article	1,058	31.18	21	21.64
Conference Review	273	8.04	13	13.40
Book Chapter	200	5.89	2	2.06
Review	147	4.33	0	0
Book	17	0.50	0	0
Editorial	9	0.26	0	0
Note	9	0.26	1	1.03
Others	12	0.32	0	0
Total	**3,393**	**100%**	**97**	**100%**

Table 3 shows that the top subject areas for AR in education research are Computer Science (2,166), Social Sciences (1,092), Engineering (1,032), Mathematics (451) and Medicine (264). As for the top subject areas for AR research in physics education are Computer Science (57), Social Sciences (28), Physics and Astronomy (27), Engineering (23) and Mathematics (9). Based on this data, it is clear that computer science and social science are the top subjects because AR is included in the realm of computer science, while education becomes the realm of social science (Bennett et al., 2017; Buchner & Kerres, 2021).

Table 3. Prolific subject area in AR in education and physics education

Top Subject Area	**AR in Education**		**AR in Physics Education**	
	∑ docs	***Percentage (%)**	**∑ docs**	***Percentage (%)**
Computer Science	2,166	37.39	57	36.08
Social Sciences	1,092	18.85	28	17.72
Engineering	1,032	17.81	23	14.56

Top Subject Area	**AR in Education**		**AR in Physics Education**	
	∑ docs	***Percentage (%)**	**∑ docs**	***Percentage (%)**
Mathematics	451	7.79	9	5.70
Medicine	264	4.56	0	0.00
Physics & Astronomy	215	3.71	27	17.09
Decision Sciences	202	3.49	2	1.27
Bus. Manag. & Accounting	139	2.40	0	0.00
Materials Science	99	1.71	5	3.16
Environmental Science	94	1.62	3	1.90
Earth & Planetary Sciences	39	0.67	2	1.27
Chemical Engineering	0	0.00	2	1.27

*Note: * It is possible for an article to belong to more than one subject area.*

'Lecture Notes on Computer Science Subseries Lecture Notes of Artificial Intelligence and Bioinformatics' is the most prolific source of AR in education, as well as 'Journal of Physics Conference Series' in physics education. Meanwhile, 'Ceur Workshop Proceeding' is also leading in the second position as prolific sources in both AR in education and physics education. Thus, conference proceedings were dominated as AR's prolific sources rather than a journal.

Table 4. Prolific Sources of AR in Education and Physics Education

AR in education		**AR in physics education**	
Journal	**∑ docs**	**Journal**	**∑ docs**
Lec. Notes Comp. Sci. Subseries Lec. Notes AI & Bioinformatics	166	J. Phys. Con. Ser.	13
Ceur Work. Proc.	106	Ceur Work. Proc.	7
ACM Int. Con. Proc. Ser.	88	AIP Con. Proc.	5
J. Phys. Con. Ser.	78	Lec. Notes Comp. Sci. Subseries Lec. Notes AI & Bioinformatics	3
Adv. In Intel. Sys. & Comp.	75	Phys. Teacher	3
Comm. in Comp. & Inform. Sci.	51	Proc. SPIE Int. Soc. Opt. Eng.	3
Proc. Comp. Sci.	38	British J. Educ. Tech.	2
Educ. Sciences	24	Comp. & Educ.	2
Proc. SPIE Int. Soc. Opt. Eng.	24	Int. J. Interactive Mobile Tec.	2
App. Sciences Switzerland	22	Educ. Sciences and other 6 proceedings	2

6.4. The authorship pattern and prolific author of documents in AR

Table 5 lists the top 10 authors of AR in education and physics education. In the domain of education, the top author of AR in education was Billinghurst from the University of South Australia. Totally, he produced 543 documents (16 of them were about AR in education) and 14,838 citations with h-index = 55. The last of his article in AR is entitled 'Seeing is believing: AR-assisted blind area assembly to support hand–eye coordination' (Feng et al., 2022). Meanwhile, top author of AR in physics education was Bakri from Universitas Negeri Jakarta, Indonesia, with 48 documents (3 of them about AR in physics education), 125 citations and h-index = 6. The last of his article on AR is entitled 'TPACK and AR in kinematics practicum module: Forming HOTS physics education students' (Bakri et al., 2021).

Table 5. Top Authors of AR in Education and Physics Education

Top authors of AR in education	∑ docs	Top authors of AR in physics education	∑ docs
Billinghurst, M.	16	Bakri, F.	3
Baldiris, S.	15	Cai, S.	3
Mantri, A.	15	Kapp, S.	3
Marques, M.M.	12	Kuhn, J.	3
Navab, N.	12	Modelski, J.	3
Pombo, L.	12	Romaniuk, R.	3
Radu, I.	10	Thees, M.	3
Contero, M.	9	Altmeyer, K.	2
Fabregat, R.	9	Bilous, V.V.	2
Bamidis, P.D.	8	Brünken, R. and (25 others authors)	2

