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Augmented Reality Research in Education: A Bibliometric Study

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ABSTRACT

The aim of this study is identifying the publications related to Augmented Reality (AR) in education and describing the features of those studies. The Web of Science database was searched for publications on AR in education. Bibliographic coupling of the countries, bibliographic coupling of the institutions, bibliographic coupling of the journals, bibliographic coupling of the publications, bibliographic coupling of the authors, and co-occurrences of the author keywords were examined for the selected publications. Bibliographic visualisation methods were used to analyse and visualise the characteristics of the selected publications. A total of 437 publications were selected following the research criteria between 1999 and 2018. The results revealed that virtual reality, mobile learning, interactive learning environments, and e-learning were among the most studied concepts in AR research. *Computers & Education*, *EJMSTE*, *Educational Technology and Society*, and *Interactive Learning Environments* have been among the top journals, Spain and Taiwan have been the most important countries, C.C. Tsai and G.J. Hwang have been the most important authors and National Taiwan University of Science and Technology has been the top institution in this research area. The research trend and the progress of the concept of augmented reality in education have been discussed in the paper.

Keywords: augmented reality, bibliometric analysis, bibliographic coupling, educational technology

INTRODUCTION

AR can be defined as a real-time direct or indirect view of a real setting that has been enhanced by virtual computer-aided technologies (Carmigniani & Furht, 2011). Azuma (1997) proposed that AR has three important dimensions, such as the combination of both virtual and real items in the environment, being able to interact with these items in real time, and the accurate registration of those real and virtual items.

Most of the studies on AR in education are based on constructivist and situated learning theories (Koutromanos, Sophos, & Avraamidou, 2015). In the constructivist approach, learners are encouraged to comprehend and construct their knowledge using the information they perceive from the outer world. In situated learning theory, knowledge is built actively by the learners through social processes in an enhanced environment (Fosnot & Perry, 1996). In this context, AR applications employ both real and virtual environments, and learners are encouraged to build and construct knowledge in collaboration with other learners.

Every year, the quality and the quantity of the publications in AR in educational settings are increasing, and this topic takes more interest of the researchers in education. The opportunities provided by virtual technologies will make it possible to break the boundaries of formal education (Martín-Gutiérrez, Mora, Añorbe-Díaz, & González-Marrero, 2017). AR has already broken the barriers of formal education for the ones who can access these technologies and made it possible to reach a quality education from everywhere in the world, in an informal way and through ubiquitous technologies obtained by everyone (Goff, Mulvey, Irvin, & Hartstone-Rose, 2018).

Contribution of this paper to the literature

- This study explores the characteristics of publications in the area of AR and understand the research trend in this area. The AR concept is mostly studied in the areas of science education, mathematics education, and educational technology.
- The results revealed that virtual reality, mobile learning, interactive learning environments, and e-learning were among the most studied concepts in AR research.
- The analyses showed that the leading countries in augmented reality in education are Spain and Taiwan.

There are many beneficial outcomes of using AR in educational settings, such as higher levels of academic performance, motivation to learn, enjoyment, interest in the subject, content engagement, and content retention (Atwood-Blaine & Huffman, 2017; Goff et al., 2018; Salmi, Thuneberg, & Vainikainen, 2016). Some studies also showed evidence that AR applications can help to attract the interests of the girls and the other disadvantaged groups to the science topics (Atwood-Blaine & Huffman, 2017; Mulvey, Miller, & Rizzardi, 2017).

The aim of this study is identifying the publications related to AR in education and describing the characteristics of those studies. Bibliometric analysis was employed in this study to explore the characteristics of the publications in the area of AR and understand the research trend of this area.

Bibliometrics can be defined as “the application of mathematical and statistical methods to books and other media of communication” (Pritchard, 1969). Research items in a scientific discipline can be classified through bibliographic analysis according to their bibliographic information, such as citations, keywords, topics, institutions, countries, authors, sources, and titles. Employing more sophisticated bibliographic analysis methods, a researcher can create bibliographic maps using the same data, visualise and explore those maps, analyse bibliometric networks, make bibliographic coupling, and analyse the strengths of the bibliographic coupling links.

Using these sophisticated techniques, bibliographic maps can be created, visualized, and explored. Researchers use items to create those maps. Items might be authors, publications, or terms. A map generally consists of only one type of item. There are also links between pairs of items. Links show the connections or relationships between items. In this study, bibliographic coupling links and co-occurrence links are being illustrated. Each link has strength, shown by a numerical value. A higher numerical value of link strength shows a stronger link between items. The link strength means the number of cited references two items have in common. Also, when interpreting co-occurrence links, link strength represents the counts of publications in which two terms occur at the same time. Links and items form a bibliographic network together (Newman, 2004; Perianes-Rodriguez, Waltman, & Van Eck, 2016; Waltman, Van Eck, & Noyons, 2010; Waltman & Van Eck, 2013; Van Eck & Waltman, 2009; Van Eck, Waltman, Dekker, & Van den Berg, 2010).

Both the quality and quantity of the publications are important to compare journals, countries, authors, and institutions. Bibliometrics is a kind of quantitative analysis that uses various patterns of publications. There are both evaluative and descriptive methods that can be used in bibliometrics methodology. Evaluative methods, such as bibliographic maps, bibliographic networks, and bibliographic coupling are used to evaluate and compare the impacts of publications in a more complex manner than descriptive methods. Descriptive methods, such as describing the bibliographic information (e.g. countries, institutions, authors, and journals) as it is, are simpler than evaluative methods. Simple comparisons can be made through descriptive methods, while the impact of the publications can be understood and interpreted using evaluative methods (McBurney & Novak, 2002).

