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The Use of Augmented Reality, Virtual Reality and Mixed Reality Technologies in Education: A Bibliometric and Systematic Review

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Abstract: This study aims to conduct a bibliometric analysis of the articles published on Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) research in the field of education. This study also aims to provide more comprehensive information on research trends by conducting a systematic review based on bibliometric analysis data. Therefore, this study was designed according to the multiple research methods. In this direction, bibliometric analysis was conducted first. After the bibliometric analysis, the systematic review technique was used to evaluate the most cited studies. VOSviewer was used to analyze bibliometric data, and the MaxQda program was used to analyze systematic review data. In this study, the findings showed that educational research conducted with AR and VR started to be conducted in the 1990s. On the other hand, it was determined that the integration of MR research into education began in the mid-2000s. The findings showed that the keywords virtual reality, augmented reality, education, medical education, simulation, and mixed reality, respectively, were used more in the studies found in Web of Science. Also, it was observed that research on AR, VR, and MR was mostly conducted in the United States of America and China. On the other hand, it was concluded that the studies were published more in "Education and Information Technology" and "Interactive Learning Environment" journals. Three publications by Guido Makransky ranked in the top ten regarding the number of citations. Similarly, Makransky ranked first among the authors who published the most articles. Finally, it was observed that the studies conducted with these technologies were mostly written by two, three, and four authors.

Keywords: Augmented reality, Virtual reality, Mixed reality, Education Technologies, Bibliometric analysis, Systematic review.

About the Article

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Introduction

Technological developments in recent years have led to the emergence of many innovative instructional technologies in the field of education. In this context, the potential effects of many technological systems, such as AR, VR, and MR, on education are being investigated. For this reason, there are many studies in which related technologies are applied experimentally in schools, although not as much as classical education and teaching methods (Beyoglu vd., 2020; Córcoles-Charcos vd., 2023; Marrahi-Gomez & Belda-Medina, 2024).

These technologies are based on the use of virtual data to change the physical world around the user (Lungu et al., 2020). Milgram and Kishino (1994) introduced the idea of a virtual continuum and explained the definitions of these technologies and their relationships with each other. Researchers have also depicted the virtual and real worlds as two ends of a line and defined the environments between these two worlds as MR. In other words, in MR, virtual and real spaces are spatially merged (Holz et al., 2011). In this context, it can be said that MR is a combination of both VR and AR.

On the other hand, VR technology, or virtual environment, puts users in a completely artificial world without seeing the real world (Carmigniani et al., 2011). So, the VR environment can be used to visualize a completely imaginary world (Christou, 2010). Furthermore, VR is also defined as visualizing computer graphics systems using various devices (Pan et al., 2006). In other words, VR allows users to interact with a computer-generated 3D model or virtual environment. This environment can be realistic on a macroscopic scale, or it can depict the physical world known to science but unobservable.

In contrast to VR, AR refers to a 2D or 3D virtual interface that enhances reality by embedding digital elements into the existing world. Thus, AR technology does not involve a completely virtual world (Elmqaddem, 2019). That is, AR involves overlaying computer-generated images onto the real environment (Speicher et al., 2019; Tepper et al., 2017). However, to experience the AR in real-time, a trigger is required (Maas & Hughes, 2020). Accordingly, AR technologies are mainly classified as marker-based, non-marker-based, and location-based (Burtchart, 2011). Additionally, the fact that there is no need to use intensive software to make 3D designs is another feature that distinguishes AR from VR. (Striuk et al., 2018). In addition to these differences, it is thought that there may be similarities between these technologies as a whole. This necessitates a bibliometric mapping analysis of the relevant technologies.

When the literature was examined, it was seen that many bibliometric analysis studies were conducted separately on AR, VR, and MR technologies in the field of education (Arici et al., 2019; Hincapie et al., 2021; Liu et al., 2017; Mani & Madhusudan, 2022; Rojas-Sánchez et al., 2023; Soto et al., 2020; Talan, 2021). Similarly, there are educational studies in the literature that deal with the technologies above in pairs and perform them within the scope of bibliometric analysis (Calabuig-Moreno et al., 2020; Zhao et al. 2023). However, not addressing AR, VR, and MR technologies holistically

limits the opportunity to create pedagogy (Maas & Hughes, 2020). Therefore, Zhang et al. (2022) conducted a bibliometric analysis including all three technologies. Nevertheless, in this study, only surgical studies were focused on, and other fields were ignored. Therefore, three technologies were evaluated together in this research to increase the scope of information on educational technologies. It is thought that this situation will make a significant contribution to researchers, policymakers, and teachers who examine AR, VR, and MR practices in education. It is also envisaged that this study will be a valuable resource for researchers. In line with the stated reasons, the study aims to conduct a bibliometric analysis of articles published on AR, VR, and MR research in the field of education. In addition, this study aims to provide more comprehensive information on research trends by conducting a systematic review based on bibliometric analysis data.

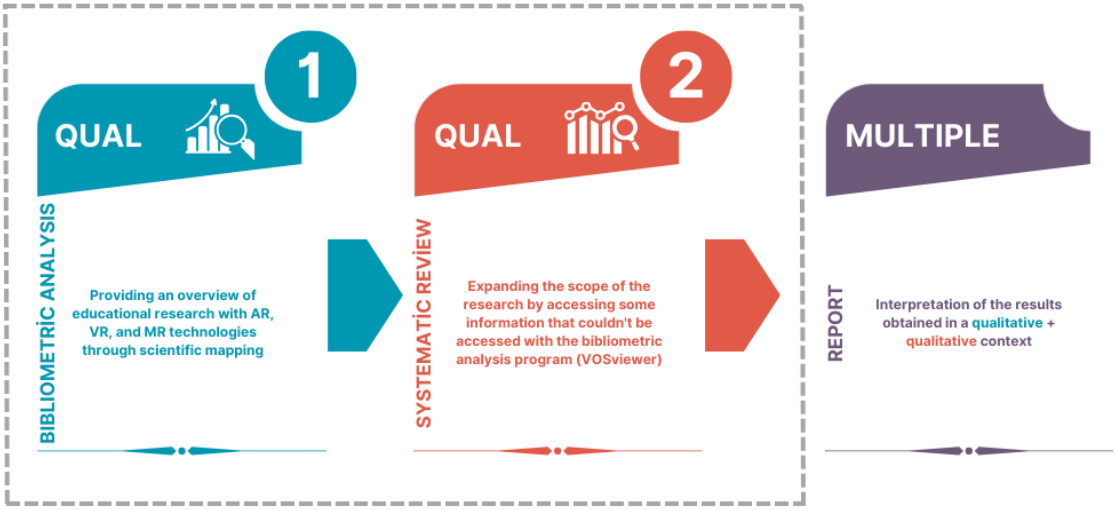
Method

Research Design

This study was designed using multiple research methods. Multiple research methods can be defined as using two or more data collection methods together to examine the research problem (Cohen et al., 2007). In the present research, this method was chosen to check the integrity of the conclusions or to increase the scope of information systematically (Christensen et al., 2014). In this direction, two different qualitative methods were utilized in this study, and bibliometric analysis was conducted first. Bibliometric analysis can be explained as a mapping technique that enables and empowers researchers to obtain an overview of the subject, identify gaps in the literature, and access new information by making large volumes of unstructured data meaningful. (Donthu et al., 2021). After the bibliometric analysis, the systematic review technique was used to evaluate the most cited studies. This technique is used to identify studies on the research topic, to assess critically, and to systematically analyze them (Moher et al., 2010). The scheme created for multiple research methods and the stages to be realized in this context are shown in Figure 1. In Figure 1, the bibliometric analysis process is symbolized in blue "■," the systematic review process in orange "■," and the progression between the stages is symbolized by the arrow "→".

Figure 1.

