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Abstract

Augmented reality applications in STEM education have increasing importance in recent years and it draws attention that scientific studies on this subject have gained momentum in the literature. The purpose of this research is to conduct a bibliometric analysis of studies on the use of augmented reality applications in STEM education in the literature. The Web of Science database has been used to collect the data. A total of 741 studies were accessed by going through various screening processes for the research. Content analysis and bibliometric analysis have been used in the analysis of the data. In the research, the distribution of publications by years and countries and the most published authors, journals, and countries were accessed. As a result of the research, in terms of the institutions with which the authors work, "National Taiwan University of Science Technology" ranked near the top for the number of citations and "National Taiwan Normal University" ranked near the top for the number of publications as the most productive institutions. It has been detected that "Wu, H. –K." and "Chang, H. –Y" are the most effective and productive researchers. According to the analysis conducted in the context of journals, "Computers & Education" and "Interactive Learning Environments" have been the journals that contributed the most to this subject. As a result of the analysis, it was found that the co-authorship network structure is predominant in England and Spain. Concepts that become apparent in clusters in co-occurrences analysis are "augmented reality", "virtual reality", "mobile learning", "science education" and "mixed reality".

Introduction

Today, with the development of mobile and smart devices, a wide variety of products, and widespread use of the internet, many people have started to use these technological tools more and more in their daily life. Therefore, it has become inevitable for individuals who grow up in this technology age to use these technologies in their education. With the developments in technology, Augmented Reality (AR) technology is one of the technologies that became widespread in many areas, and its effectiveness in the learning-teaching process is being discussed. Although there were problems such as technical problems, hardware deficiencies, and cost in use in its early days, AR applications have improved in parallel with the advances in technology and their usability increased.

In fact, studies show that AR technology is suitable for use of all age groups (López-Belmonte, Pozo-Sánchez &

López-Belmonte, 2019). However, although the foundations of AR technology that has become widespread in all areas of life date back to the 1950s, its use in education is relatively new (Billinghurst, 2002; Fleck, Hachet & Bastien, 2015). It can be stated that AR technology, which is expected to be used actively in the future as well, can have pedagogical value in the field of education and has the potential to create new methods in this field. The Horizon reports that are published regularly every year discuss that AR technology will have a significant impact on education in the future in terms of providing an enriched learning environment and facilitating learning (Cai, Wang & Chiang, 2014).

AR, which can be considered as a technological development or a derivative of virtual reality, is the placement of virtual objects in the real world (Azuma, 1997). In other words, AR is the addition of virtual objects (graphics, animation, video, sound, picture, etc.) produced by a computer onto the real world and integrating them simultaneously (Delello, 2014; Perez-Lopez & Contero, 2013). According to Azuma (1997), AR provides ease of learning to the user, ideally by complementing reality rather than completely replacing real-world objects. In this context, it can be argued that the main purpose of AR technology is to enrich real-world data. However, it can be stated that there are three basic conditions of AR technology (Azuma et al., 2001; Kaufmann, 2003). These are the coexistence of real and virtual environments, providing real-time interaction, and aligning real and virtual objects with each other in three dimensions. In this case, AR can be described as a technology where the real world and virtual objects interact in a combined fashion. All of this happens in real-time by using electronic devices (Maas & Hughes, 2020).

It is argued in the literature that AR technology introduces a different dimension to education and has many benefits. For example, AR enables the use of hard-to-reach and costly educational environments and objects that are impossible to use under normal conditions (Bower et al., 2014; Wu, Lee, Chang & Liang, 2013). It ensures that potentially dangerous practices are carried out safely in education (Abdüsselam, 2014; Wojciechowski & Cellary, 2013). In addition, abstract concepts that are difficult to understand become clearer with three-dimensional visuals and this makes it easier to understand these concepts (Chang, Hou, Pan, Sung & Chang, 2015; Huang, Chen & Chou, 2016; Lin, Duh, Li, Wang & Tsai, 2013; Wu, Lee, Chang & Liang, 2013). It improves student motivation by increasing their interest in the subject (Chin, Wang & Chen, 2019; Diegmann et al., 2015). It makes the learning activity fun (Rambli, Matcha & Sulaiman, 2013; Zarzuela et al., 2013) and increases participation in the lesson (Batdı & Talan, 2019; Wojciechowski & Cellary, 2013).

In traditional classroom environments, students lose their focus in a short time, but they can keep their focus in AR environments for a longer time (Abdüsselam & Karal, 2012). Thus, AR positively affects the academic achievement of students by drawing their attention to the subject (Abdüsselam, 2014; Batdı & Talan, 2019; Chiang et al., 2014; Moreno-Guerrero et al., 2020). Besides, AR technology supports many learning approaches and contributes to them. For example, AR technology supports approaches such as constructivist learning, game-based learning, inquiry-based learning, situational learning, cooperative learning, problem-based learning, and learning by doing and experiencing (Billinghurst, 2002; Delello, 2014; Dunleavy & Dede, 2014; Dunleavy, Dede & Mitchell, 2009; Kirner, Reis & Kirner, 2012; Wojciechowski & Cellary, 2013; Yuen et al., 2011).

AR was originally used in the fields of aviation, military, medicine, and industry. With the development of technology, AR has started to be used in the field of education in addition to being used for commercial, entertainment, and social purposes. AR has a high potential for use in education and training environments, as it can be used with easily accessible technological devices and offers rich content. This situation supports the idea that AR applications, which have attracted attention in recent periods, can also be effective in the field of education. Due to its features, AR has managed to attract attention in a short time about its use in education anywhere from preschool to university level. In the literature, it has been observed that AR is effectively applied in different disciplines such as science, social sciences, medical science, math's and language education (Batdı & Talan, 2019), it increases student participation in educational activities, and offers them an individualized learning environment (Arici, et al., 2019).