This study used the Web of Science (WoS) to search for the most important publications in augmented reality literature in education. WoS is the world-leader to store and process the scientific information in all scientific disciplines and contains the most important databases, such as Social Sciences Citation Index (SSCI), Science Citation Index (SCI) Expanded, Arts and Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI). The researchers retrieved and analysed the information from those databases, employing both descriptive and evaluative bibliographic analysis methods.

MATERIALS AND METHODS

The researchers searched for Social Sciences Citation Index (SSCI), Science Citation Index (SCI) Expanded, Arts and Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI) of the Web of Science Core Collection on November 17, 2018 to retrieve the publications on augmented reality in education. Augmented reality was entered into the topic field as a keyword to search for it in the titles, abstracts, author keywords, and keywords plus of the publications. At first, there were a total of 5095 publications within these databases published at all fields (e.g. computer science, software engineering, electrical and electronic engineering, information systems, surgery, telecommunications, biomedical engineering, cybernetics, optics, robotics, ergonomics, clinical neurology, construction building technology, automation control systems, industrial engineering, materials science, applied

Table 1. Publication Records and Percentages by Publication Years

Publication Years	Publication Records	% of 437
2018	86	19.67
2017	115	26.32
2016	63	14.41
2015	42	9.61
2014	47	10.75
2013	35	8.01
2012	19	4.34
2011	13	2.97
2010	3	0.68
2009	6	1.37
2008	2	0.46
2007	1	0.23
2006	1	0.23
2003	2	0.46
2001	1	0.23
1999	1	0.23

physics, neurosciences, urology, nephrology, dentistry, archaeology, chemistry, architecture, applied psychology, mechanical engineering, general medicine, geosciences, environmental sciences, applied mathematics, and oncology). Among the Web of Science categories, only the categories of Education, Educational Research and Education Scientific Disciplines were selected, and the search results were refined. When search results were refined, there were 445 publications. The content of each publication was checked to ensure their relevancy to the subject matter, and the irrelevant ones were excluded. After the final check, 8 publications were excluded and there were 437 publications to be analysed. In other words, 8.57% of the publications in the world literature were exactly related to education, educational research, and education scientific disciplines. When the researchers generally overviewed the content of those publications, it was determined that most of those publications were related to science and math education.

This study used bibliometric visualisation methods and bibliometric analysis. As a quantitative method, the bibliometric analysis uses both evaluative and descriptive approaches to represent the research trend and the characteristics of a set of publications (McBurney & Novak, 2002). Bibliometric visualising methods are employed to show a structural overview of a specific area of research (Garfield, 2009). CitNetExplorer and VOSviewer are among the most popular computer software designed and developed to present some visualising techniques (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014a; Van Eck & Waltman, 2014b; Van Eck, Waltman, & Glanzel, 2017). VOSviewer software was used in this study to retrieve, analyse, and visualise the information about the publications in this area. Bibliographic coupling of the countries, bibliographic coupling of the institutions, bibliographic coupling of the journals, bibliographic coupling of the publications, bibliographic coupling of the authors, and co-occurrences of the author keywords were extracted and analysed through VOSviewer. For each type of analysis, there is a threshold value that indicates the minimum number of items to be included in the analysis. VOSviewer allows the user to determine the threshold value case sensitively. For instance, while the journals coupled bibliographically, the minimum number of publications per journal was determined as 10 by the researchers. This number is the threshold value for this analysis.

437 publications have been retrieved and analysed in total. Most of the items were articles (406 items), and the rest of them were reviews (14 items), editorial materials (10 items), book reviews (4 items), and proceedings papers (4 items). **Table 1** shows the publication records and their percentages by publication years. According to the results, the first item on AR was published in 1999, and the number of publications differed from year to year. The number of publications increased meaningfully after 2011 and 2017 was at the top of this list.

RESULTS

The results of the analyses are presented in this section. While presenting different categories of bibliometric analysis results, the researchers followed a deductive way similar to the one followed by Lee, Felps, and Baruch (2014) and Ersozlu and Karakus (2019). The results have been presented in a way starting from the more general findings and flowing to more specific ones, namely, bibliographic coupling of the countries, bibliographic coupling of the institutions, bibliographic coupling of the journals, bibliographic coupling of the publications, bibliographic coupling of the authors, and co-occurrences of the author keywords. This flow of the content enables readers to follow the relationships starting from the more general information and then to find out specific information that explain the former ones respectively.