Stages Followed in the Research According to Multiple Research Methods

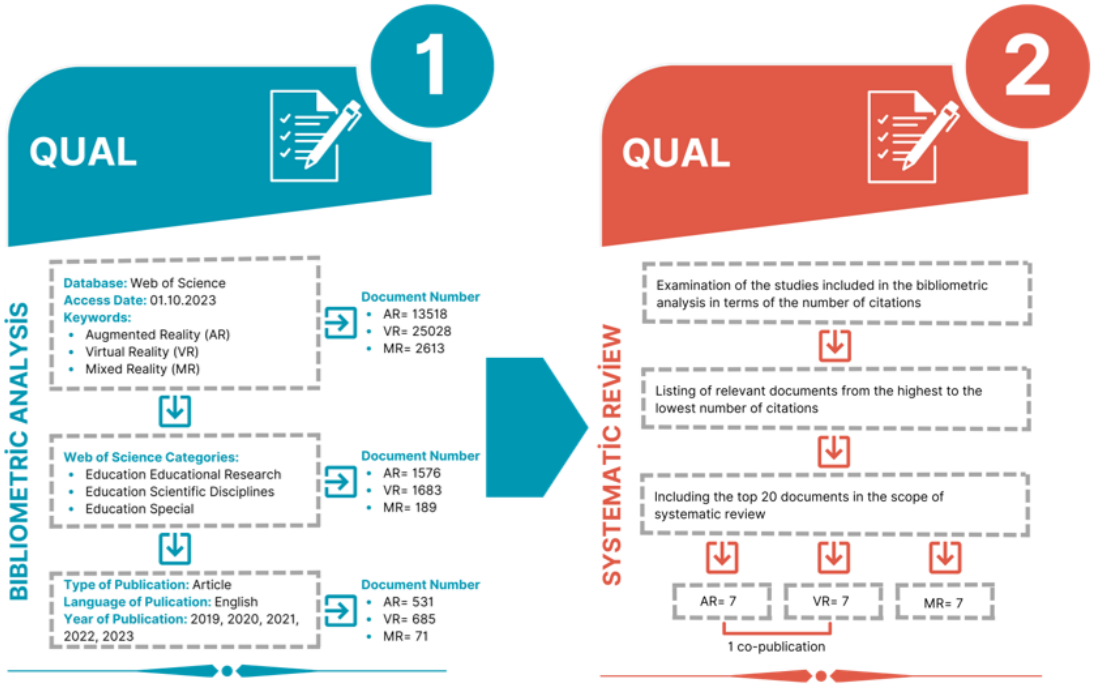


Data Collection Process

The data collection process in this study was carried out in two stages within the scope of multiple research methods. The first stage included the bibliometric analysis process to determine the general trends of educational research on AR, VR, and MR. The second stage involved a systematic review to expand the scope of this research by accessing some information that could not be reached with the bibliometric analysis program. This data collection process is shown in Figure 2 and explained in detail.

Figure 2.

Data Collection Process

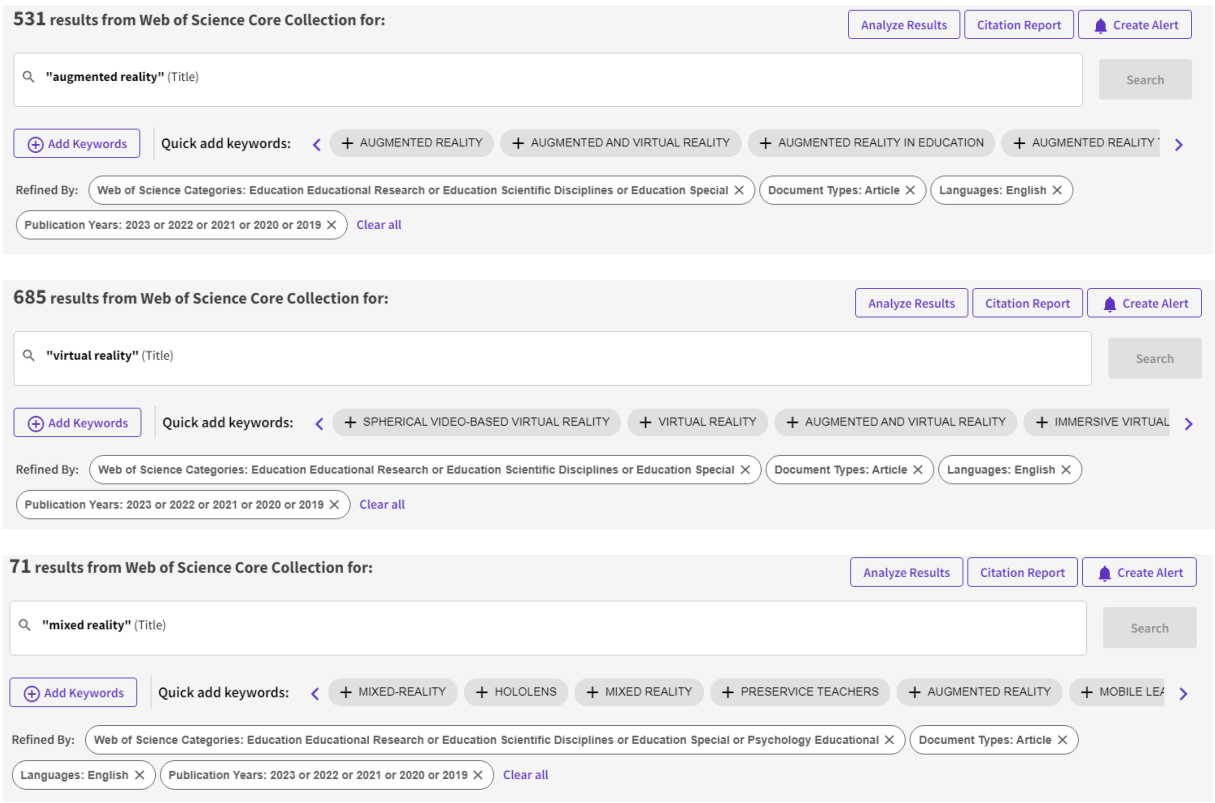


Selection of Documents Included in Bibliometric Analysis

In the present research, the keywords "augmented reality," "virtual reality" and "mixed reality" were used for scanning. A search was conducted on the Web of Science database on 01.10.2023, considering the title category according to the relevant keywords. In this context, 13518 studies for AR, 25028 studies for VR, and 2613 studies for MR were reached. Then, education as the field, articles as the type of publication, English as the language, and the last five years as the date were taken as criteria. Thus, the number of studies was limited, and 1287 studies on AR (n=531), VR (n=685), and MR (n=71) were downloaded in .txt format. Screenshots of the scans made in line with these criteria are presented in Figure 3.

Figure 3.