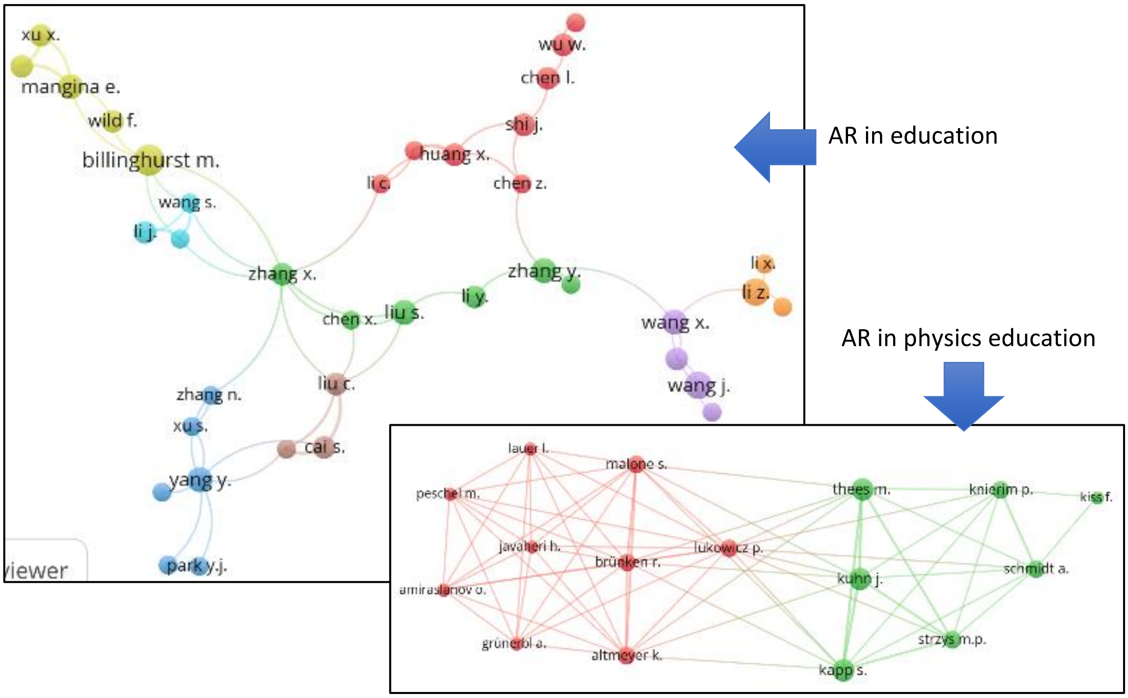

Figure 4. Network Visualisation of Co-Authorship of AR in Education Versus AR in Physics Education

Furthermore, Figure 4 shows the network visualisation of co-authorship of AR in education versus AR in physics education. The first cluster has red nodes (*n* = 8) in AR in education, all from China. The second cluster has green nodes (*n* = 6), all from China. The third cluster has a blue node (*n* = 6), with authors from China and Korea. The fourth cluster has a yellow node (*n* = 5), with authors from Australia, China, the United Kingdom and Ireland. Other clusters have fewer occurrences. Meanwhile, AR in physics education has only two clusters: the first cluster with red nodes (*n* = 9) and the second cluster with green nodes (*n* = 7). Mapping results in AR in physics education have fewer clusters because the topic is more specific than in AR in education. The level of collaboration is also higher because each researcher has a specific or similar scientific background, namely physics education instead of more general education.

6.5. Top countries and institutions of AR research

According to data in Table 6, the dominant country in researching AR in education is the USA, with 477 documents, followed by Spain (277), China (178), Malaysia (167) and Germany (163). According to the researchers' predictions, this is because the inventor of AR, Morton Heilig, is a cinematographer from the USA so the development of AR, also in the field of education, has a very significant number compared to other countries. This finding is also consistent with research by Prahani et al. (2022) that USA is leading the way in research on AR. The institutions that research AR the most in education are the *Universiti Teknologi* Malaysia (*n* = 31), followed by *Tecnologico de Monterrey* (*n* = 25) and Technical University Munich (*n* = 22).

Table 6. Top Countries and Institutions of AR in Education and Physics Education

AR in education				AR in physics education			
Country	**∑ docs**	**Institution**	**∑ docs**	**Country**	**∑ docs**	**Institution**	**∑ docs**
USA	477	Univ. Tek. Malaysia	31	Indonesia	13	Univ. Negeri Jakarta	5
Spain	227	Tecnologico de Monterrey	25	USA	12	Politechnika Warszawska	3
China	178	Technical Univ. Munich	22	Germany	8	Tech. Univ. Kaiserslautern	3
Malaysia	167	Univ. Kebangsaan Malaysia	21	China	5	Beijing Normal Univ.	3
Germany	163	Univ. Tun Hussein Onn Malaysia	20	Malaysia	5	German Res. Center for AI DFKI	3
UK	156	Kryvyi Rih Nat. Univ.	20	Ukraine	5	Borys Grinchenko Kyiv Univ.	3
Indonesia	142	Univ. Politècnica de València	19	Austria, Canada, Italy, Kazakhstan, Poland, Russian Fed., UK	3	Int. Information Tech. Univ.	3
India	131	Univ. de Aveiro	19			Univ. Colorado Boulder, Univ. Calgary, Harvard Univ., etc.	2
Taiwan	129	Univ. Negeri Malang	19				
Australia	114	Kryvyi Rih State Pedagogical Univ.	18				

Meanwhile, Indonesia excelled in AR in physics education (*n* = 13) research, followed by the USA (*n* = 12), Germany (*n* = 8), China (*n* = 5), Malaysia (*n* = 5) and Canada (*n* = 5). In Indonesia, the AR trend became an emerging technology during the COVID-19 pandemic to support physics learning because the learning used was based on digital technology. AR in physics learning will assist students in visualising abstract and microscopic materials. (Suprapto et al., 2020b; Wulandari et al., 2021), such as modern physics (Ismail et al., 2019), thermodynamics (Ismalina et al., 2018) and magnetic field (Cai et al., 2017), when carrying out distance learning. The institution that conducts the most research on AR in Physics Education is Universitas Negeri Jakarta (*n* = 5), consistent with Bakri F. as the top author in this field.