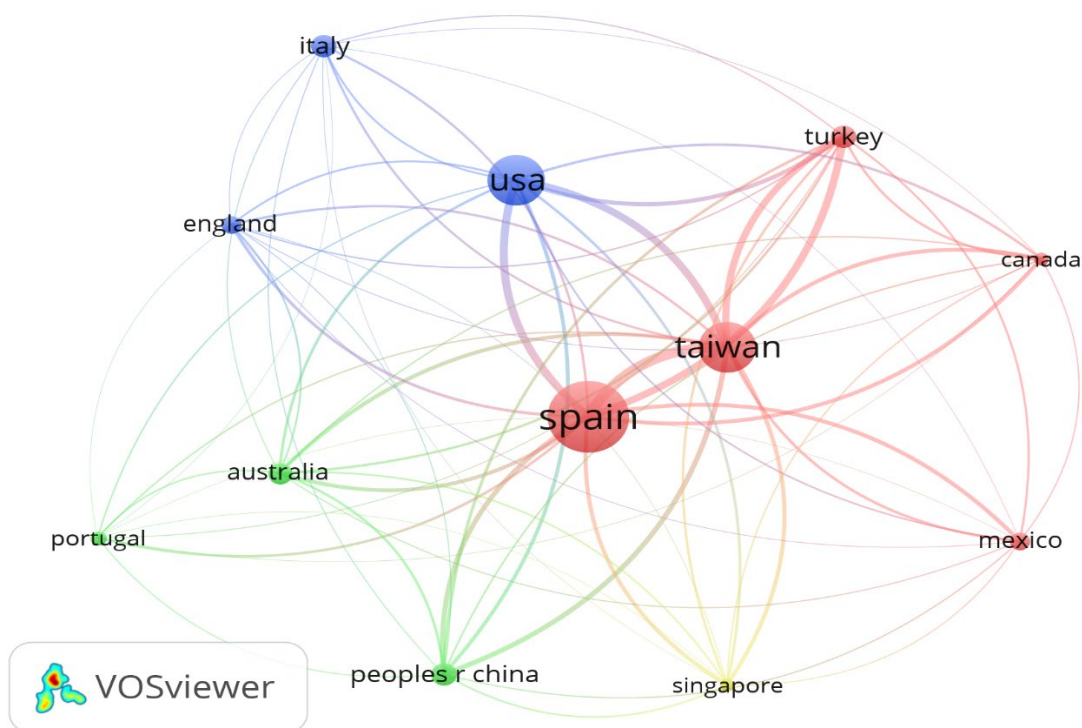


Figure 1. Bibliographic coupling of the countries (network visualization)

Bibliographic Coupling of the Countries

Bibliographic coupling of the countries is presented in **Figure 1** with network visualization. A country's minimum number of publications was 8. Of the 58 countries, 12 met the threshold. For all of the countries, the number of publications, the number of citations, and total link strength were calculated. The countries with the greatest total link strengths were selected. Number one was Spain with 120 publications, 988 citations, and 13941 total link strength. For the other countries, the first numbers stand for the number of publications, the second ones are the number of citations, and the third ones are the total link strengths. The other countries were; Taiwan (69; 1253; 12794), USA (67; 1376; 7279), Turkey (19; 62; 6244), Peoples Republic of China (18; 85; 3371), Australia (17; 189; 2526), Canada (8; 125; 2254), Singapore (8; 64; 2063), Mexico (13; 12; 1552), England (13; 122; 1121), Italy (18; 68; 786), and Portugal (9; 22; 665). In **Figure 1**, different colours show different clusters that were more frequently linked with each other. It means that the studies originated from the countries in the same cluster cite each other more frequently. At the biggest cluster, there are Spain, Taiwan, Turkey, Canada, and Mexico. USA, England, and Italy are included at the second cluster. Australia, Peoples Republic of China, and Portugal are at the third cluster.

Bibliographic Coupling of the Institutions

Bibliographic coupling of the institutions is presented in **Figure 2** with overlay visualisation. Only the organisations that have the minimum number of 6 publications were included in the analysis. Of the 424 organisations, 16 met the threshold. For all those organisations, the total strengths of the bibliographic coupling links and the number of publications and citations were calculated. The organisations with the highest total link strengths were selected. National Taiwan University of Science and Technology (Taiwan) was the most influential institution in this list with 21 publications, 726 citations, and 3156 total link strength. National Taiwan Normal University (Taiwan) was the second with 18 publications, 455 citations, and 2294 total link strength. For the other institutions, the first number stands for the number of publications, the second one is the numbers of citations, and the third one is their total link strengths: University of Seville (Spain) (15; 21; 2101), Carlos III University of Madrid (Spain) (9; 258; 1322), Ataturk University (Turkey) (6; 25; 1314), National Central University (Taiwan) (8; 129; 1110), University of Cordoba (Spain) (7; 4; 1100), National Chiao Tung University (Taiwan) (6; 129; 1089), University of Malaga (Spain) (6; 2; 688), University of La Laguna (Spain) (12; 42; 632), Universitat Politècnica de València (Technical University of Valencia) (Spain) (6; 128; 482), University of Salamanca (Spain) (6; 15; 458), University of Valladolid (Spain) (6; 16; 302), University of Murcia (Spain) (7; 2; 259), University of Huelva (Spain) (6; 87; 198), and

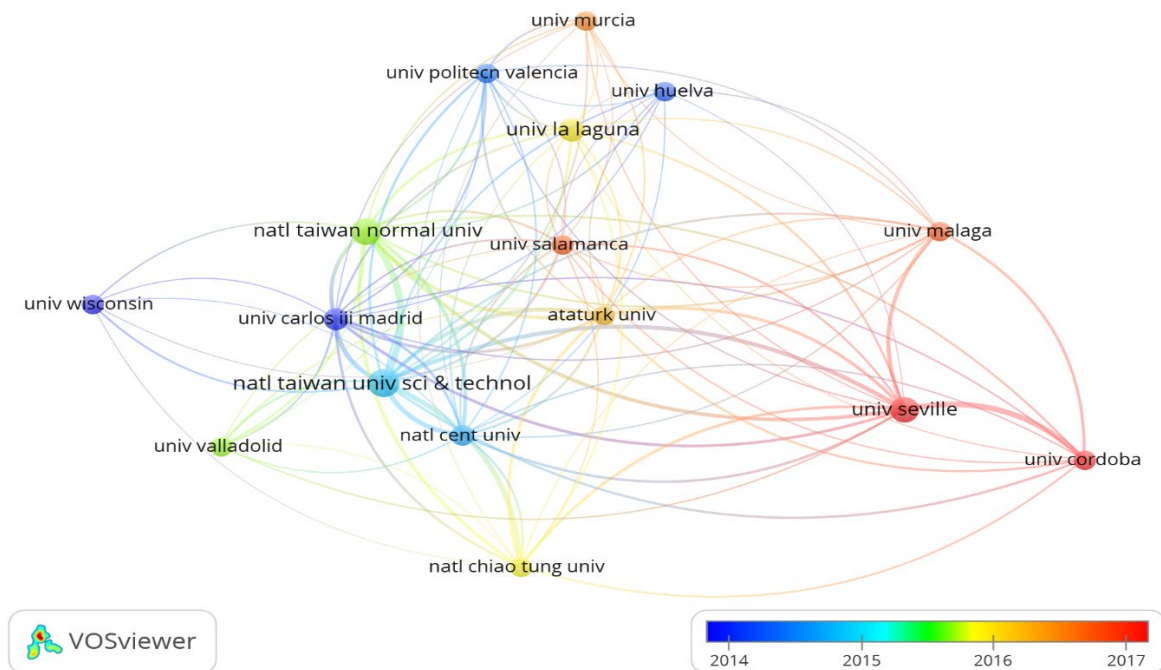


Figure 2. Bibliographic coupling of the institutions (overlay visualization)