Screenshots of the Scans

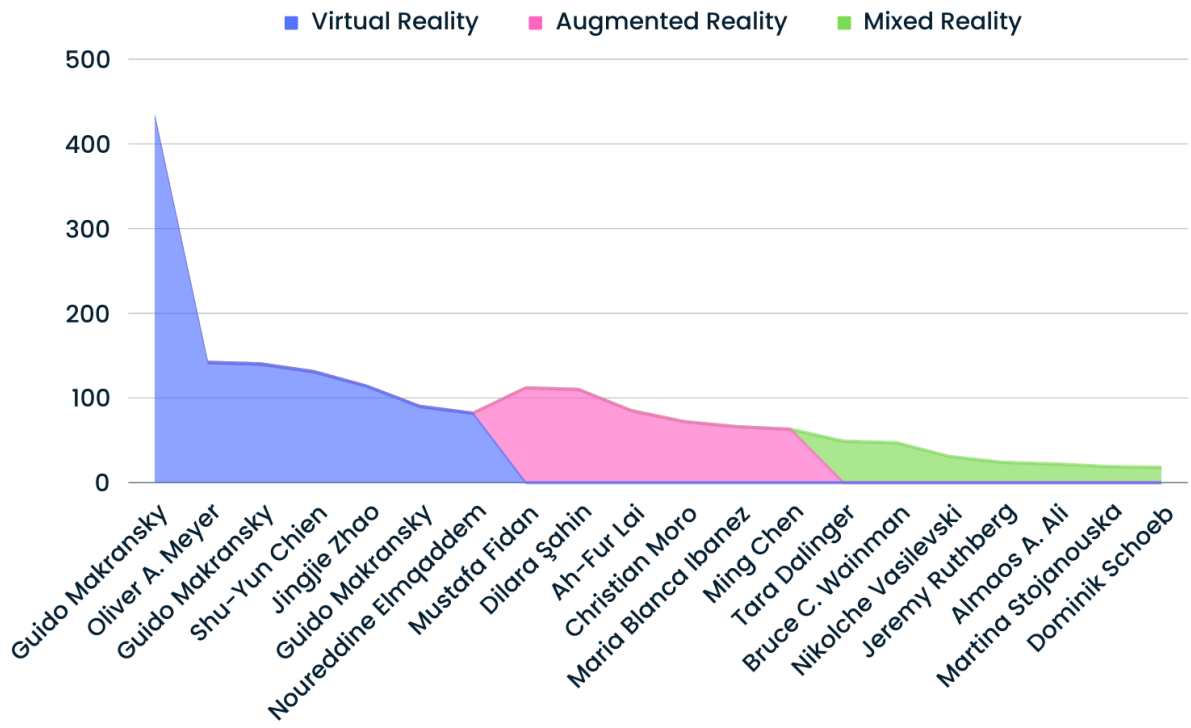


Selection of Documents Included in Systematic Review

The number of citations was taken into consideration in the selection of the articles included in the systematic review because it was thought that studies with a high number of citations contributed more to other studies. Therefore, due to the bibliometric analysis, the documents were first sorted regarding the number of citations from highest to lowest. Then, they were categorized as AR, VR, and MR. In this direction, seven articles from each technology according to the number of citations were transferred to the systematic review process. Thus, 21 documents were reviewed. However, since Noureddine Elmqaddem uses both AR and VR technologies, 20 documents in total were systematically evaluated. The publications analyzed are presented in Figure 4, along with their citation ranking.

Figure 4.

Studies Included in the Systematic Review



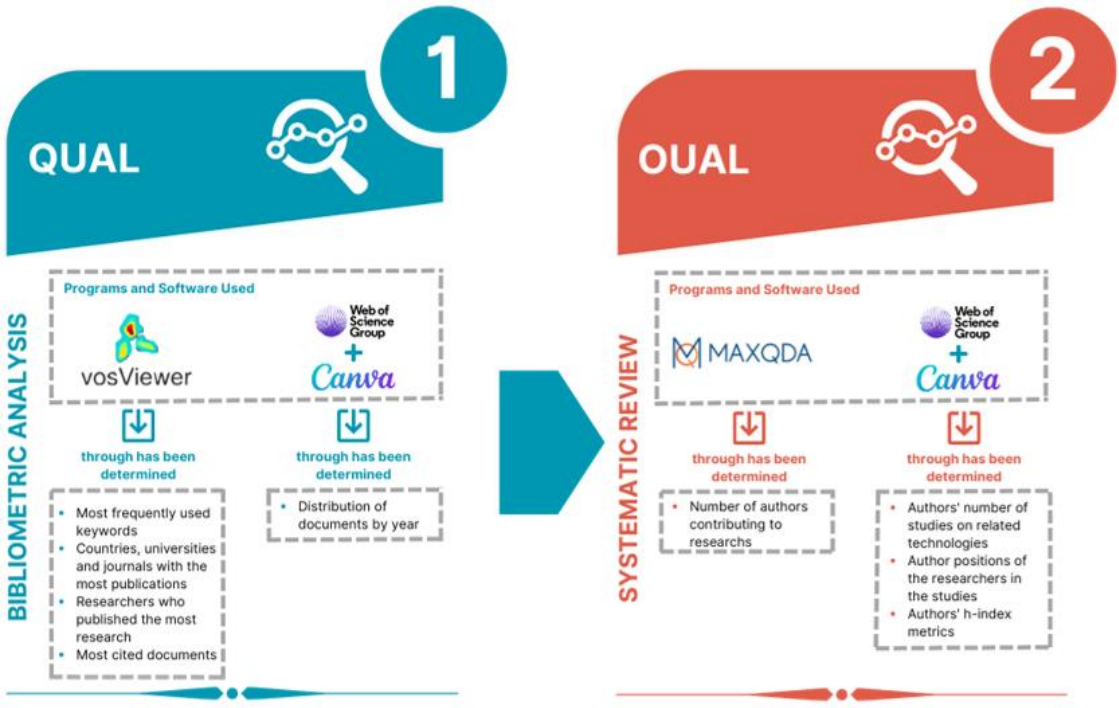
Based on Figure 4, it can be stated that VR studies are cited more than AR and MR studies. In addition, the citations for MR technology are relatively fewer than the others. When the studies were considered in general, it was determined that the number of citations of Guido Makransky was approximately five times more than the second-ranked study (Oliver A. Meyer). On the other hand, it is remarkable that Guido Makransky had three publications in the first 20 documents. Hence, Guido Makransky was evaluated once in the analyses made in terms of the author, and the analyses were made by over 18 researchers.

Data Analysis

The data analysis process in this study was carried out in two stages within the scope of multiple research methods. The first stage involved the analysis of bibliometric data, and the second stage involved the analysis of systematic review data. This analysis process is explained in detail in Figure 5.

Figure 5.

Data Analysis Process



Analysis of Bibliometric Data

The analysis of the documents accessed within the scope of this research was carried out using the VOSviewer program developed by van Eck and Waltman (2010). VOSviewer was chosen for its high ease of use, user flexibility, and capability to export electronic maps (Arruda et al., 2022). Other advantages of VOSviewer are the lack of programming knowledge and the zoom and pan options to facilitate detailed examination of the maps created (Moral-Muñoz et al., 2020). In this study, the most frequently used keywords in the relevant documents were identified through VOSviewer; the countries, universities, and journals with the highest number of publications were revealed. In addition, the researchers who published the most research and the most cited documents were identified using the program. On the other hand, the distribution of relevant documents by year was analyzed through the Web of Science database, and a holistic graph of the years was created with Canva software.

Analysis of Systematic Review Data

The documents included in the systematic review were transferred to the MaxQda 20 program. In this context, the documents were analyzed in terms of the number of authors. However, since the number of studies of the authors on AR, VR, and MR technologies, the author positions of the researchers in the studies, and the h-index metrics of the authors could not be analyzed with the MaxQda program, other systematic data were

done manually using Web of Science. All data obtained from the systematic review were transformed into figures, and only author names and frequency information were presented in these figures.

Findings

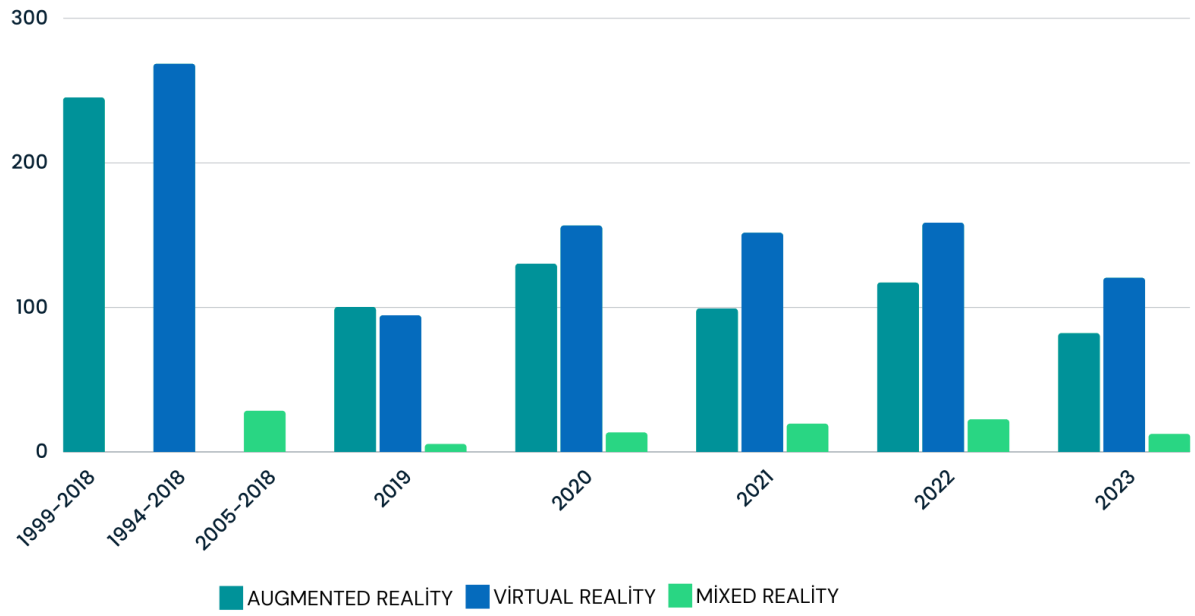
Findings from Bibliometric Analysis

Distribution of Research by Year

A total of 1819 articles in the field of education with AR, VR, and MR technologies indexed in the Web of Science database were reached. Of the related studies, 947 were related to VR, 773 to AR, and 99 to MR technologies. In this context, studies were presented as 2019 and later, and all studies before this date are shown together. The distribution of studies by year is visualized in Figure 6.