Figure 5 shows the mapping visualisation of countries that contributed to AR in education and AR in physics education research with a total of 17 clusters. The AR in the education field has a main cluster (*n* = 10) with a red node in the centre of Spain. The second cluster (*n* = 9) has a green node, consisting of African countries: Kenya, Uganda, South Africa, Tunisia, Zimbabwe and Nigeria. The third cluster (*n* =

7) has blue nodes consisting of Asia-Pacific countries: China, Hong Kong, Australia, Thailand and New Zealand. Some other clusters have a smaller number of items. An interesting finding from the results of this visualisation is that the USA as the most productive country turned out to be included in cluster 14 (*n* = 4) with Canada and Tanzania. This means that the close relationship between the USA and other countries is still lacking, so that in cluster 14 has few countries (van Eck & Waltman, 2014).

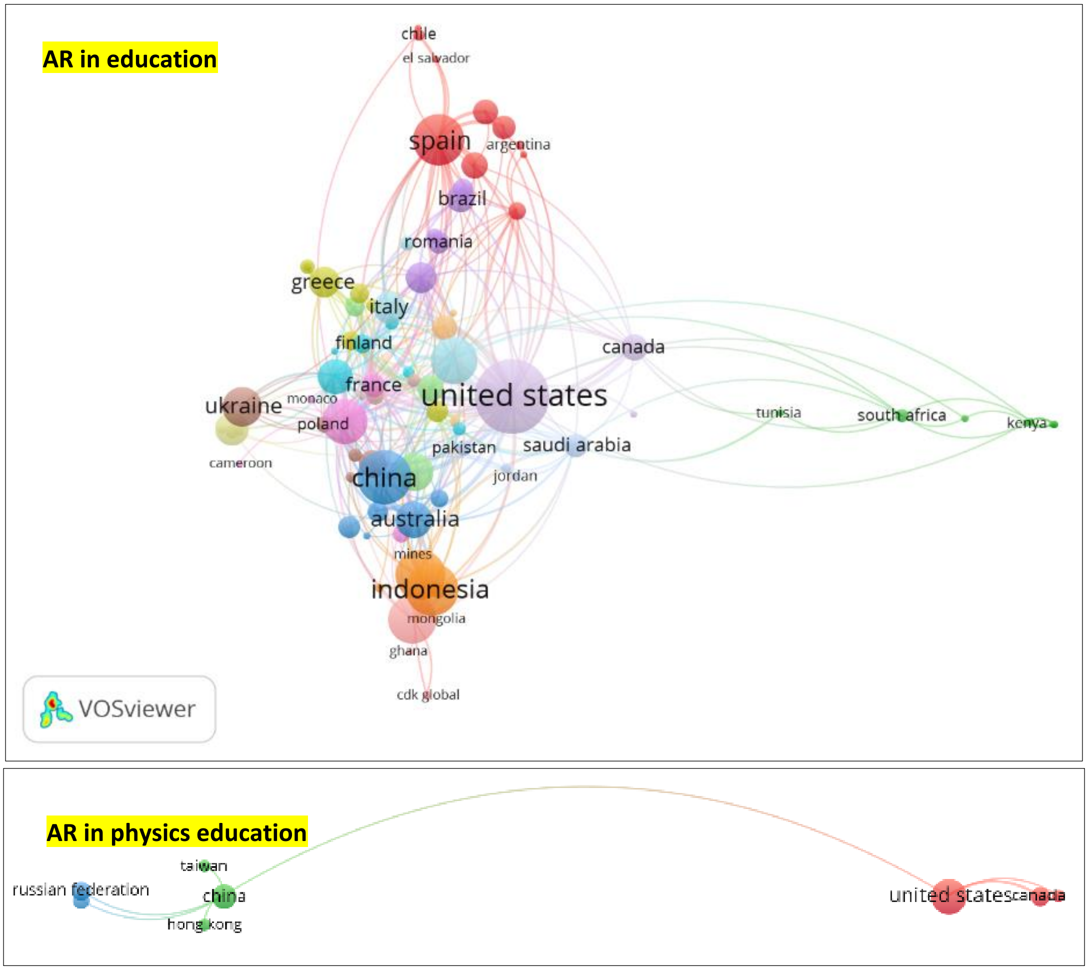

Figure 5. Top Countries of AR in Education and AR in Physics Education

While in AR in physics education, there are only three clusters, where the first cluster with red nodes (*n* = 3) consists of American countries: USA, Canada and one undefined. The second cluster with green nodes (*n* = 3) consists of Asian countries: China, Taiwan and Hong Kong. The third cluster with blue nodes (*n* = 2) consists of European countries: Czech Republic and Russia. An interesting finding from the results of this network mapping is that Indonesia as the top productive country in AR in physics education research is not included in this cluster. This shows that Indonesia also has low relations with other countries and tends to collaborate with researchers from the same country. One of the papers resulting from the collaboration between USA and Canada entitled '*RealitySketch*: Embedding responsive graphics and visualisations in AR through dynamic sketching' that discusses about *RealitySketch*: an AR interface for sketching interactive graphics and visualisations. These publications contributed to a class of interaction techniques that allow for the capture, parameterisation and visualisation of real-world motion without the use of pre-defined programmes and configurations (Suzuki et al., 2020).