University of Wisconsin-Madison (USA) (7; 387; 147). Of those top universities in the area of augmented learning, there are ten universities from Spain, four universities from Taiwan, a university from Turkey, and a university from the USA. Colours in **Figure 2** show the clusters of those universities according to the publication years of the related studies. It shows that the most recent publications originated from the Spanish universities: the University of Seville, University of Malaga, University of Cordoba, University of Salamanca, and the University of Murcia.

Bibliographic Coupling of the Journals

Bibliographic coupling of the journals is presented with density visualisation in **Figure 3**. As inclusion criteria, a journal's minimum number of publications was 10. Of the 143 journals, 12 met the threshold. For those 12 journals, the number of publications, their citations, and their total strength of the bibliographic coupling links with other journals were calculated. The journals with the greatest total link strength were selected. In **Figure 3**, each circle stands for a journal, the density of the journal was illustrated through different colours. This density visualization was weighted by the number of publications for each journal. The colours turning to yellow and then red means bigger number of publication for the related journal. The number one is Computers & Education with 39 publications, 1657 citations, and 3500 total link strength. Although Eurasia Journal of Mathematics, Science, and Technology Education (EJMSTE) has the second biggest number of publications in this area (17), it is in the fifth order according to the overall scores. For all the sources, the first number stands for the number of publications, the second one is the number of citations, and the third one is the total link strength. The other journals are; Educational Technology & Society (14; 300; 1913), Interactive Learning Environments (16; 127; 1629), IEEE Transactions on Learning Technologies (11; 104; 1532), EDMETIC (14; 16; 1348), EJMSTE (17; 32; 861), Computer Applications in Engineering Education (12; 218; 738), International Journal of Engineering Education (12; 61; 675), TechTrends (11; 139; 606), British Journal of Educational Technology (10; 89; 594), International Journal of Emerging Technologies in Learning (11; 9; 579), and Pixel-Bit: Revista de Medios y Educación (10; 5; 419).

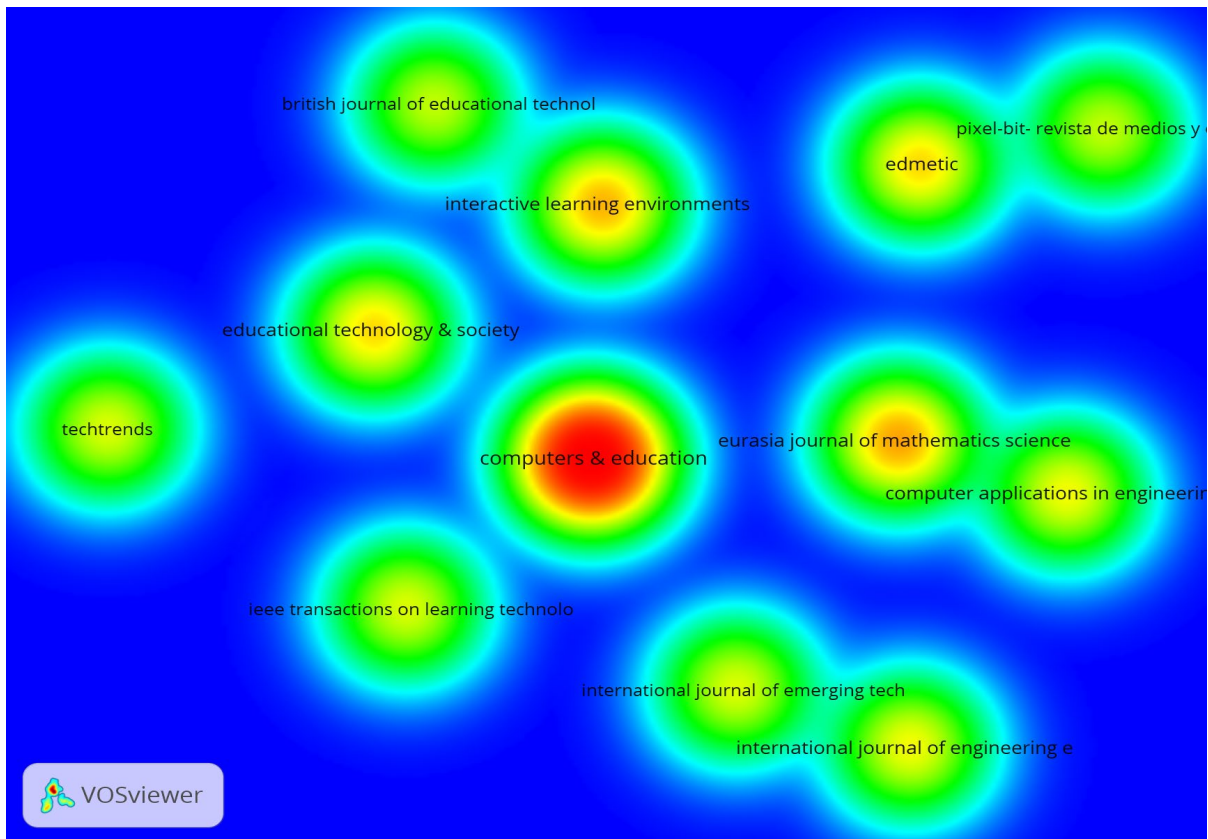


Figure 3. Bibliographic coupling of the journals (density visualization)