Figure 6.

Distribution of Studies by Year

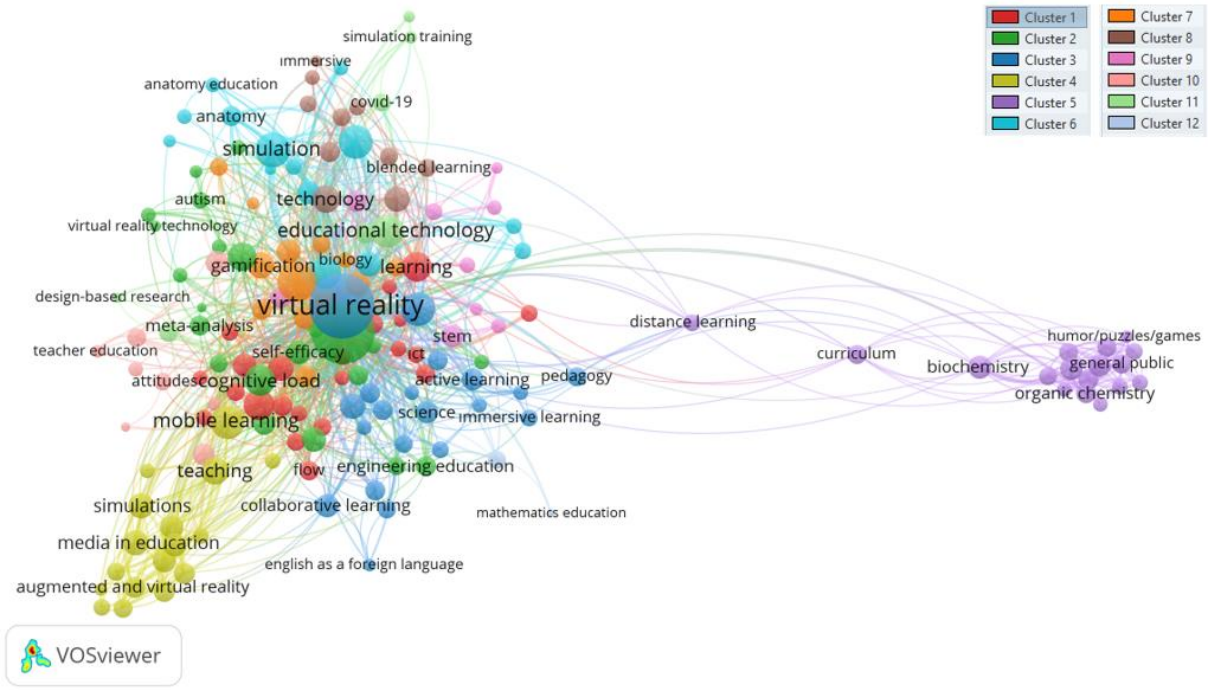


When Figure 6 is analyzed, it can be said that AR research has been conducted since 1999, VR technology was first used in education in 1994, and studies on MR technology started in 2005. However, it can be stated that educational research in related fields has increased in the last five years. In this context, it was determined that the number of studies published in 2019 and later is higher than all the studies published before this date. In addition, Figure 6 shows that the number of studies integrating VR with education is higher than other reality technologies.

Keywords Most Frequently Used in Studies

Cooccurrence (author keywords) analysis was performed to determine the keywords used in the studies performed with AR, VR, and MR. It was determined that the studies included in the analysis contained 2978 keywords. However, in this study, the minimum number of repetitions of keywords was set to 5 to make the map generated by the program more understandable. Thus, it was seen that only 161 keywords met the specified criteria. Link strength was calculated for each of these words, and the map of the words with the highest link strength is presented in Figure 7.

Figure 7.
Keywords Most Frequently Used in Studies



As shown in Figure 7, it was determined that the keywords used in the studies on AR, VR, and MR technologies consisted of 12 clusters. Different colors were used to represent the relevant clusters. It was also found that keywords, such as virtual reality (n=458), augmented reality (n=389), education (n=60), medical education (n=53), simulation (n=49), mixed reality (n=38), mobile learning (n=36), educational technology (n=32) and computer-based learning (n=30), were frequently preferred in the documents included in the present study. Furthermore, in the related studies, it is generally observed that AR, VR, and MR have a strong connection with the words self-efficacy, language learning, teachers, usability, online learning, music education, education, training, educational technology, and higher education. On the other hand, it can be stated that the links of keywords with words, such as computer-based learning, organic chemistry, English as a foreign language, biochemistry, curriculum, distance learning, media in education, simulation, simulation training, anatomy, anatomy education, immerse,

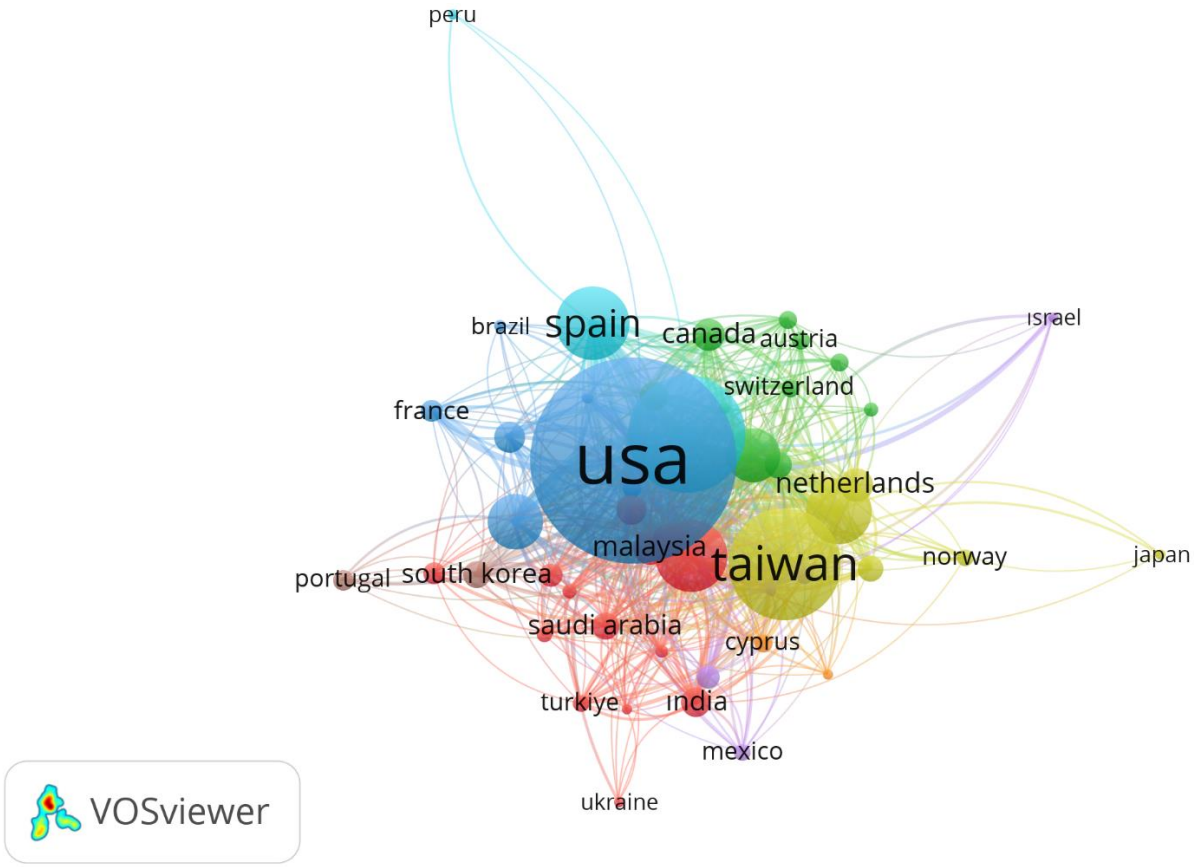
COVID-19, surgical training, and dental education, are weak. Therefore, it can be said that AR, VR and MR studies are less preferred than others in health education.