6.6. Visualization of the co-occurrence keywords

Figure 6 shows the visualisation of the top keywords, indicating that AR in education has nine clusters. The first cluster with red nodes (*n* = 199) has topics related to supporting AR in education, such as learning, curriculum, surgical training, image reconstruction and procedures. The second cluster with green nodes (*n* = 137) has topics related to AR construction technology, such as android, digital library, intelligent systems, marker-based tracking and mobile apps. The third cluster with blue nodes (*n* = 116) has topics related to AR visualisation, such as 3D models, architectural design, climate change, data visualisation, disasters, kinematics and visual representations. Other clusters have fewer occurrences.

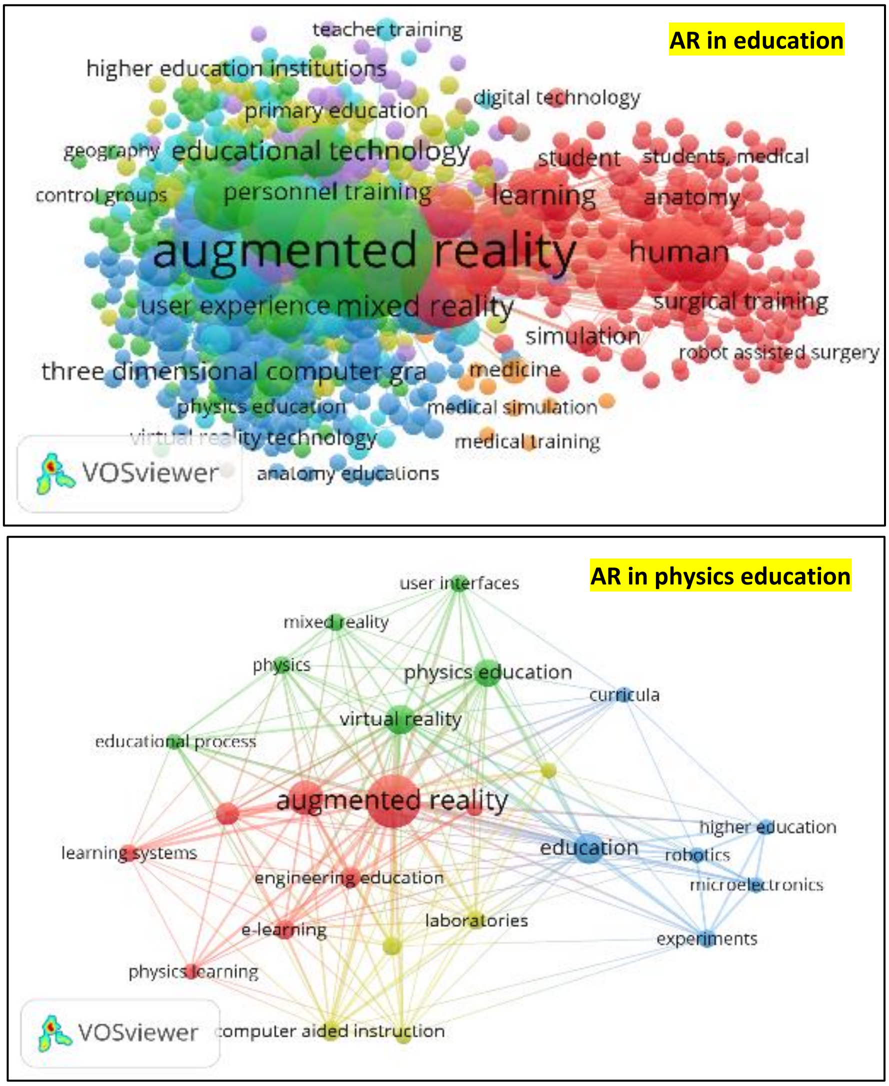

Figure 6. Visualisation of the Co-Occurrence's Keywords of AR in Education and AR in Physics Education

The results of keyword network visualisation in AR in education research have a strong network of virtual reality, students, engineering education, e-learning and mixed reality, so the research theme related to this has a less good novelty. Weak AR network maps show some interesting research novelty, such as virtual laboratories, inclusive education, primary schools, neural networks etc. In addition, the most common number of keywords appearing in AR in education research are AR (*n* = 1,497), virtual reality (479), students (406), e-learning (286) and engineering education (*n* = 265). These results are consistent with Avila-Garzon et al.'s (2021) research revealing that AR, virtual reality and engineering education are among the keywords with the most occurrences.

Meanwhile, AR in physics education has fewer clusters than AR in education, namely four clusters. The first cluster has a red node (*n* = 8) discussing AR, e-learning, physics learning, students, education computing, emerging technologies, learning systems and engineering education. The second cluster has a green node (*n* = 6) discussing educational processes, mixed reality, virtual reality, physics, physics education and user interfaces. The third cluster with blue nodes (*n* = 6) discusses curricula, education, experiments, higher education, microelectronics and robotics. The fourth cluster with yellow nodes (*n* = 5) discusses computer-aided instruction, laboratories, learning environments, physics laboratories and teaching. The most common number of keywords occurring are AR (*n* = 65), students (26), virtual reality (18), education (20) and physics education (16).