Bibliographic Coupling of the Publications

Bibliographic coupling of the publications is presented in **Figure 4** with network visualisation. Only the publications that have a minimum number of 85 citations were included in this analysis. Of the 437 documents, 9 met the threshold. For all the publications, the number of citations and their total link strengths were calculated. The documents with the greatest total link strength were selected. The strongest one was Wu, Lee, Chang, and Liang (2013) with 258 citations and 29 total link strength. Although Dunleavy, Dede, and Mitchell (2009) is the second most cited article in this area with 242 citations, it was in the fifth order because of the smaller total link strength (13). For each publication, the first number stands for the number of citations and the second one is the total link strengths. The other publications are listed in order of their total link strengths; Cheng and Tsai [2013; (96; 25)], Kamarainen, Metcalf, Grotzer, Browne, Mazzuca, Tutwiler, and Dede [2013; (85; 22)], Squire and Klopfer [2007; (142; 18)], Dunleavy et al. [2009; (242; 13)], Klopfer and Squire [2008; (187; 13)], Bacca, Baldiris, Fabregat, and Graf [2014; (95; 13)], Di Serio, Ibáñez, and Kloos [2013; (129; 10)], and Liu [2009; (88; 1)].

The most cited and most influential article in this field is Wu et al. (2013). This review article overviewed the definitions, taxonomies, and technologies of AR in education. They suggested viewing AR as a concept rather than a type of technology. They explained certain characteristics and affordances of various AR applications. They compared it to other technological systems or learning environments, such as ubiquitous and mobile learning environments. They emphasised the instructional approach, technology design, instructional approach, and learning experiences in AR applications. Instructional approaches are divided into three categories emphasizing the roles, tasks, and locations, and discussed their effectiveness in student learning. They also mentioned the technological, pedagogical, and learning challenges brought about by AR applications and offered suggestions for those challenges.

The second most influential publication in this field is Cheng, and Tsai (2013). This review article aimed to understand how augmented reality (AR) could increase the effectiveness of science education. AR technology in science education was taken up within two main utilisation methods, such as image-based AR and location-based AR. The affordances of each approach in science education were explained in detail. It was proven that inquiry-based scientific activities are afforded by location-based AR while image-based AR supports spatial ability, practical skills, and conceptual understanding of students. Suggestions were also made for future research attempts in this area. Learning experience and learner characteristics related to AR were proposed as two main topics that

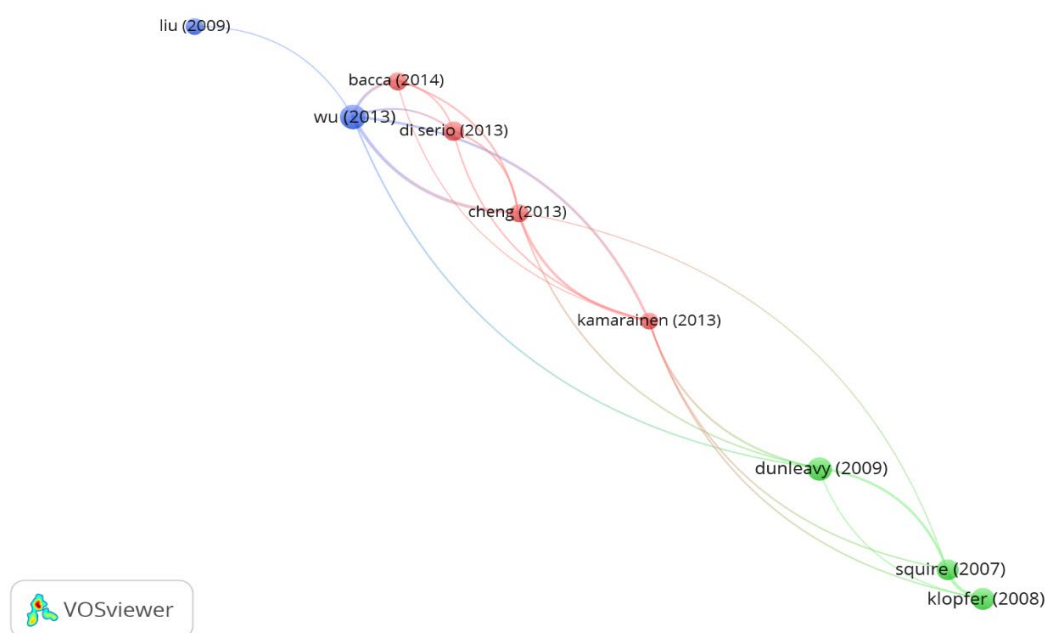


Figure 4. Bibliographic coupling of the publications (network visualization)

Notes: Wu (2013): Wu, Lee, Chang, & Liang (2013); Cheng (2013): Cheng & Tsai (2013);

Kamarainen (2013): Kamarainen, Metcalf, Grotzer, Browne, Mazzuca, Tutwiler, & Dede (2013);

Squire (2007): Squire & Klopfer (2007);

Dunleavy (2009): Dunleavy, Dede, & Mitchell (2009);

Klopfer (2008): Klopfer & Squire (2008);

Bacca (2014): Bacca, Baldiris, Fabregat, & Graf (2014);

Di Serio (2013): Di Serio, Ibáñez, & Kloos (2013);

Liu (2009): Liu (2009).

should be explored by future research. Mixed methods and in-depth examination of user experiences were offered as the best methodological approaches. Combining image-based and location-based AR technology was suggested for science education researchers.