Developments in STEM (Science, Technology, Engineering, Mathematics) fields show that STEM education plays a critical role in building the future of societies. For this reason, developed countries make an effort to find ways to increase the quality of education in STEM fields. It can be argued that it can be beneficial to use AR technologies in STEM lessons to increase the quality of STEM education, to improve the reasoning skills of students during STEM lessons, to help them discover information, and to improve their problem-solving skills. In addition, studies show that using AR applications directly or indirectly in STEM education gives positive results. AR plays a very important role in overcoming misconceptions, making abstract concepts clearer, and having an opportunity to observe dangerous and difficult situations in real life (Demirer & Erbaş, 2015; Yılmaz & Batdı 2016). It can also be stated that AR applications that appeal to different senses with their interesting features can bring a fresh perspective to teaching subjects that are difficult to understand during STEM lessons. Therefore, considering its contributions to STEM education, the position of AR is extremely important.

Although there are publications in the literature that examine scientific studies on educational AR applications, it can be said that the number of bibliometric studies is still quite limited. It is observed that existing bibliometric studies have become widespread especially in recent years. For example, there are several bibliometric studies on the subject. In a recent bibliometric study, Abad-Segura et al. (2020) examined the evolution of scientific publications on the sustainability of AR-oriented educational technologies in higher education and identified the current and future trends.

In line with the purpose of the study, a bibliometric analysis of 1977 studies published between 2005 and 2019 was carried out and scientific productivity results were obtained. Similarly, Karakus et al. (2019) conducted a bibliometric analysis of 437 studies on educational AR applications in the Web of Science (WoS) database published between 1999-2018. Again, López-Belmonte et al. (2019) analyzed the performance of AR in the field of education from a bibliometric perspective. In this study, 777 publications published in WoS between 1999-2019 have been included in the analysis. Arici et al. (2019) conducted a bibliometric analysis of articles published in WoS between 2013-2018 on the use of AR in science education. In another study, Batdi and Talan (2019) examined the studies published in various databases between 2013-2019 on the use of AR in education with a holistic approach. As can be seen, bibliometric methods related to the subject have been used especially in recent years.

Objectives of the Study

In many countries, research and development activities on the use of AR technology in STEM education are carried out, taking into account the developments in technology and the requirements of the age, and the practices are reviewed and rearranged in the light of the data obtained. At this point, various scientific studies are carried out to follow, research, and examine the changes and developments in this subject. The increasing number of scientific studies makes it necessary to interpret and summarize the accumulation of knowledge, thus revealing the need for bibliometric research on the subject. For this reason, the purpose of this study is to identify scientific research on the use of AR technology in STEM education and to examine and evaluate the bibliometric characteristics of these studies. Conducting such a study is important in terms of having a general idea about the research conducted on this subject, avoiding repetitive research, and helping researchers to have a road map for future studies. The research questions of the study are as follows:

1. What is the distribution of the relevant publications by years?
2. What is the distribution of the relevant publications by country?
3. What are the citation rankings of relevant publications, authors, journals, authors, and institutions?
4. What kind of a structure emerges regarding co-author analysis?
5. What kind of a structure emerges regarding co-citation analysis?
6. What kind of a structure emerges regarding co-occurrences?

Method

In this research, studies on the use of AR technology in STEM education are examined using the bibliometric analysis method. Bibliometrics is a method used in many disciplines today, in which mathematical and statistical methods are used to measure and analyze scientific publications (Pritchard, 1969). Bibliometric analysis is often used to analyze the issue of citation and to make a general judgment about the performance of publications. The basic parameters of citation are the most cited study, the most cited author, the most cited journal, the most studied topic, the most collaborated country, bibliometric coupling, authors cited together in a study, and keywords and concepts they frequently use regarding a certain subject. The issues that come to the fore regarding the performance of the publications are mostly to comparatively examine the situations of individuals, institutions, and countries (Kurutkan & Orhan, 2018).

Data Collection

In this study, the WoS database has been used to obtain the bibliometric data to be examined. WoS is regarded as a reputable citation index in scientific circles and it is recognized as the world's leading academic database with the multitude and variety of publications it scans. WoS includes over 20.000 journals. The reasons for conducting the analysis in WoS are that the relevant database includes indexes such as Science Citation Index (SCI), Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI), regarded as reputable citation indexes by the academic circles and that it enables

scanning a wide range of the literature.

Below are the codes created on how the contents are scanned and filtering options in the topic area (article title, abstract, keywords) of WoS's search engine:

TOPIC: *("augment* realit*") AND* ***TOPIC:*** *(STEM OR science OR technolog* OR engineer* OR math*)*

WEB OF SCIENCE CATEGORIES: *(Education Educational Research OR Psychology Educational OR Education Scientific Disciplines OR Education Special)*

DOCUMENT TYPES: *(Article)*

Timespan: *All years.*

Indexes: *SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI.*

No restriction was made regarding the starting year in the scanning process. No filtering was made for the language of the publications either. Also, with the help of WoS's filtering features, works such as editorial articles, book chapters, conference booklets, etc. were identified and removed from the data set. The last screening was carried out in February 2021 and a total of 741 studies were reached. The bibliographic data of these publications (such as publication years, publication types, publication languages, titles, author names, author's countries of origin, citation numbers, abstract, keywords, and references) were reached.

Data Analysis

Bibliometric and descriptive content analyses were used in the analysis of the data in the study. The WoS database's own system was used for content analysis. VOSviewer (Version 1.6.16, Centre for Science and Technology Studies of Leiden University), a mapping, and visualization software tool, was used for bibliometric analyses. Among all the data obtained at the end of the data collection process, the distribution of the studies by years and countries was examined first. Afterward, the sources where the most published studies were referenced, the authors and institutions, and the number of citations of the studies were included in the content analysis process. During the bibliometric analysis process of the studies on the subject, co-author (author, countries, institution), co-citation (author), and co-occurrences analyses were carried out.

Results

The following findings have been reached in accordance with the purpose of the research. The findings of the research are presented in tables and figures.