The similarity of the results of visualisation of AR in education networks with AR in physics education is that research focuses on students and the majority is integrated with virtual reality. This is indicated by the similarity of the number of keyword occurrences. While the difference is that the keyword ‘physics education’ has a small number of occurrences (*n* = 12) and a fairly weak total link strength (63). In addition, AR in physics education tends to talk a lot about the laboratory, whereas AR in education discusses less about it. Laboratory activities in physics are very important because it is the highest learning experience, according to the cone of Edgar Dale's learning experience (Slavin, 2011).

6.7. Top citations of documents in AR research

Table 7 shows the most seized publications on AR in education and physics education research. The majority of journal publishers with the top 10 cited publications have a quartile level of Q1. The first top-cited publication in AR in education is a paper owned by Wu et al (2013) entitled ‘Current status, opportunities and challenges of AR in education’ (Radu, 2014). They divide instructional approaches into three categories that emphasise ‘roles’, ‘tasks’ and ‘locations’, and they discuss what and how different types of AR approaches can help students learn. They also discussed technological, pedagogical and learning issues related to the use of AR in education. This paper suggests topics and issues for future research as well as possible solutions to some of the challenges.

Table 7. Top Citations of AR in Education and Physics Education

No	AR in Education				AR in Physics Education			
	Author(s)	**Journal**	**∑ cite.**	**Ref(s).**	**Author(s)**	**Journal**	**∑ cite.**	**Ref(s).**
1	Wu et al.	Comp. & Educ. 62, 41-49	998	(Wu et al., 2013)	Potkonjak et al.	Comp. & Educ. 95, 309-327	363	(Potkonjak et al., 2016)
2	Akçayır et al.	Educ. Res. Rev. 20, 1-11	650	(Akçayır & Akçayır, 2017)	Cai et al.	Inter. Learn. Env. 25(6), 778-791	95	(Cai et al., 2017)
3	Bacca et al.	Educ. Tech. & Soc. 17(4), 133-149	541	(Bacca et al., 2014)	Saidin et al.	Int. Educ. Stud. 8(13), 1-8	91	(Saidin et al., 2015)

No	AR in Education				AR in Physics Education			
	Author(s)	**Journal**	**∑ cite.**	**Ref(s).**	**Author(s)**	**Journal**	**∑ cite.**	**Ref(s).**
4	Di Serio et al.	Comp. & Educ. 68, 586-596	514	(Di Serio et al., 2013)	Dünser et al.	Proc. 24th Aus. Com. Hum. Int. Con. 107-114	76	(Dünser et al., 2012)
5	Klopfer et al.	Educ. Tech. Res. & Dev. 56(2), 203-228	436	(Klopfer & Squire, 2008)	Fidan & Tuncel	Comp. & Educ. 142,103635	70	(Fidan & Tuncel, 2019)
6	Lee	TechTrends 56(2), 13-21	411	(Lee, 2012)	Kaufmann & Meyer	ACM SIGGRAPH ASIA 2008	65	(Kaufmann & Meyer, 2008)
7	Potkonjak et al.	Comp. & Educ. 95, 309-327	363	(Potkonjak et al., 2016)	Cai et al.	Int. J. Eng. Educ. 29(4), 856-865	50	(Cai et al., 2013)
8	Cheng & Tsai	J. Sci. Educ. & Tech. 22(4), 449-462	361	(Cheng & Tsai, 2013)	Strzys et al.	Phys. Teacher 55(6), 376-377	31	(Strzys et al., 2017)
9	Radu	Personal & Ubiquitous Com. 18(6), 1533-1543	358	(Radu, 2014)	Altmeyer et al.	Brit. J. Educ. Tech. 51(3), 611-628	26	(Altmeyer et al., 2020)
10	Pan et al.	Comp. & Educ. (Pergamon) 30(1), 20-28	335	(Pan et al., 2006)	Modelski & Romaniuk	Proc. SPIE- Int. Soc. Opt. Eng. 7745,774504	24	(Modelski & Romaniuk, 2010)