The third most influential publication in this field is Kamarainen et al. (2013). This research article combined AR experiences with the use of environmental probeware during a field trip to a local pond environment. This activity was a part of the larger EcoMOBILE project that aimed to assist middle school students' understanding and interpretation of water quality measurements. This pilot study was performed with five groups of sixth graders, with pre-field trip training, a field trip to a local pond environment, and post-field trip discussions in the classroom. During their field trip, students used a mobile wireless device, which is an augmented reality application, to navigate the environment and observe virtual media and information in this environment. They also implemented a probeware-based activity to collect water quality measurements at designated areas. The authors measured the variables related to learning and instruction, such as written and verbal feedbacks provided by teachers, attitudes of students, and content learning gains. They also observed some affective variables of students and their understanding of the content after the implementation. As a result, they found that student interaction with the environment and with classmates increased after they used combined technologies in a student-centred manner. They measured a deeper understanding of the subject matter than with other field trips without AR applications. This application also caused students to develop positive attitudes towards those kinds of scientific activities.

Bibliographic Coupling of the Authors

Bibliographic coupling of the authors is presented in [Figure 5](#) with overlay visualisation. An author's minimum number of publications was 5 to be included in this analysis. Of the 1045 authors, 12 met the threshold. For all the authors, the number of publications, the number of citations, and their total link strengths were calculated. The authors with the greatest total link strengths were selected. The strongest author was C.C. Tsai (from Taiwan, National Taiwan University of Science and Technology) with six publications, 192 citations, and 915 total link strength. Although G.J. Hwang (from Taiwan, National Taiwan University of Science and Technology) has the

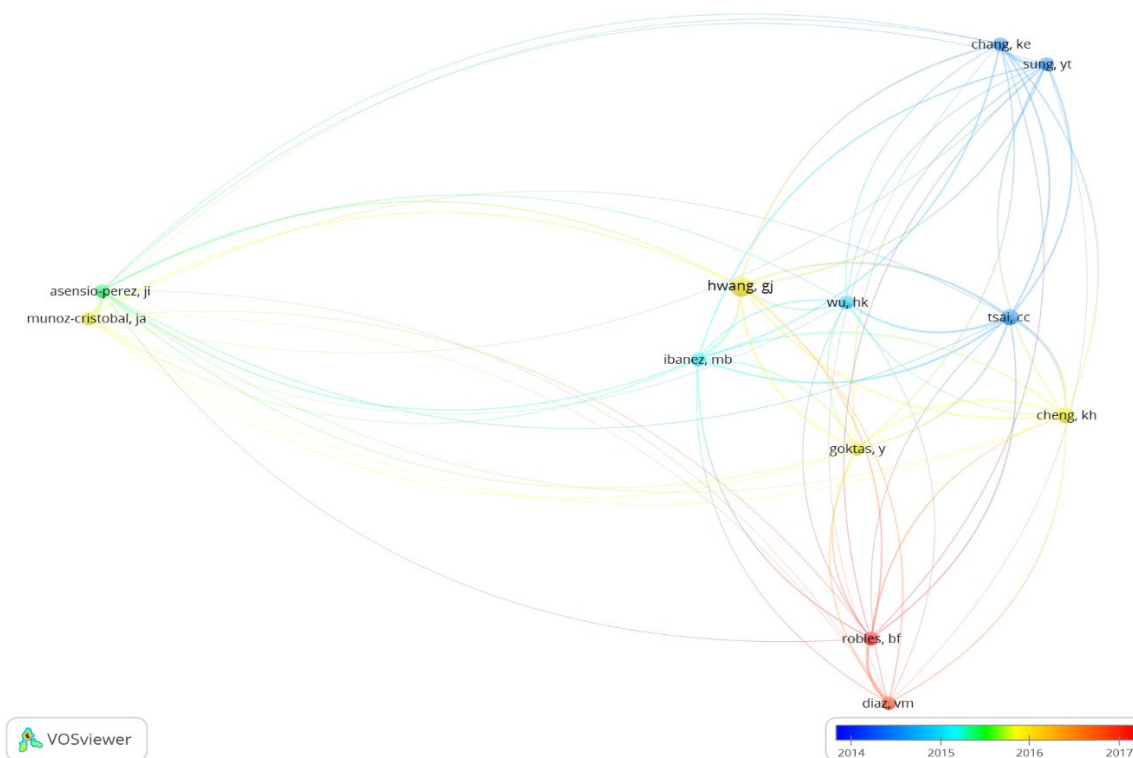


Figure 5. Bibliographic coupling of the authors (overlay visualization)

biggest number of publications (9), he was the second strongest author in this bibliographic coupling due to a lesser number of citations (147) and total link strength (843). For all the authors, the first number stands for the number of publications, the second one is the number of citations, and the third one is the total link strengths. The rest of the authors are presented in order; K.H Cheng (from Taiwan, National Chiao Tung University) (6; 129; 759), M.B. Ibanez (from Spain, Carlos III University of Madrid) (5; 233; 754), Y. Goktas (from Turkey, Ataturk University) (5; 25; 630), K.E. Chang (from Taiwan, National Taiwan Normal University) (5; 131; 605), Y.T. Sung (from Taiwan, National Taiwan Normal University) (5; 131; 605), J.I. Asensio-Perez (from Spain, University of Valladolid) (5; 16; 538), J.A. Munoz-Cristobal (from Spain, University of Valladolid) (5; 13; 529), B.F. Robles (from Spain, University of Isabel) (5, 0, 477), H.K. Wu (from Taiwan, National Taiwan Normal University) (5, 299, 418), V.M. Diaz (from Spain, University of Cordoba) (5; 1; 349). H.K. Wu is the most cited author in this field with 299 citations; however, she is at the eleventh order in this list due to her lesser number of total link strength. Of those 12 strongest authors, there are six scholars from Taiwan, five scholars from Spain, and a scholar from Turkey. It proves the prevalence of Spain and Taiwan in this area of research. There are also three scholars from National Taiwan Normal University, two scholars from National Taiwan University of Science and Technology, and two scholars from the University of Valladolid in the list of the strongest authors. It shows the addresses of the strongest research teams in this area. Colour differences in **Figure 5** show the clusters of those authors according to the publication years of their studies. It shows that B.F. Robles and V.M. Diaz have the most recent studies among these authors.