Countries with the Most Publications

Educational studies supported with AR, VR, and MR technologies were analyzed in the context of countries. For this purpose, citation (country) analysis was performed, and at least five publications were accepted as criteria. Accordingly, only 49 out of 88 countries were included in the analysis. The countries with the highest number of publications are given in Figure 8.

Figure 8.

Countries with the Most Publications



According to Figure 8, it can be stated that most AR, VR, and MR research is conducted in the United States of America (n=296). Following the United States, China (n=144), Taiwan (n=136), and Spain (n=79) were found to integrate these technologies more in educational research. In addition, the studies conducted in Taiwan and China were shown separately. However, since the official name of Taiwan is China, the researchers took the initiative to combine these data (n=280). Thus, it can be said that the number of studies conducted in China is getting closer to the number of studies conducted in the United States. Moreover, both Turkey (n=78) and Turkiye (n=12) were used separately

in the related studies. Therefore, these technologies have been used in educational research in Turkey a total of ninety times. Thus, the ranking of the countries where AR, VR, and MR technologies are most frequently used has changed, and Turkey, which was ranked fifth, has risen to third place, above Spain. On the other hand, while there were almost no studies on educational technologies in Africa, this situation is more evenly distributed in Europe. The distribution of countries' research on AR, VR, and MR is shown in Figure 9.

Figure 9.

Distribution of Research by Country

Universities with the Most Publications

The studies in which AR, VR, and MR were used were reviewed regarding universities. In this context, firstly, an analysis was made in the citation (organizations) section by considering five publication criteria. Therefore, only 84 out of 1421 universities were included in the analysis. The universities with the highest number of publications are given in Table 1.

Table 1.

Universities with the Highest Number of Publications

University	Country	Number of Publication	Number of Citation
National Taiwan Normal University	China	35	668
National Taiwan University of Science and Technology	China	25	428
University of Copenhagen	Denmark	17	1043
The Chinese University of Hong Kong	China	17	451
Beijing Normal University	China	13	162
Nanyang Technological University	Singapore	13	111
National University of Singapore	Singapore	12	114
Comenius University Bratislava	Slovakia	12	67
Chıtkara Unıversıty	India	11	125
National Changhua University of Education	China	10	86
National Yunlin University of Science and Technology	China	10	134
Bond University	Australia	10	144
University of North Texas	USA	10	104
University of North Carolina	USA	10	159

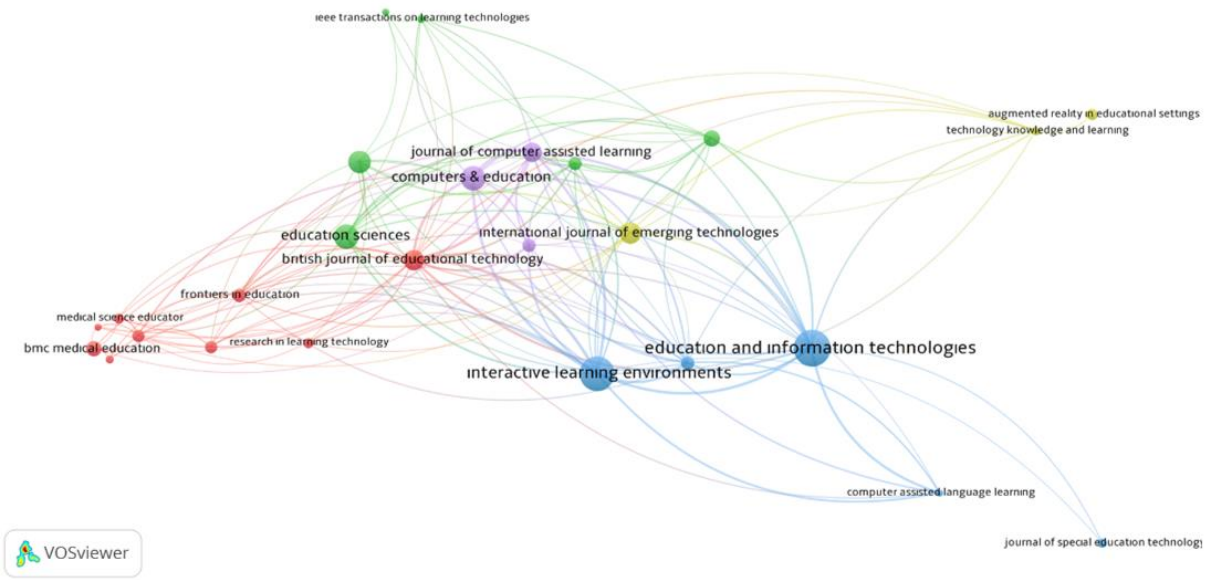
As shown in Table 1, it was seen that "National Taiwan Normal University" was the university that conducts the most research on AR, VR, and MR technologies. "National Taiwan University of Science and Technology" is followed by "National Taiwan Normal University" regarding the number of publications. In this context, it is noteworthy that the top two places are held by universities in China and that there are four different Chinese universities in the top five. It was also seen that only one European country (Denmark) is in the top five. The majority (n=9) of the universities with the highest number of publications on AR, VR, and MR technologies were from Asian countries. However, Figure 8 shows that the United States of America ranked first. Similarly, although Turkey ranked third among countries in terms of publications, it did not make it into the top fourteen at the university level. On the other hand, when the universities in Table 1 were compared according to the number of publications and citations, it was determined that "University of Copenhagen" in the third place (17 articles) received more citations (n=1043) than the others. Thus, the average number of citations for each publication at the mentioned university was 61, which can be considered a high level.

Journals with the Most Publications

Educational research studies in which AR, VR, and MR technologies were used were reviewed in terms of the journals in which they were published. In this direction, citation (sources) analysis type was used. In addition, the minimum number of publications was taken as 10, and journals with publications below this limit were excluded. Thus, 27 out of 281 journals were included in the analysis. The journals that published the most research among the relevant journals are given in Figure 10.

Figure 10.

Journals with the Most Publications



Considering Figure 10, it can be said that AR, VR, and MR studies, respectively, were published in "Education and Information Technology" and "Interactive Learning Environment" journals. Following these journals, it can be stated that "Education Sciences," "Computers and Education" and "Journal of Chemical Education" journals had more educational research on related technologies. When these journals were analyzed in terms of the index and impact factor, it was found that "Education and Information Technology" (Q1, JIF =5,3), "Interactive Learning Environment" (Q1, JIF=5,4), and "Computers and Education" (Q1, JIF=12,6) were indexed in SSCI. In addition, "Education Sciences" is indexed in ESCI (Q1, JIF=2,8), and "Journal of Chemical Education" is indexed in SCI-E (Q2, JIF=2,8). Moreover, when analyzed regarding the number of publications, it can be stated that the journals in the top ten were generally technology-oriented (n=8). On the other hand, when the journals in the figure are compared, it was seen that "Computers and Education" received more citations (n=1986) than the others despite having 51 articles.

Authors with the Most Publications

Citation (authors) analysis was conducted to determine the authors of the studies on AR, VR, and MR. It was determined that the studies included in the analysis included 4103 authors. However, in this study, the minimum number of repetitions of the number of documents belonging to the authors was set to three to make the map created by the program more understandable. Thus, it was seen that only 135 authors met the specified criteria. Link strength was calculated for each of these authors, and the map of the authors with the highest link strength is presented in Figure 11.

Figure 11.