Descriptive Findings

Distribution of Publications by Years

In the study, the distribution of the studies published in WoS by years was examined first. The findings obtained are presented in Figure 1.

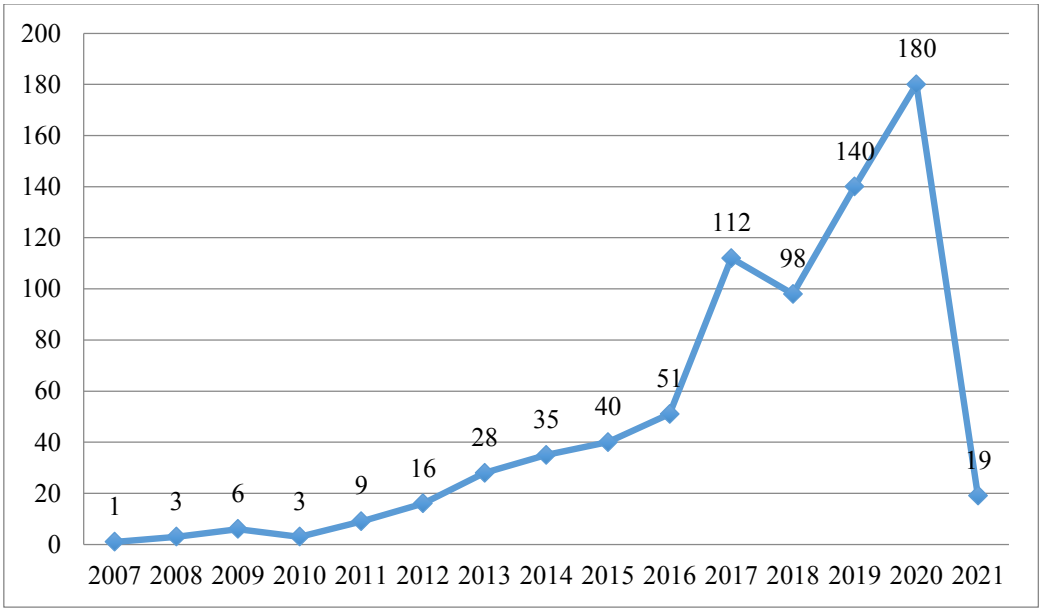

Figure 1. Distribution of Publications by Years

When Figure 1 is examined, it is seen that the first study was conducted in 2007. It is observed that there is an increase in the number of studies conducted in general. It was found that the number of publications was low between 2007 and 2011 but reached the highest number in the past five years. In 2018, there was a partial decrease. The year 2020 has been the year with the most publications on this subject with 180 studies.

Distribution of Publications by Country

When the distribution of the studies conducted on the subject by countries is examined, the chart below (Figure 2) shows the top 10 countries with the highest number of publications.

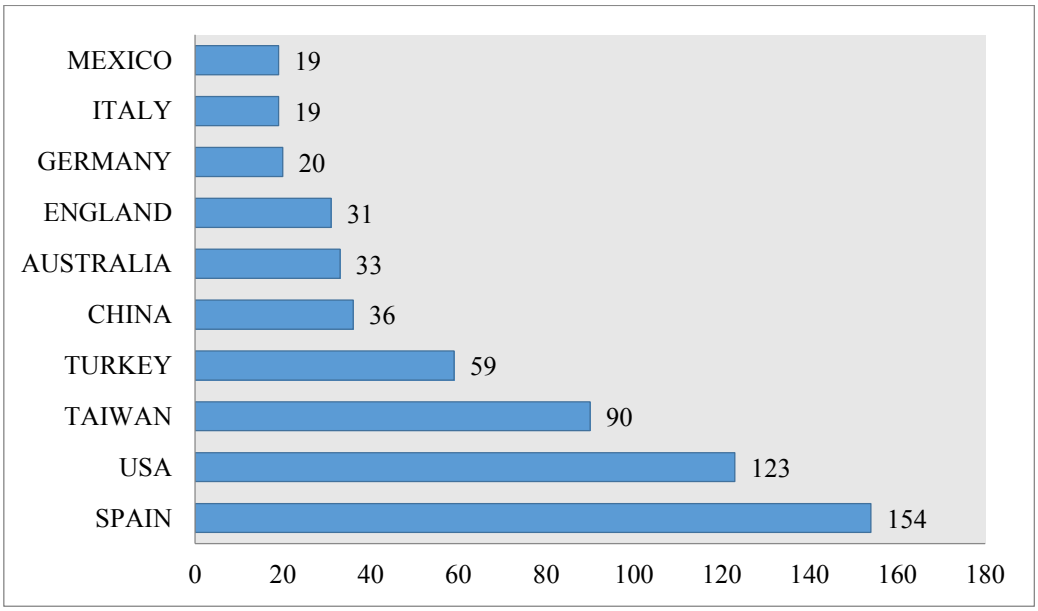

Figure 2. Distribution of Publications by Country

According to this distribution, Spain ranks first with 154 articles, and USA ranks second with 123 publications. Taiwan (f=90) followed the list, Turkey (f=59) and China (f=36) and others.

Bibliometric Findings

Citation Analysis (Journal, Author, Institution and Document)

Citation analysis of the journals with the highest number of publications on the subject in WoS was examined first. The relevant data are presented in Table 1.

Table 1. Journal Distribution of Publications and Number of Citations

Journal	Number of articles	Number of citations	Link strength	Number of citations per research
Computers & Education	39	3402	653	87.23
Interactive Learning Environments	38	420	207	11.05
International Journal of Emerging Technologies in Learning	25	121	51	4.84
Education and Information Technologies	23	43	101	1.87
Computer Applications in Engineering Education	19	87	77	4.58
British Journal of Educational Technology	17	210	81	12.35
Education Sciences	17	39	42	2.29
Journal of Educational Computing Research	16	106	88	6.63
Anatomical Sciences Education	15	273	41	18.20
Journal of Chemical Education	15	104	13	6.93

When the journal-based distribution of the publications is examined, it is seen that the most published journals are "Computers & Education" (f=39) and "Interactive Learning Environments" (f=38). When the number of citations per article is examined, it is seen that the journals "Computers & Education", "Anatomical Sciences Education" and "British Journal of Educational Technology" are cited the most.