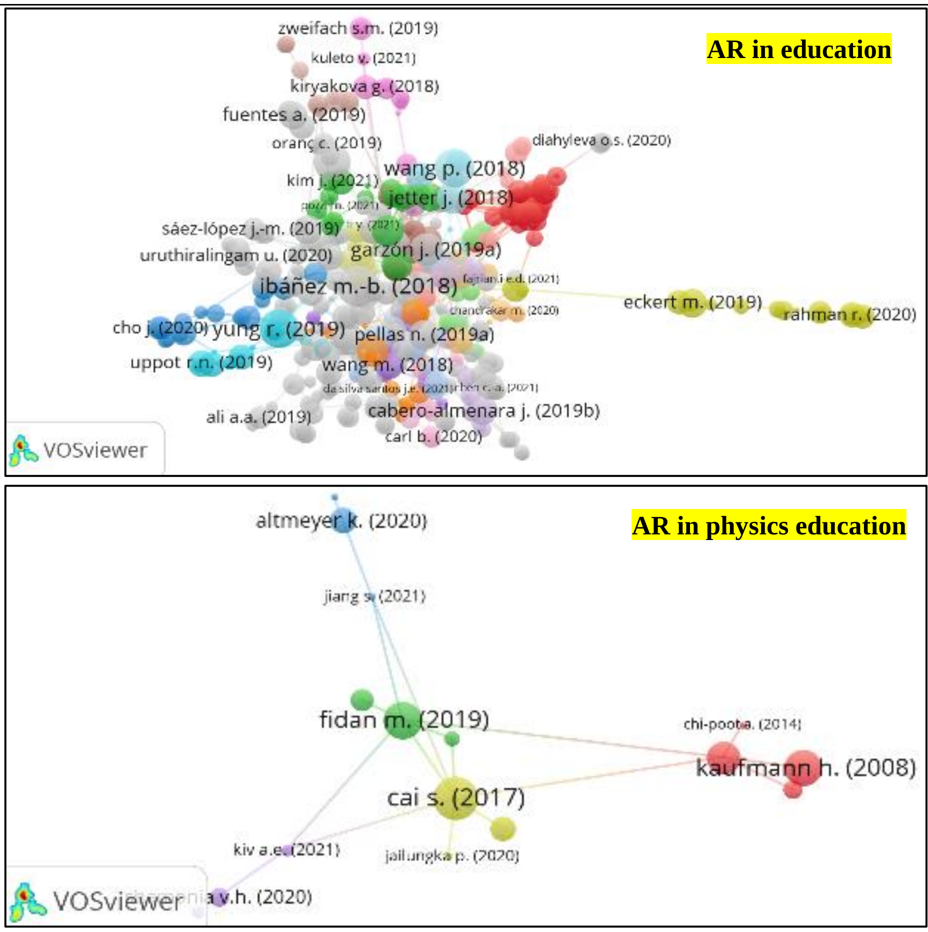

Figure 7. Visualisation of Top Co-Citation of AR in Education and AR in Physics Education

Meanwhile, The first top-cited publication in AR in physics education is a paper owned by Potkonjak et al. (2013) entitled 'Virtual laboratories for education in science, technology and engineering: A review' (Potkonjak et al., 2016). They summarised the state of the art in the virtual laboratories and virtual worlds in science, technology and engineering. According to them, the main research activity in these fields is discussed, but due to the maturity of this area within the virtual education community, special emphasis is placed on the field of robotics. They claim that, in addition to the technical issues addressed in this paper, the implementation of immersive education, distance learning and virtual worlds raises significant pedagogical and design issues in the field of effective learning 'experiences'. As an additional goal, they may create a hybrid system that includes a lab with both real (authentic, physical) and virtual (co-present) equipment.

Figure 7 shows the results of co-citation mapping on AR in education and AR in physics education research. AR in education has 39 clusters and a total of 578 items. Ibáñez and Delgado-Kloos' Spanish publication 'AR for STEM learning: A systematic review' became the most appearing publication (266 citations) and link strength 12. Other publications with the most co-citations are Wang (214), Yung (202), Suh (152) and Garzon (101).

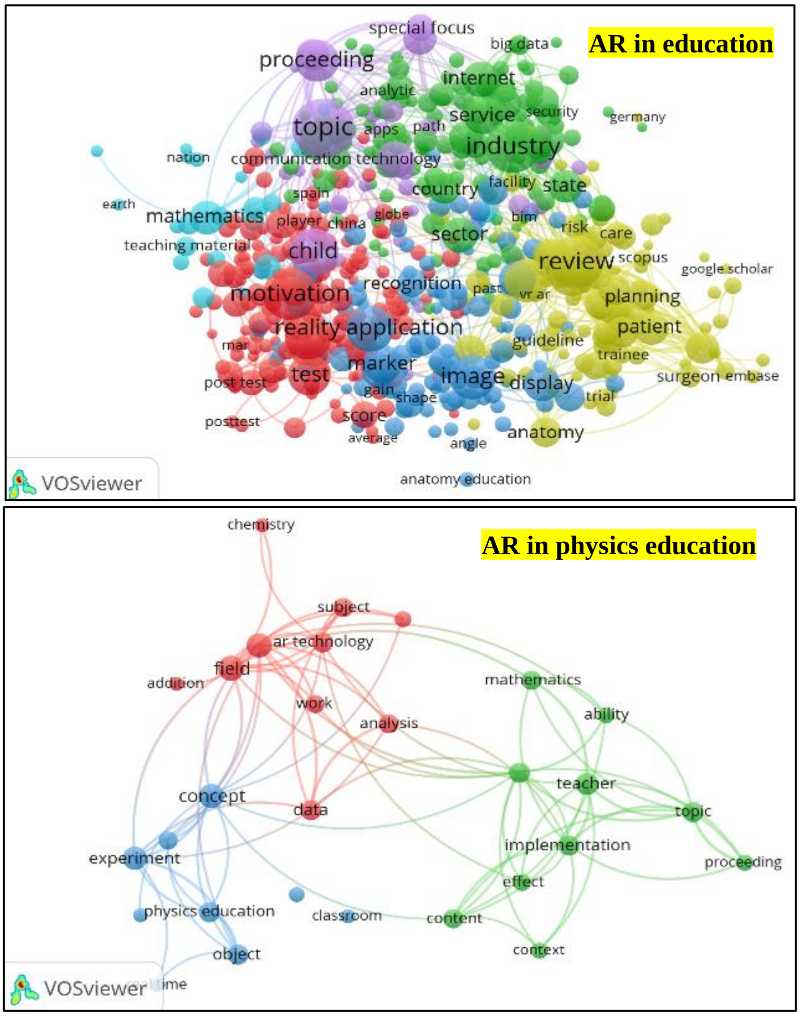

Figure 8. A Network Visualisation of the Whole Picture of AR in Education and AR in Physics Education