Authors with the Most Publications

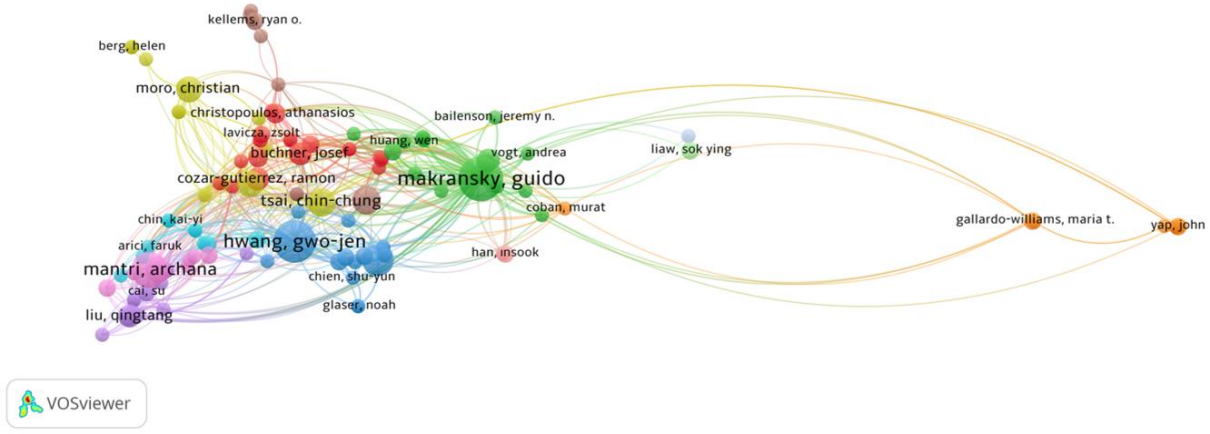


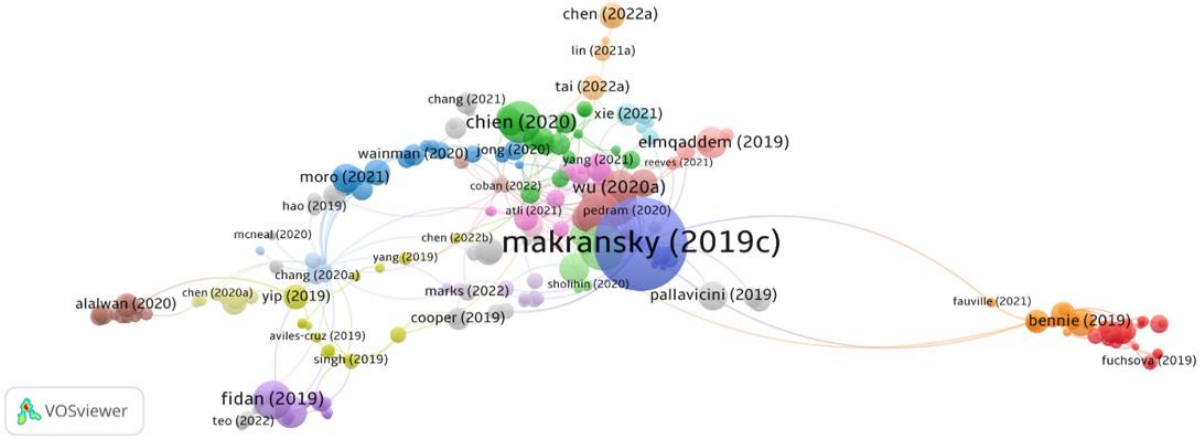
Figure 11 shows that Guido Makransky (n=15), Gwo-Jen Hwang (n=14), and Archana Mantri (n=11) were the authors who published the most articles. Similarly, Makransky also ranked first in terms of citations. However, it is remarkable that Richard Meyer received a high number of citations (n=728) despite having five publications. Accordingly, it can be said that Meyer's average number of citations per article was 146. In addition, the presence of Turkish researchers (n=7) in the author list created by the program is important regarding the position and future of technology in the Turkish education system.

Most Cited Articles

Educational studies supported with AR, VR, and MR technologies were analyzed in terms of citations. For this, citation (document) analysis was performed, and at least 10 citations were accepted as a criterion. Accordingly, only 399 out of 1262 studies were included in the analysis. The most cited articles are presented in Figure 12.

Figure 12.

Most Cited Articles



Considering Figure 12, it was determined that three publications by Makransky ranked in the top ten in terms of the number of citations. It was observed that the researcher published these studies in 2019. This may be attributed to the fact that Makransky is the researcher with the highest number of publications on related topics, as indicated in Figure 11. In addition, when the data obtained from Table 1 and Figure 12 are compared, it is found that there are consistent results. In this context, it was determined that the most cited researcher worked at the university with the highest number of citations. From this point of view, it can be claimed that Makransky contributed significantly to the number of citations of the University of Copenhagen (n=1043) with 795 citations, and thus increased the recognition of the university. On the other hand, it is remarkable that there are three articles from Turkey in the top ten and that these studies received 345 citations. According to the results, it is important that this study covers 28% of the total number of citations (n=1232) received by the studies conducted in Turkey.

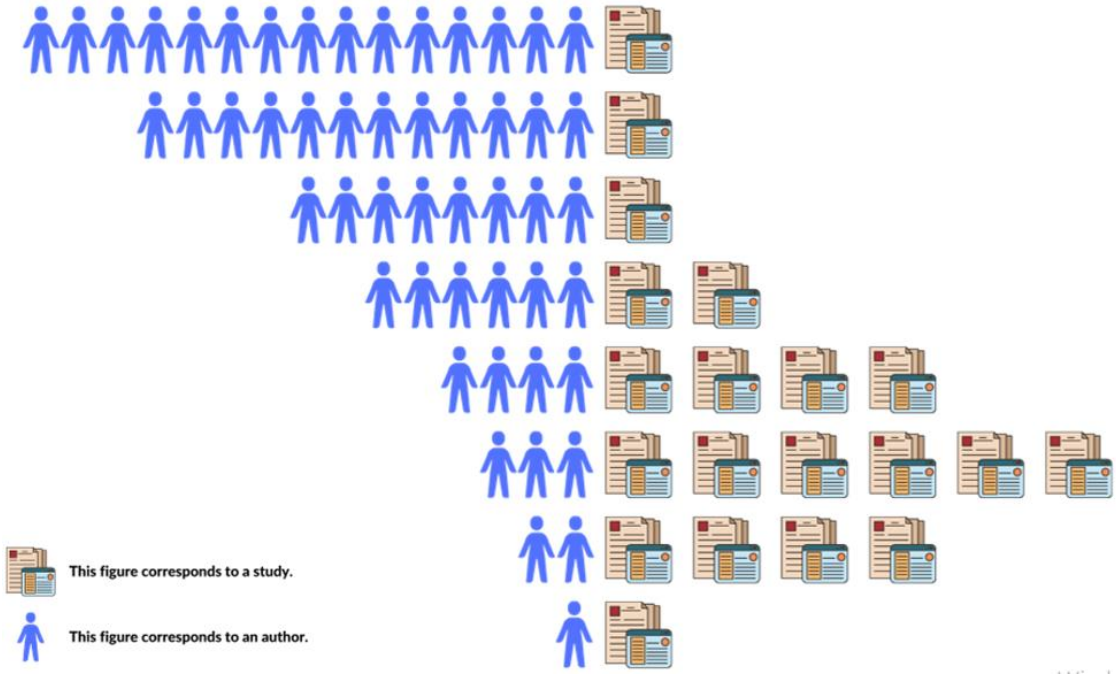
Findings from Systematic Review

Number of Authors Contributing to Research

Systematically analyzed 20 documents were reviewed in terms of the number of authors. Thus, it was tried to make predictions about how many teams of people technological studies can usually be conducted with. In addition, through the findings, suggestions on how to provide an effective and efficient collaboration environment in technological research were presented. The findings obtained in this context are presented in Figure 13.

Figure 13.

Number of Authors Contributing to Research



Considering Figure 13, it can be said that AR, VR, and MR studies are generally conducted with two, three, and four authors. It is also remarkable that studies were conducted with at least six authors. In this context, it can be stated that there were two studies with six authors and one study each with eight, twelve, and fifteen authors. Four of the related studies cover MR, and one of them covered AR. Moreover, some of the related studies resulted from the cooperation of different countries, universities, and departments. On the other hand, it was determined that there was a single-authored study.