The study also examined the authors of the articles on the subject based on WoS citation data. Table 2 contains the number of articles and citations of the most productive and influential authors on the subject.

The top 10 authors with at least three articles in the relevant references are listed according to their citation count. When the table is examined, it is seen that the authors "Wu, H. –K." and "Chang, H. –Y." stand out in terms of productivity and impact.

Table 2. Author Rankings

Author	Institution	Country	Number of articles	Number of citations	Link strength
Wu, Hsin-Kai	National Taiwan Normal University	Taiwan	4	634	141
Chang, Hsin-Yi	National Taiwan Normal University	Taiwan	5	625	148
Dede, Chris	Harvards Grad Sch Educ	USA	4	618	144
Liang, Jyh-Chong	National Taiwan Normal University	Taiwan	4	611	140
Squire, Kurt	University of California Irvine	USA	4	533	79
Delgado Kloos, Carlos	Universidad Carlos III de Madrid	Spain	3	522	75
Blanca Ibanez, Maria	Universidad Carlos III de Madrid	Spain	3	507	75
Klopfer, Eric	Massachusetts Institute of Technology	USA	3	484	77
Hwang, Gwo-Jen	National Taiwan University of Science and Technology	Taiwan	9	473	106
Yang, Stephen J. H.	National Central University	Taiwan	3	282	56

In the study, the article and citation rankings of the institutions where the authors work were examined. The data related to this are given in Table 3.

Table 3. Citation Ranking of Institutions

Institution	Country	Number of articles	Number of citations	Link strength
National Taiwan University of Science Technology	Taiwan	25	1587	554
National Taiwan Normal University	Taiwan	30	1119	448
National Kaohsiung Normal University	Taiwan	4	679	232
Harvard University	USA	5	610	194
University of Sevilla	Spain	22	152	185
Atatürk University	Turkey	13	172	175
University of Wisconsin	USA	8	571	161
Universidad Carlos III De Madrid	Spain	9	582	150
Massachusetts Institute of Technology	USA	4	483	124
University Simon Bolivar	Venezuela	3	525	122

When the table is examined, "National Taiwan University of Science Technology" stands out as the most productive institution in terms of the number of citations. "National Taiwan Normal University", on the other

hand, is the most productive institution in terms of the number of publications and ranks second in terms of the number of citations. The institutions in the top three are located in Taiwan.

Within the scope of the research, the data obtained by examining the most cited publications on the subject are given below (see Table 4).

Table 4. Most Cited Articles

NO	Article	Authors	Year	Source	Number of citations
1	Current status, opportunities and challenges of augmented reality in education	Wu, H. K., et al.	2013	Computers and Education	595
2	Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning.	Dunleavy, M., Dede, C., & Mitchell, R.	2009	Journal of science Education and Technology	424
3	Impact of an augmented reality system on students' motivation for a visual art course	Di Serio, Á., Ibáñez, M. B., & Kloos, C. D.	2013	Computers and Education	332
4	Environmental detectives - the development of an augmented reality platform for environmental simulations	Klopfer, E., & Squire, K.	2008	Educational Technology Research and Development	296
5	Augmented Reality in Education and Training	Lee, K.	2012	Techtrends	2013
6	New technology trends in education: Seven years of forecasts and convergence	Martin, S., et al.	2011	Computers and Education	197
7	Virtual laboratories for education in science, technology, and engineering: A review	Potkonjak, V., et al.	2016	Computers and Education	196
8	Augmented reality simulations on handheld computers	Squire, K., & Klopfer, E.	2007	Journal of the Learning Sciences	188
9	EcoMOBILE: Integrating augmented reality and probeware with environmental education field trips	Kamarainen, A. M., et al.	2013	Computers and Education	183
10	Evaluation of learners' attitude toward learning in ARIES augmented reality environments	Wojciechowski, R., & Cellary, W.	2013	Computers and Education	171

Table 4 gives information about the authors and citation numbers of the most frequently cited publications in WoS. According to these data, the most frequently cited publication with 582 citations was "Wu et al. (2013)". This is followed by the publications of "Dunleavy et al. (2009)" and "Di Serio et al. (2013)". Six of the most cited publications were published in the journal "Computers and Education".

Co-author Analysis (Author, Countries, Institution)

The data obtained by examining cooperation between the authors of the publications in WoS are given below (see Figure 3).