Co-Occurrences of the Author Keywords

Co-occurrences of the author keywords are presented in **Figure 6** with network visualisation. As inclusion criteria, the minimum number of occurrences of a keyword was 8. Of the 1098 keywords, 18 met the threshold. For all the keywords, the number of occurrences and their total link strength with other keywords were calculated. The keywords with the greatest total link strength were selected. Augmented Reality was the most frequent keyword with 238 occurrences and 136 total link strength. For the others, the first number stands for their occurrences and the second one is their total link strength. Virtual reality was the second (35; 41), and mobile learning was the third (37; 38). The other terms were; interactive learning environments (24; 36), education (22; 24), e-learning (15; 20), teaching/learning strategies (9; 17), applications in subject areas (9; 17), elementary education (10; 16), ubiquitous learning (10; 15), mobile devices (12; 14), mixed reality (8; 13), educational technology (10; 12), gamification (8; 11), higher education (11; 11), learning (9; 11), blended learning (8; 10), and informal learning (8; 8). In **Figure 2**, different

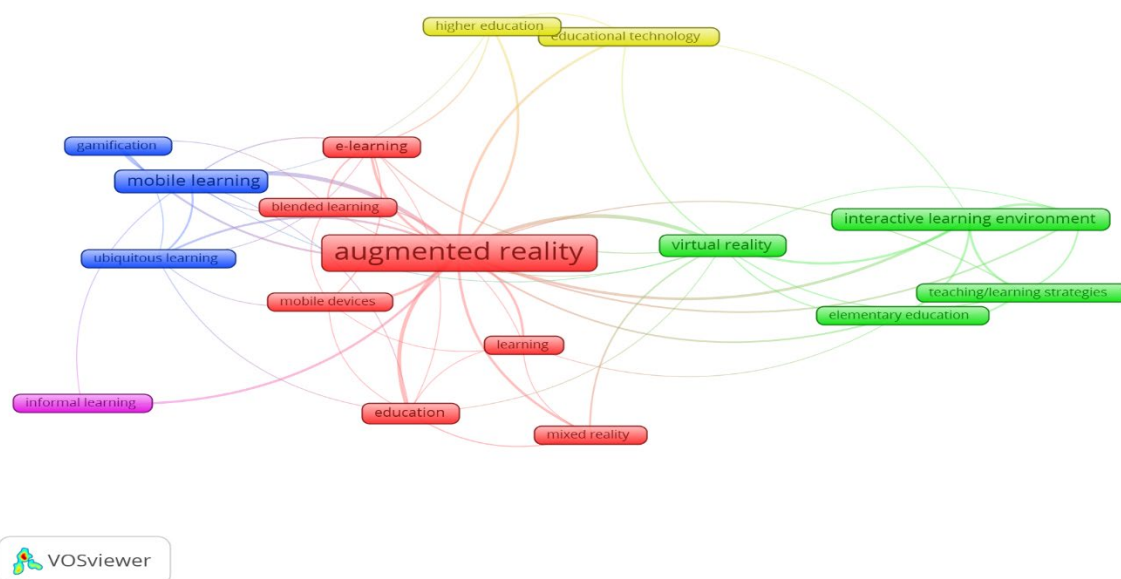


Figure 6. Co-occurrences of the author keywords (network visualization)

colours show different clusters in which the terms are more frequently linked with each other. The biggest cluster is comprised of AR, e-learning, blended learning, mobile devices, learning, education, and mixed reality. The second cluster is comprised of virtual reality, interactive learning environment, teaching/learning strategies, and elementary education. This cluster shows the most frequently studied concepts at the elementary education level. The third cluster has three concepts: gamification, mobile learning, and ubiquitous learning. The fourth cluster has only two concepts: higher education and educational technology. It shows that most of the studies in the augmented reality literature at the higher education level have been conducted in an educational technology discipline.

DISCUSSION

In this paper, the publications on augmented reality in education in SSCI, SCI-Expanded, AHCI, and ESCI databases of WoS were retrieved, analysed, and visualised through both descriptive and evaluative bibliometric analysis methods. VOSviewer software was used to conduct evaluative analyses and to visualise all this information. In this context, bibliographic coupling of the countries, bibliographic coupling of the institutions, bibliographic coupling of the journals, bibliographic coupling of the publications, bibliographic coupling of the authors, and co-occurrences of the author keywords were analysed and visualised.

According to the bibliographic coupling of the journals, the most important journal in augmented reality literature in education has been *Computers & Education*. *Eurasia Journal of Mathematics, Science, and Technology Education* has been the second according to the number of publications; however it has been the fifth journal, and *Educational Technology & Society* has been the second one as to the total link strengths. The other important journals in this field were; *Interactive Learning Environments*, *IEEE Transactions on Learning Technologies*, *EDMETIC*, *Computer Applications in Engineering Education*, *International Journal of Engineering Education*, *TechTrends*, *British Journal of Educational Technology*, *International Journal of Emerging Technologies in Learning*, and *Pixel-Bit: Revista de Medios y Educación*. The scope of those top journals shows that AR concept is mostly studied in the areas of science education, mathematics education, and educational technology.