Authors' Number of Studies on Related Technologies

It was determined that the 20 studies included in the systematic review were conducted by 90 authors (Figure 13). Due to the large number of authors, only the number of studies on related technologies conducted by the (first) researchers responsible for the studies was analyzed. However, since Makransky was the corresponding author in three studies, he was evaluated once. Thus, the number of studies by 18 authors was reviewed. In this direction, the authors' studies in Web of Science were considered. The distribution of authors according to the number of studies is visualized in Figure 14.

Figure 14.

Distribution of Authors According to the Number of Studies

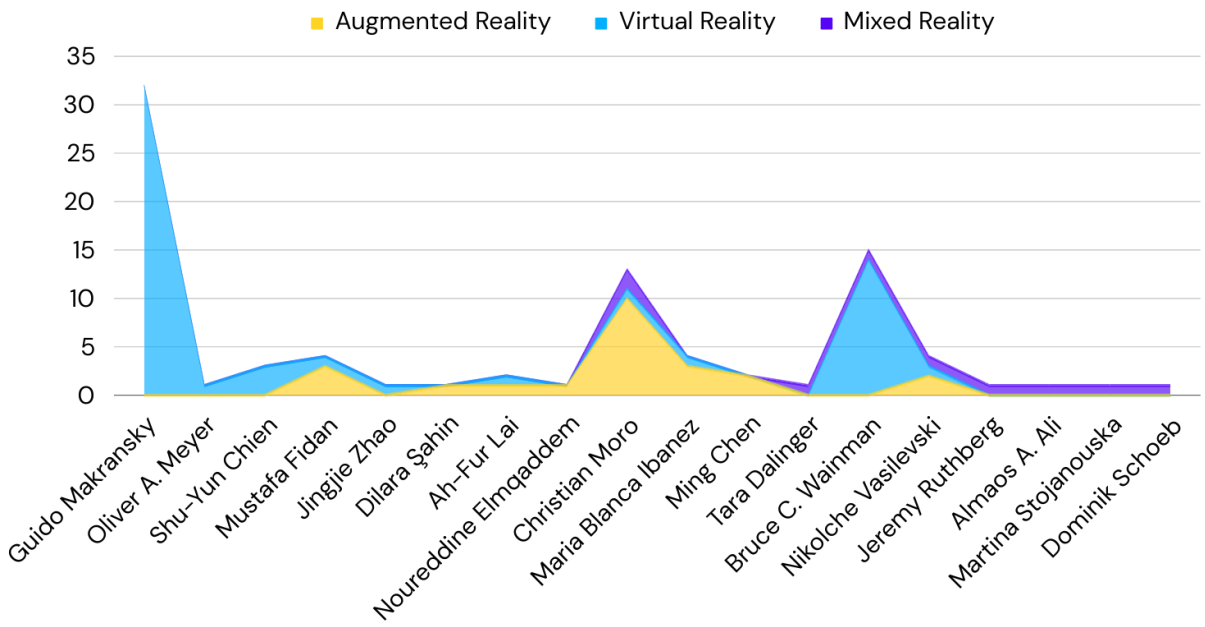


Figure 14 shows that some researchers (Christian Moro, Bruce C. Wainman, and Nikolche Vasilevski) used related technologies together. In this case, the related studies were evaluated within the scope of the technology the author used more in his research. For example, Christian Moro conducted 10 AR, 5 VR, and 2 MR studies. However, four of the VR studies and one of the MR studies were conducted with AR technology. Therefore, since the number of AR studies conducted was higher than the others, four VR and one MR study were presented only as AR studies. In the new situation, it is accepted that Christian Moro conducted 10 AR, one VR, and one MR study. Based on this, when Figure 14 is analyzed, it was seen that the number of studies conducted by Guido Makransky with related technologies in general (n=32) was more in Web of Science. Similarly, Guido Makransky was the author who had published the most articles in the last five years, with 15 studies (Figure 11). Figure 11 also shows that Gwo-Jen Hwang and Archana Mantri were second and third in the ranking of authors who published the most articles with 14, and 11 publications, respectively. However, Figure 14 does not include these authors. Therefore, it can be said that although the relevant authors published many publications in the last five years, these publications were insufficient in receiving citations. However, according to Figure 14, it is remarkable that although nine authors had only one study each with AR, VR, and MR technologies, they were highly cited.

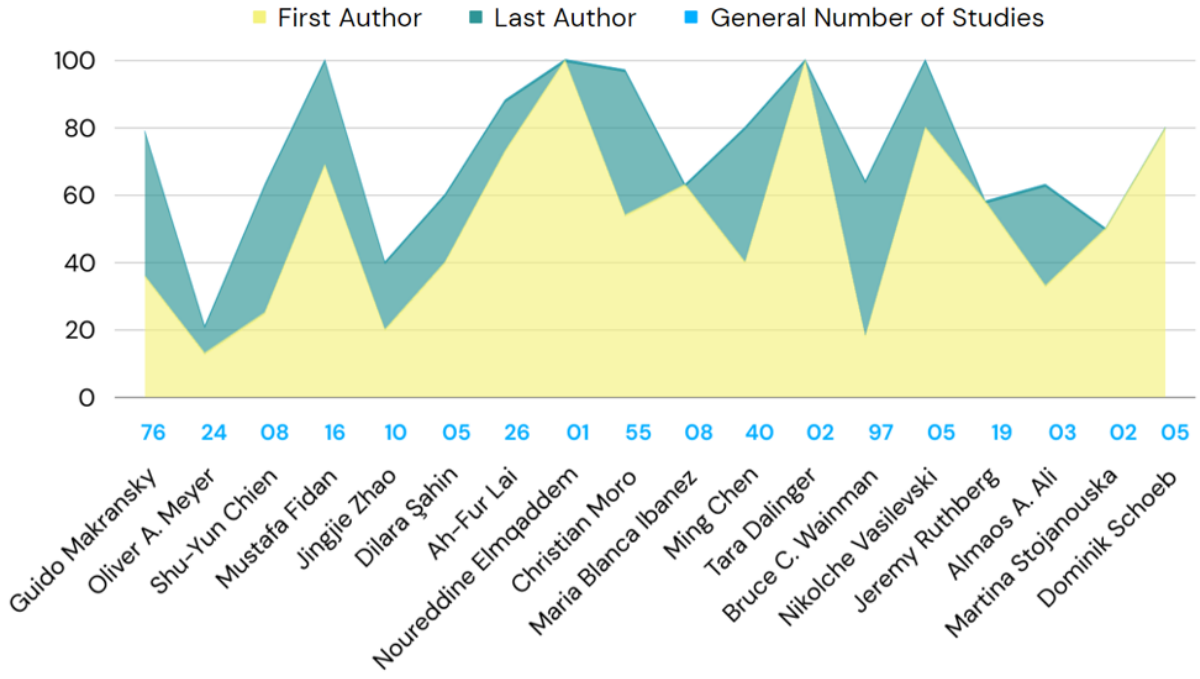
Author Positions of the Researchers in the Studies

Figure 14 shows the number of studies of the authors on the related technologies in the Web of Science database. However, the author's position of these researchers in all the

studies they conducted was also important. Therefore, all studies of 18 researchers indexed in Web of Science were checked for author rankings. Thus, the rates of researchers being the first and last authors in the studies were determined. The findings obtained in this direction are given in Figure 15.

Figure 15.

Author Positions of the Researchers in the Studies



When the author positions of the researchers in the studies were analyzed, it was seen that Noureddine Elmqaddem (100%) and Tara Dallinger (100%) had the highest rate of being the first authors. However, these authors have 1 and 2 articles in Web of Science, respectively (Figure 15). Similarly, the fact that Nikolche Vasilevski and Dominik Schoeb contributed only five articles can be considered the main factor that increased their percentage to 80. Therefore, it is useful to look at how many articles this rate corresponds to in all studies rather than the rate of first authorship. From this point of view, when all studies are multiplied by first-author ratios, it can be said that Christian Moro is the first author with 30 studies. However, it is remarkable that Moro ranked third in terms of the total number of studies. In addition, Guido Makransky stood out as the second researcher with the highest number of first authors, with 27 studies. These researchers were followed by Ah-Fur Lai with 19 studies and Bruce C. Wainman with 17 studies. However, it is remarkable that Wainman had the highest number of publications (n=97) among these researchers. Thus, although Wainman published many studies on the Web of Science, it can be stated that he was the first author in a very small fraction of them.