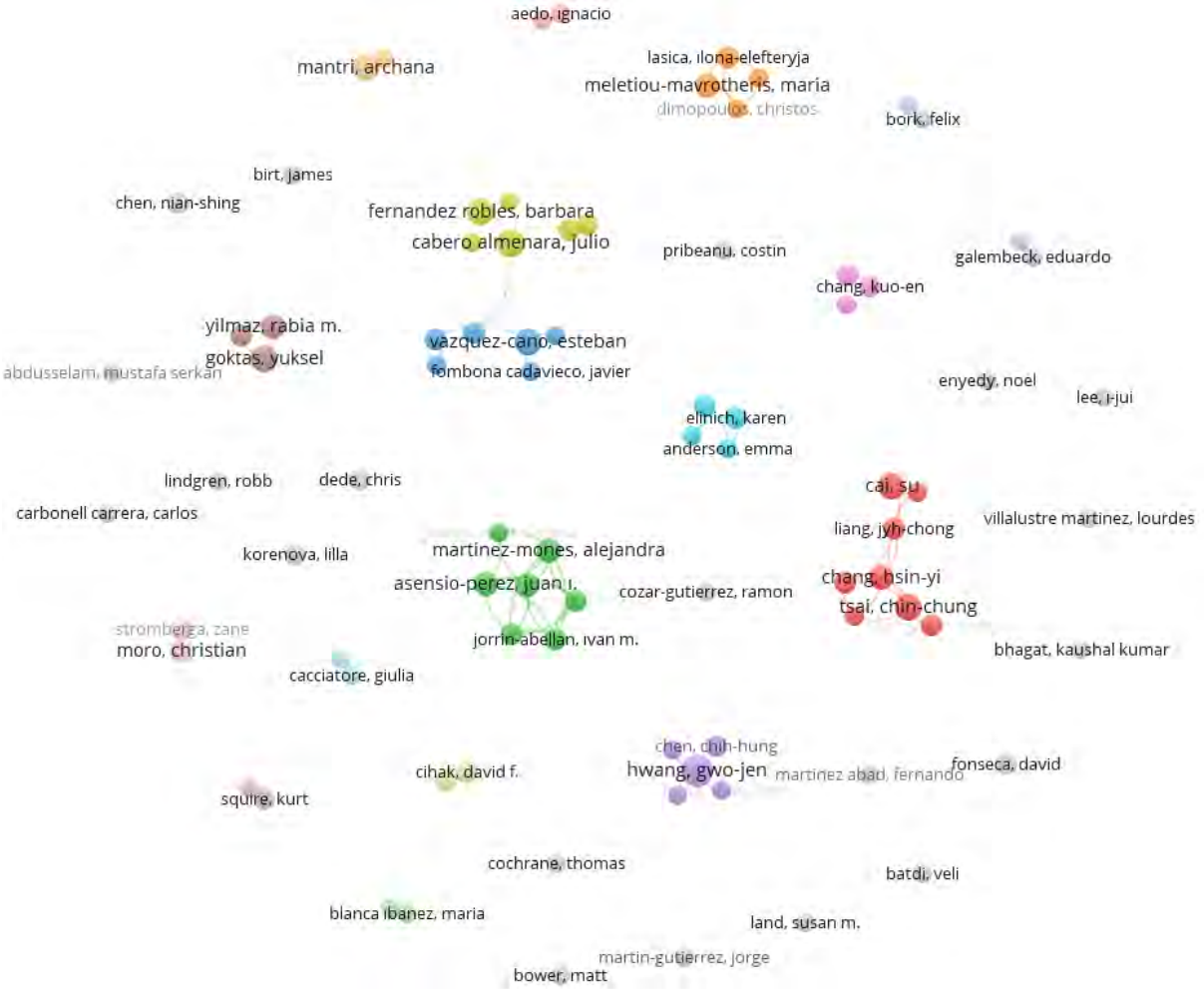

Figure 3. Co-author (Author) Network

When the co-author analysis of the studies on the subject is examined, it is seen that the authors who publish together generally have publications separately and in small groups. In addition, it is seen that there are authors who publish individually. Examples of outstanding author collaborations are "Tsai, C. - C.", "Chang, H. -S.", "Liang, J. –C." and "Cai, S.".

The analysis of co-authors for cross-country cooperation is presented in Figure 4. This figure shows that the closer the two countries are, the stronger and wider the connections of these countries.