The results of the bibliographic coupling of the countries showed that the most influential country of origin in this area had been Spain and the second one has been Taiwan. The other important countries have been: USA, Turkey, Peoples Republic of China, Australia, Canada, Singapore, Mexico, England, Italy, and Portugal. The studies that originated from the cluster of Spain, Taiwan, Turkey, Canada, and Mexico were linked more frequently with each other than the remaining of this list. The second cluster was comprised of the USA, England, and Italy. The last cluster, Australia, Peoples Republic of China, and Portugal were frequently linked with each other.

According to the bibliographic coupling of the authors, the most influential author in this area of research has been C.C. Tsai. Although the most prolific author was G.J. Hwang, he was the second according to the bibliographic coupling criteria. H.K. Wu was the most cited author; however, she was in the eleventh order when all the criteria had been taken into account. The other important authors were K.H. Cheng, M.B. Ibanez, Y. Goktas, K.E. Chang, Y.T. Sung, J.I. Asensio-Perez, J.A. Munoz-Cristobal, B.F. Robles, and V.M. Diaz. Most of the strongest authors are from Taiwan and Spain, indicating the predominance of these two countries in the field. In addition, most of those authors are from National Taiwan Normal University, National Taiwan University of Science and Technology, and the University of Valladolid, addressing the affiliations of the most important teams in this area. Among those authors, B.F. Robles, and V.M. Diaz from Spain have had the most recent publications in this area.

The results related to the bibliographic coupling of the institutions presented that the most influential institution in this area has been National Taiwan University of Science and Technology (Taiwan). The most influential authors in this area have also been affiliated with this university. National Taiwan Normal University (Taiwan) has been the second strongest institution in this area. The other important universities are: University of Seville (Spain), Carlos III University of Madrid (Spain), Ataturk University (Turkey), National Central University (Taiwan), University of Cordoba (Spain), National Chiao Tung University (Taiwan), University of Malaga (Spain), University of La Laguna (Spain), Universitat Politècnica de València (Technical University of Valencia) (Spain), University of Salamanca (Spain), University of Valladolid (Spain), University of Murcia (Spain), University of Huelva (Spain), and University of Wisconsin-Madison (USA). Among the most influential institutions in this area of research, Taiwan has some top universities on this list, however most of the top universities are from Spain and the most recent publications originated from several Spanish universities (the University of Seville, University of Malaga, University of Cordoba, University of Salamanca, and University of Murcia).

The results of the co-occurrences of author keywords indicate that the researchers have mostly studied these concepts related to the main concept of augmented reality in educational settings: Virtual reality, mobile learning, interactive learning environments, education, e-learning, teaching/learning strategies, applications in subject areas, elementary education, ubiquitous learning, mobile devices, mixed reality, educational technology, gamification, higher education, learning, blended learning, and informal learning. The most frequently related concepts are shown in separate clusters. Augmented reality has most commonly been studied with e-learning, blended learning, mobile devices, learning, education, and mixed reality (first cluster). Virtual reality, interactive learning environment, and teaching/learning strategies are the most studied concepts in the elementary education level (second cluster). Gamification, mobile learning, and ubiquitous learning have been frequently studied with each other (third cluster). Most of the studies in the augmented reality literature at the higher education level have been conducted in the educational technology discipline (fourth cluster).

Concerning the bibliographic coupling of the publications, the most influential publication in this area of research has been "Wu et al. (2013)". "Dunleavy et al. (2009)" has been the second most cited article; however, it was in the fifth order according to the general criteria. The other important publications in this area were Cheng and Tsai (2013), Kamarainen et al. (2013), Squire and Klopfer (2007), Dunleavy et al. (2009), Klopfer and Squire (2008), Bacca et al. (2014), Di Serio et al. (2013), and Liu (2009).

The findings about the co-occurrences of author keywords, the bibliographic coupling of the publications, and bibliographic coupling of the journals, showed that most of the publications in augmented reality literature in education are related to science and math education. This finding corroborates the findings of the reviews conducted by Chen, Cheng, and Huang (2017) and Koutromanos et al. (2015). Koutromanos et al. (2015) explained the reason of this finding in such a way that the problem-based natures of science and math lessons lead the teachers to benefit the investigative and problem-solving strengths of the augmented reality technology.

The results of the descriptive and evaluative analyses show that the leading countries in augmented reality in education are Spain and Taiwan, regarding the bibliographic couplings of countries, authors, and institutions. Spain and Taiwan have had the biggest numbers of publications, citations, and total link strength. The most eminent authors and institutions are also from Spain and Taiwan. The results showed that the most prominent authors and research teams are from these two countries. These scholars are currently working on the hottest topics in this area and also have the most recent publications. Spain and Taiwan have prevalence in terms of both quality and quantity in the literature of this important area over the last two decades. Similarly, Chen, Liu, Cheng, and Huang (2017) also found that Spain and Taiwan are the leading countries in education-related augmented reality literature. This is the natural result of the investments made by public and private organisations in these countries on those types of educational technologies (Cheng & Tsai, 2013; Martín-Gutiérrez et al., 2017; Wu et al., 2013). The tangible and intangible outcomes of those kinds of educational investments can be observed after a long time, but the results can be brilliant concerning the quality of education and the social and economic development of the whole nation in the long run.

Augmented reality is a relatively new technology used in education and various other disciplines. The publications and inventions in this promising area of research are increasing and getting more sophisticated from

year to year. It is difficult to measure all the benefits of using those kinds of technologies in science and math education and other areas of education, because some of their outcomes are not measurable quantitatively but can be seen in the long run in all the areas of human life. The researchers argue the nations that invest in these types of technologies will benefit the advantages of those technologies more than the others will. This study has shed light on the development and the trend of the literature of augmented reality in education.

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