AR in physics education has 5 clusters and 16 items. Potkonjak's publication, titled 'Virtual laboratories for education in science, technology and engineering: A review' has the most citations (363), but has no links with other co-citations and so it does not appear in the mapping results. The other most popular co-ideals are Cai (95), Saidin (91), Dunser (76) and Fidan (70).

6.8. Visualisation of the co-occurrence keywords

Research trends on AR in education resulted in six clusters, as shown in Figure 8. The first (dark blue) is the discussion of AR application, including the process of developing the visualisation. The second AR is AR and students' motivation. The third (yellow) is the review and evaluation of using AR in specific topics. The fourth (green) is the use of AR on an industrial scale. The fifth (purple) is AR in the specific topic/focus, such as application and technology. The last (blue) is AR as teaching material, especially in mathematics.

Meanwhile, AR in physics education resulted in only three clusters: AR in a specific physics concept (blue), AR technology in physics (red) and the implementation of specific AR context and content by teachers. Among those clusters, in both AR in education and physics education, Figure 9 shows an overlay visualisation of the whole picture of AR in both domains. For the last 5 years (2016–2021), all AR themes in education boomed, especially in 2020–2021 or during the COVID-19 outbreak. On the contrary, the dominant theme of AR in physics education appeared in the interval 2018–2020.

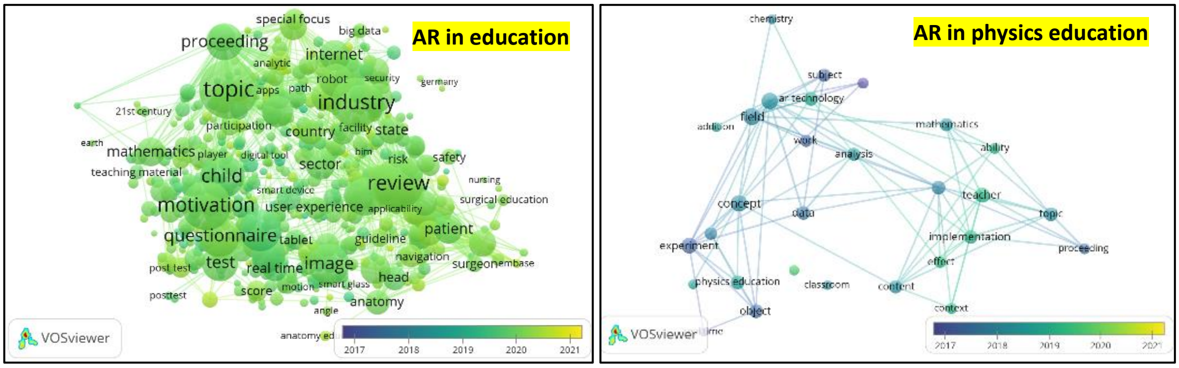

Figure 9. An Overlay Visualisation of the Whole Picture of AR in Education and AR in Physics Education

Finally, Figure 10 shows the relationship between AR, education and physics education. The figure succeeds in visualising the comparison of AR in education versus AR in physics education. Through this figure, the researchers gain a new direction of research in both AR in education and physics education domains.

7. Conclusion

This study reviews the research trends of AR with an emphasis on education and physics education. There are several conclusions based on this research as follows:

1. The year-wise distribution of AR-related to education and physics education documents shows that the use of AR in both education and physics education fluctuated from 2010 to 2016. However, it experienced a significant increase from 2016 and is still prospective to be researched to date.
2. The main language used in AR-related education is English, followed by Spain, Portuguese and Chinese. Almost similar, the main language used in AR in physics education is English, followed by Chinese and Portuguese.