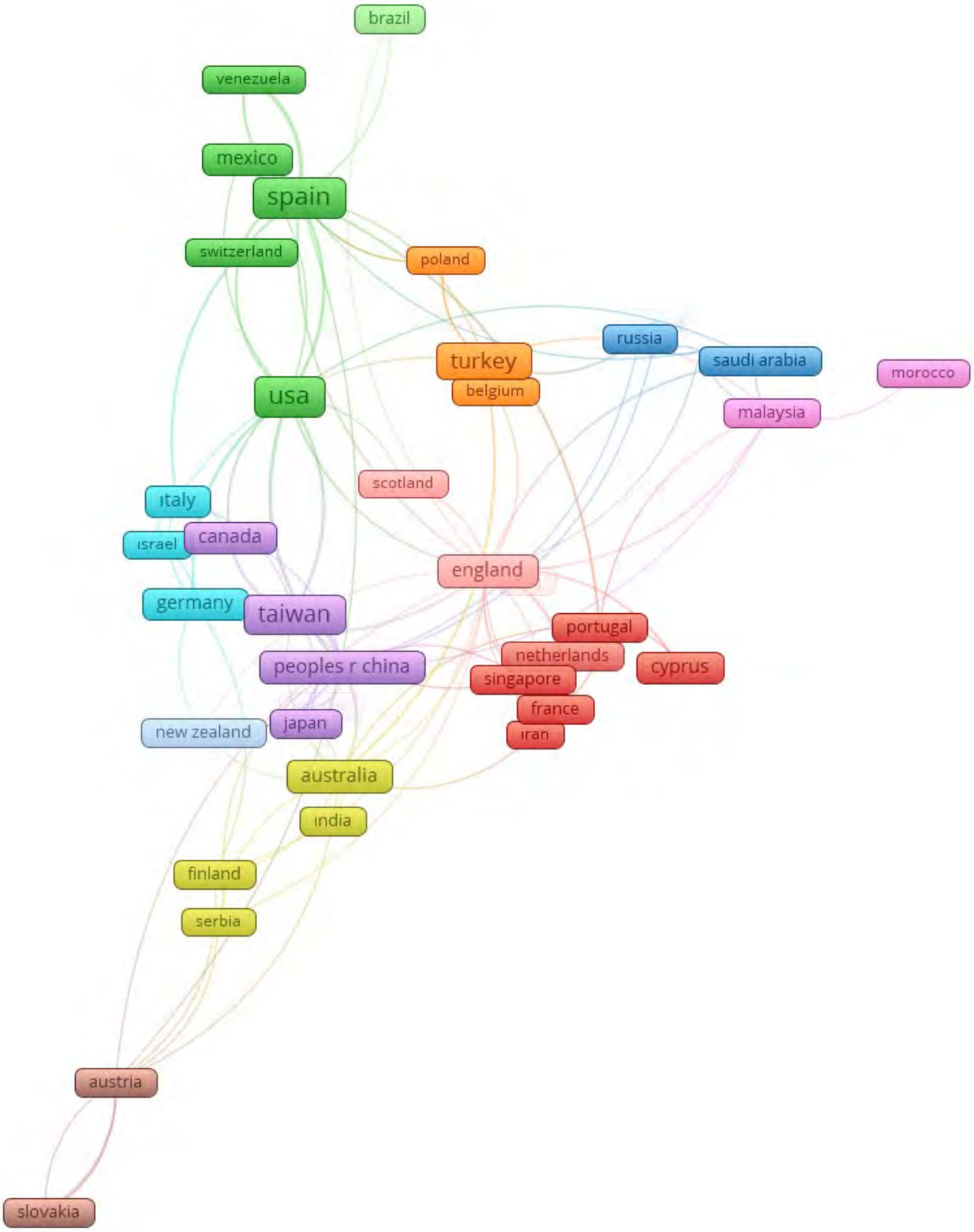

Figure 4. Network of Cooperation between Countries

When the countries of the co-authors are examined, it is seen that England worked with 21 countries and Spain with 15 countries. Australia followed the list (12 links), China (12 links), USA (11 links) and others.

A heat map has been used to comment on the co-authors' institutions. The co-author analysis for interinstitutional cooperation is presented in Figure 5.

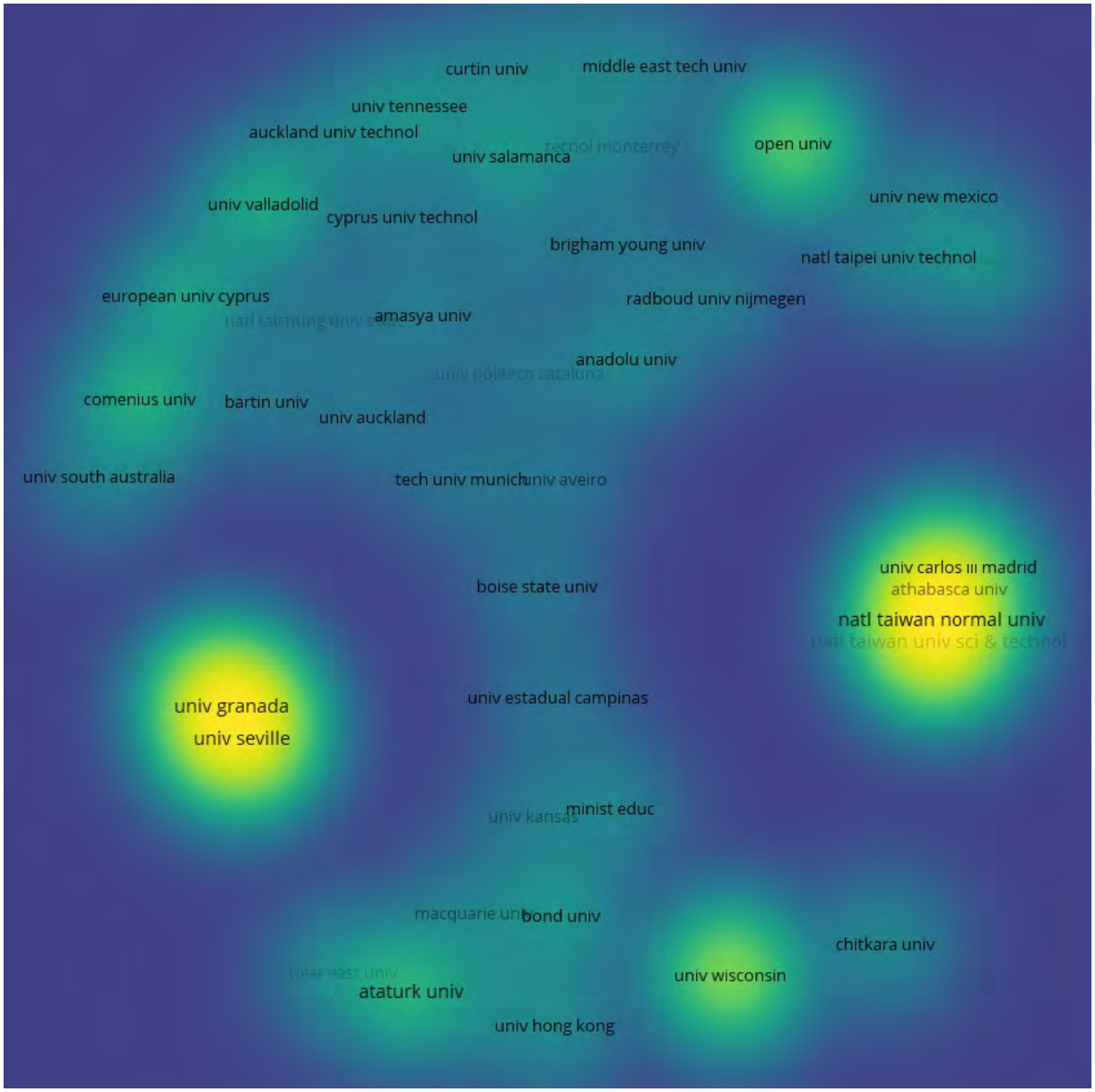

Figure 5. Institutional Cooperation Network

As can be seen in Figure 5, when the institutions of the co-authors are examined, it is seen that the network structure is very complex and there is no significant association structure. When the map is evaluated in general, it is seen that "University of Sevilla", "University of Granada", "Open University UK", "National Taiwan Normal University", "National Taiwan University of Science Technology", "Universidad Carlos III De Madrid" and "University of Wisconsin" dominantly take place.

Co-citation Analysis (Author)

The network structure of the co-citation analysis of the publications on the subject is given in Figure 6.

