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Augmented Reality in STEM Education: Bibliometric Analysis

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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".

Keywords: *Photography, Augmented reality, STEM, Bibliometric, Content analysis*

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Background to the Study

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. 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). 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 try 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.

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 greatest 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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