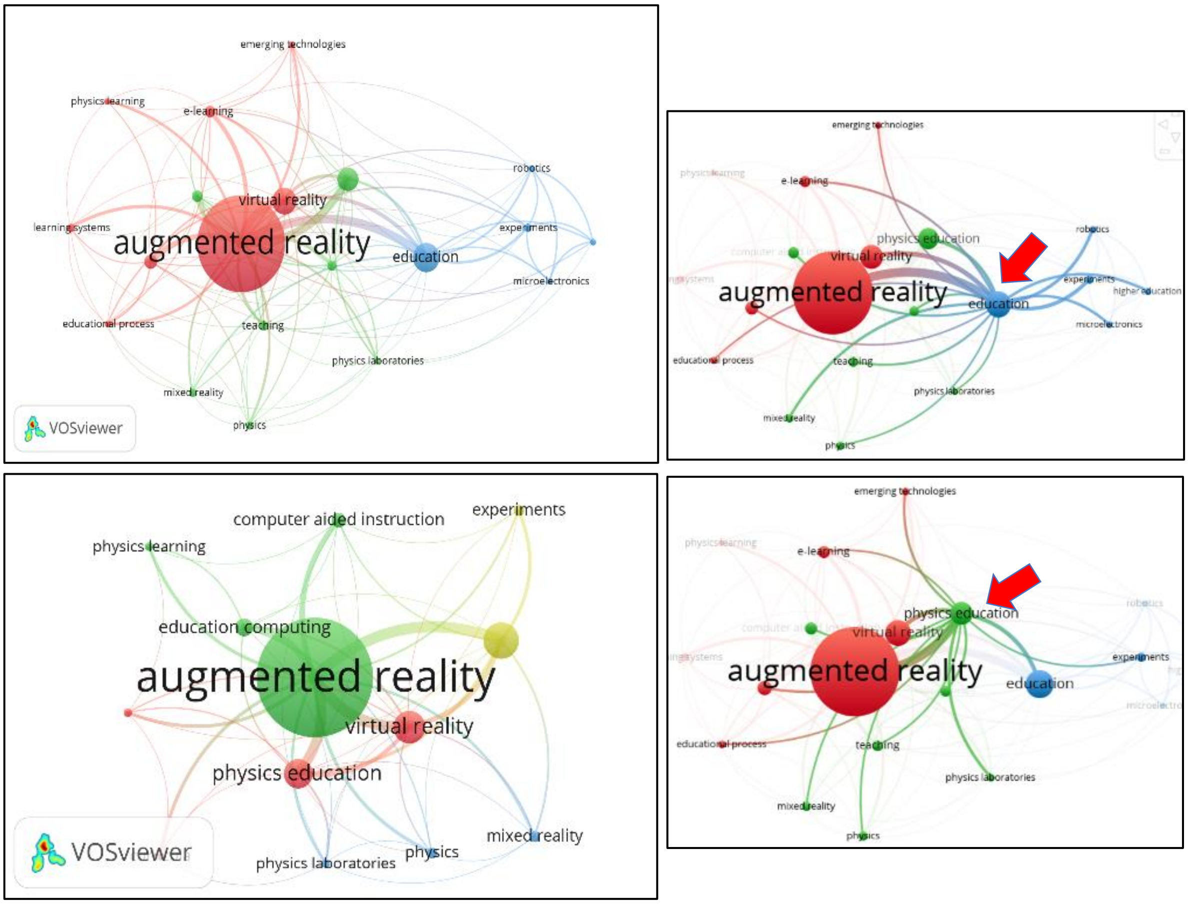

Figure 10. The Relationship of AR, Education, and Physics Education

3. The main sources publishing documents in AR related to education are conference papers (49.16%) and articles (31.18%). Similarly, the main sources publishing documents in AR related to physics education are conference papers (61.85%) and articles (21.64%).

4. In the domain of education, the top author of AR in education was Billinghurst from the University of South Australia. Meanwhile, the top author of AR in physics education was Bakri from Universitas Negeri Jakarta. Mapping results in AR in physics education have fewer clusters because the topic is more specific than AR in education.

5. The most productive country in the publication of AR in education is USA, with 477 documents, while the publication of AR in physics education is Indonesia, with 13 documents. Nevertheless, network visualisations show that the USA and Indonesia as the top countries have little collaboration with other countries. Judging from the institution, *Universiti Teknologi* Malaysia leads with 31 AR in education documents and Universitas Negeri Surabaya with a total of 5 AR in physics education documents.

6. The results of keyword network visualisation in AR in education research have a strong network on virtual reality, students, engineering education, e-learning and mixed reality. While AR in physics education has the most common number of keywords: AR, students, virtual reality, education and physics education. The similarity of the results of visualisation of AR in education networks with AR in physics education is: that research focuses on students and the majority is integrated with virtual reality.

7. The first top-cited AR publications in education are a paper owned by Wu et al (2013) entitled 'Current status, opportunities and challenges of AR in education'. While in AR in physics education is a paper owned by Potkonjak et al. (2013) entitled 'Virtual laboratories for education in science, technology and engineering: A review'.

8. Research on AR in education versus AR in physics education resulted different paradigm which can be counted from the number of clusters resulted (six *vs.* three clusters). However, this study succeeds in illustrating the relationship of AR, education and physics education, including the visualisation of AR in education *vs.* AR in physics education.

This research has implications for providing insight to the next researcher in finding gap research and novelty in the field of AR in education and physics education. This research contributes to the international literature, which can provide new insights to subsequent researchers to find updates in the field of AR in education and physics education research that is impactful and quality. The current emerging and trending research topics in AR in education are special educational needs, Industry 4.0, storytelling, 3D printing, mobile applications, STEM education and higher education.

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Appendix

A.1. The year-wise distribution of documents in AR in education and physics education

Year	∑ docs of AR in Education	∑ docs of AR in Physics Education
1978	1	0
1982	1	0
1995	1	0
1996	0	0
1997	5	0
1998	1	0
1999	1	0
2000	6	0

Year	∑ docs of AR in Education	∑ docs of AR in Physics Education
2001	6	0
2002	7	0
2003	3	0
2004	9	0
2005	3	0
2006	18	0
2007	22	0
2008	26	1
2009	21	1
2010	35	5
2011	68	0
2012	72	3
2013	125	2
2014	121	2
2015	158	4
2016	158	3
2017	279	8
2018	403	7
2019	548	17
2020	618	23
2021	677	21
Total	3,393	97