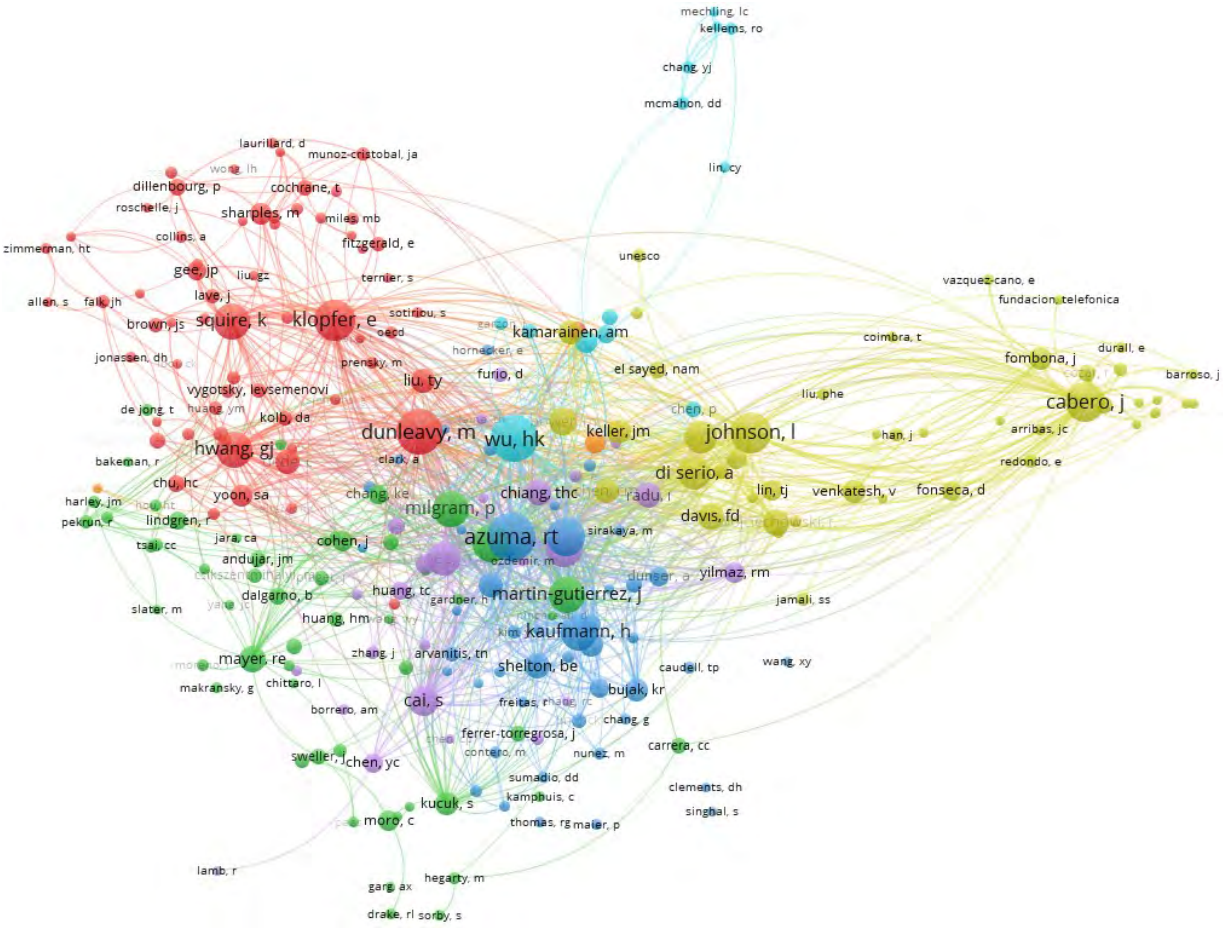

Figure 6. Co-citation (author) Network

Each round figure in Figure 6 indicates an author. Large circles indicate the predominance of cited publications. If there is a line between two author names, it indicates that these two authors work together. When the common citation network is examined, six different colored clusters are seen. Authors who receive many citations together are gathered in the same cluster. Publications in the center show that they are often cited from different fields and have more detailed connections with many clusters. Examining Figure 6 in its entirety, the red, green, yellow, and blue clusters are large and more prominent than the others. In addition, authors such as "Azuma, R. T.", "Wu, H. K.", "Dunleavy, M.", "Kaufmann, H.", "Cabero, J." and "Klopfer, E." appear to take place nearly at the center and be associated with many different clusters.

Co-occurrences Analysis

The network structure of the relationships between keywords is given in Figure 7. A bigger circle size indicates a more frequently discussed subject, while the yellow areas show current subjects. As can be seen in Figure 7, the words "augmented reality", "virtual reality", "mobile learning", "science education" and "mixed reality" are located at the center of the map. These words are concepts that have been studied together with other clusters and have been identified as the most frequently used keywords. It is noteworthy that current subjects are subjects such as "STEM education", "computer-based learning", "3D printing" and "usability."

Figure 7. Keywords Network Based on Co-Occurrence

Discussion and Conclusion

In this study, scientific studies published in international journals on the use of AR technology in STEM education have been examined through descriptive and bibliometric analysis. VOSviewer software has been used to analyze and visualize all this information. According to the results obtained, it was found that the first study on the subject was conducted in 2007 and that there has been an increase in the studies carried out in general from the past to the present. When the distribution of the studies by countries is examined, it is seen that especially Spain and the USA stand out, and Taiwan, Turkey, and China follow. In the study carried out by Abad-Segura et al. (2020), it was found that the publications on the sustainability of AR in higher education increase every year. Similar to our study results, López-Belmonte et al. (2020) found that the number of publications on this subject reached the highest level in the last five years. Again, in the same study, it was found that the country with the most publications on this subject is Spain (López-Belmonte et al., 2020). In the research conducted by Karakus et al. (2019), it was found that the year with the most number of publications on this subject was 2017, and Spain, Taiwan, and the USA are the countries with the most publications on this subject. Spain and Taiwan have been among the countries that have been prevalent both qualitatively and quantitatively in the literature of this important field for the last two decades. Similarly, Chen, Liu, Cheng and Huang (2017) found that Spain and Taiwan are the leading countries in education-related AR publications. In recent years, it has been observed that investments made in such educational technologies by both public and private institutions have increased in these countries (Cheng & Tsai, 2013; Martín-Gutiérrez et al., 2017; Wu et al., 2013).

When the distribution of the highest number of publications on the subject by journals is analyzed, the journals that included publications on this subject the most were found to be "Computers & Education" and "Interactive Learning Environments". When the number of citations per publication are examined, it is seen that "Computers & Education", "Anatomical Sciences Education" and "British Journal of Educational Technology" stand out. It

can be stated that these journals are among the important journals related to the use of technology in education. Similar results have been obtained in the literature on this subject. For example, Arici et al. (2019) found that the most cited journals were "Computers & Education", "Educational Technology & Society" and "The Journal of Science Education and Technology". Again Abad-Segura et al. (2020) and López-Belmonte et al. (2020), found that "Computers & Education" was among the journals that included publications on this subject the most. One of the journals with the highest h-index, this journal attracts great attention among academics and researchers with the highest number of citations and the highest average number of citations per published article. Similarly, Karakus et al. (2019) found that "Computers & Education", "Educational Technology and Society", "Eurasia Journal of Mathematics, Science and Technology Education" and "Interactive Learning Environments" were the journals with the most publications on the subject.

When the number of articles and citations of the most productive and influential authors were examined, it was found that "Wu, H. –K." and "Chang, H. –Y." authors stand out. Since these authors are among the leading authors on AR in the literature, it can be stated that this result is not surprising. Five of the 10 most prolific authors in publishing articles on this subject are located in Taiwan, which demonstrates the country's superiority in this field. In addition, most of these authors are from "National Taiwan Normal University", "National Taiwan University of Science and Technology", and "National Central University" and discuss the connections of the most important teams in this field. The most distinguished writers and institutions are also from Taiwan, USA, and Spain. Arici et al. (2019), in a bibliometric analysis of published studies on the use of AR in science education, concluded that Azuma, Dunleavy, and Klopfer are the most cited authors in this field. On the other hand, Karakus et al. (2019) found that "Tsai, C. C." and "Hwang, G. J." were the most productive and effective authors in this field. In the same study, it was concluded that "Wu, H. –K." was the most cited author (Karakus et al., 2019).

According to the research results, the most frequently cited publication belongs to "Wu et al. (2013)". Publications by "Dunleavy et al. (2009)" and "Di Serio et al. (2013)" follow respectively. Similar to our study, López-Belmonte et al. (2020) found that the publications by the same authors are the most frequently cited publications. Again, Karakus et al. (2019) found that the most frequently cited publications belong to "Wu et al. (2013)" and "Dunleavy et al. (2009)".

When institutions are considered in terms of productivity, "National Taiwan University of Science Technology" stands out as the most productive institution in terms of the number of citations. "National Taiwan Normal University", on the other hand, is the most productive institution in terms of the number of publications and ranks second in terms of the number of citations. Some of the most influential writers in this field also work in these institutions. The institutions in the top three are located in Taiwan. Also, three institutions are in the USA, two in Spain, one in Turkey, and one in Venezuela. In the research carried out by Abad-Segura et al. (2020), it was found that "National Taiwan University of Science Technology" is the most productive institution. Similarly, Karakus et al. (2019) found that "National Taiwan University of Science and Technology" and "National Taiwan Normal University" are the best institutions in this research area.

When the co-author analysis of the studies on the subject is examined, it is seen that the authors who publish together generally have publications separately and in small groups. In addition, it is seen that there are authors who publish individually. Examples of outstanding author collaborations are "Tsai, C. - C.", "Cheng, K. -H." and "Wu, H. - K.". When the countries of the co-authors were examined, it was found that England worked with 21 countries, Spain with 15 countries, and Australia with 12 countries. Abad-Segura et al. (2020) found that England works with 36 countries, Spain with 29 countries and Australia with 29 countries. When the institutions of the co-authors are examined, it is seen that the network structure is very complex and there is no significantly prominent association structure. As a result of the research, it was found that "University of Sevilla", "University of Granada", "Open University UK", "National Taiwan Normal University", "National Taiwan University of Science Technology", "Universidad Carlos III De Madrid" and "University of Wisconsin" take place predominantly.

Co-occurrences analysis reflects the content analysis of the examined studies and reveals commonly-used concepts. It is seen that the concepts that come to the fore in the clusters of the analysis are "augmented reality", "virtual reality", "mobile learning", "science education" and "mixed reality". Similarly, Arici et al. (2019), in the analysis of the studies on the use of AR technology in science education, found that the most used keywords are "mobile learning", "e-learning" and "science education/learning". Abad-Segura et al. (2020) revealed that the keywords "augmented reality", "simulation", "education" and "learning" come to the fore. Karakus et al. (2019) found that "mobile learning", "virtual reality", "e-learning" and "interactive learning environments" are the most studied concepts.

Recommendations

AR is a relatively new technology used in education and various other disciplines. This research provides an overview of the developments in published research on the use of AR technology in STEM education. In this context, it can be considered a limitation that the publications in other databases such as "Scopus (A&I)", "Taylor & Francis Online" and "ERIC" could not be included in the analysis. As the digital era in education has begun, more research is needed in this field in order to take more concrete steps in educational institutions. Therefore, it may be suggested that similar studies be conducted in the future use different databases. Studies to be conducted in journals with high impact factors, in particular, may be among the research topics. Additionally, it may be suggested to use methods such as meta-analysis in future studies. It is thought that the study will guide the field experts in determining different study topics and can be a resource that they can refer to for new research on this subject.

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