Authors' h-index Metrics

Figure 12 shows the most cited articles and authors, Figure 11 shows the researchers with the highest number of publications on AR, VR, and MR in the last five years, and Figure 14 shows the number of studies conducted by authors on these technologies in general. However, these are not considered sufficient to demonstrate a researcher's contribution to science. Therefore, the h-indexes in the Web of Science database were checked to determine the scientific impact of the authors included in the systematic review. The findings obtained in this direction are presented in Figure 16.

Figure 16.

Authors' h-index Metrics

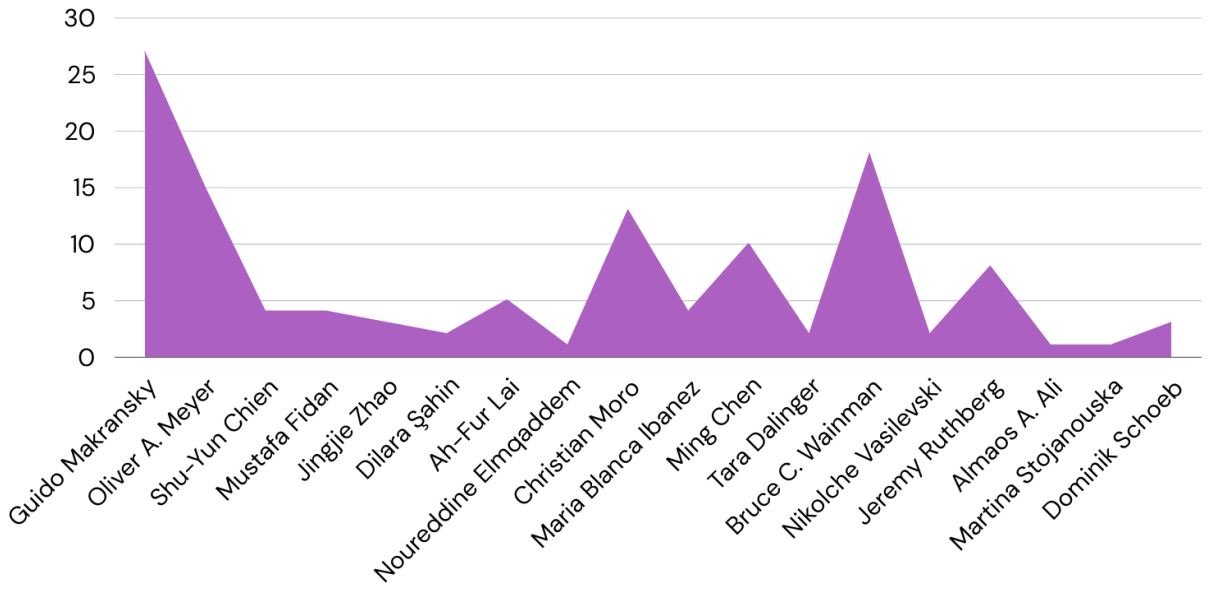


Figure 16 shows that Guido Makransky (n=27), Bruce C. Wainman (n=18), Oliver A. Meyer (n=15), and Christian Moro (n=13) scored higher regarding h-index than the others. Similarly, Figure 14 shows that these authors, except Oliver A. Meyer, published more on AR, VR, and MR technologies. On the other hand, Guido Makransky was the author who has published the most on related technologies in the last five years (Figure 11). Figure 12 shows that Guido Makransky has been the most cited author in the last five years for his educational research with the mentioned technologies. In addition, when the technologies used in this research are considered separately, it can be stated that Bruce C. Wainman ranks second with the number of citations (n=47) in MR research. Figure 15 shows that Wainman had more studies on the Web of Science than other authors. Considering the same figure, Wainman was followed by Gudio Makransky with 76 studies and Christian Moro with 55 studies. Considering all these together, it can be stated that Guido Makransky, Christian Moro, and Bruce C. Wainman contributed more to science on these issues than other authors.

Conclusion and Discussion

In this study, it was determined that educational research conducted with AR and VR technology started to be conducted in the 1990s. Consistent with the findings obtained in this study, some studies in the literature show that the first educational research on AR was conducted in 1999 (Karakus et al., 2019). On the other hand, Rashid et al. (2021) state that the first publication on VR in higher education was made in 1994, which is consistent with the results of this study. However, it was determined that the integration of MR research into education coincided with the mid-2000s. Therefore, it can be said that AR, VR, and MR are relatively new technologies for various disciplines, especially education. In addition, the result of an increase in the number of studies on related technologies in the last five years supports this conclusion. Likewise, it has been suggested that the number of publications in the literature has increased significantly after the 2010s (Hincapie et al., 2021; Liu et al., 2017). Rojas-Sánchez et al. (2023) argued that in recent years, there have been developments in VR-assisted learning processes and significant progress, has been made in the application and use of this technology. This may be because relevant technologies have become a necessity in contemporary education. Similarly, Sala (2021) emphasizes the importance of improving modern educational environments with new technologies, such as AR, VR, and MR. On the other hand, when these technologies are compared, it is seen that VR is used more in education than other reality technologies. This may be because studies with VR technology both started earlier as year and researchers were more familiar with the technology. AR can be envisioned as a variation of virtual environments or VR technology as it is more commonly called (Azuma, 1997). Therefore, it can be thought that researchers do not have sufficient knowledge about AR and MR. However, the increase in the number of AR and MR studies in the last five years shows that the interest in these two technologies has increased. This increase is expected to continue as a search was conducted on 01.10.2023 for this research. In fact, in the search conducted on 20.01.2024 with the same inclusion criteria, it was observed that 112 new publications were made, 34 for AR, 71 for VR, and 7 for MR.

It was found that the keywords virtual reality, augmented reality, education, medical education, simulation, mixed reality, mobile learning, educational technology, and computer-based learning were used more in the studies found in Web of Science. This may be because in most of the studies in the literature, keywords and title or topic are chosen in harmony (Lin et al., 2017; Mirault et al., 2021; Tiwari et al., 2024; Tosik-Gün & Atasoy, 2017) because some researchers suggest that a good headline should include keywords (Gemayel, 2016; Lippi, 2017; Sharma, 2019). On the contrary, it has been observed that the literature also includes expressions that are in the title but not used in the keywords or that are in the keywords but not in the title (Vogel et al., 2006). It is also remarkable that some studies on related technologies do not have any keywords (Hughes & Maas, 2017; Kim, 2006). On the other hand, the fact that virtual reality and augmented reality are the two most used keywords can be directly related to the number of studies. Similarly, the fact that the mixed reality keyword is not ranked third is thought

to be due to the low number of MR publications. In addition, it was observed in the studies that AR, VR, and MR were strongly related to the words self-efficacy, language learning, teachers, usability, and online learning. From this point of view, it can be said that the words related to AR, VR, and MR technologies are frequently used together in the literature (O'Connor & Mahony, 2023; Heintz et al., 2021; Huang, 2022; Özgen et al., 2021; Zhang et al., 2023).

It was found that most of the research on AR, VR, and MR was conducted in the United States and China, respectively. In addition, the fact that the universities conducting the most research on AR, VR, and MR technologies are located in China and that there are four different Chinese universities in the top five ranks supports this situation. In this context, it has been observed that "National Taiwan Normal University" is the university that conducts the most research on AR, VR, and MR technologies. The "National Taiwan University of Science and Technology" followed the relevant university in terms of the number of publications. Therefore, it can be stated that the studies conducted in Asian countries are carried out in certain universities. However, the findings suggest that the research conducted in the United States of America is not clustered in a single university so that there is a distribution of publications in different universities. In the systematic review conducted by Cannizzaro et al. (2022), it was observed that the United States ranked first and China ranked third in terms of AR publications per country. Similarly, Agbo et al. (2021) argue that the United States is the most productive country in terms of publishing articles related to VR in computer science education. This may be because the technologies in question first emerged and were developed in the United States. In fact, Sensorama, the first example of a multi-sensory simulator that incorporates all the features of VR technology, was invented by the American Heilig in 1962 (Gigante, 1993; Wikipedia, 2023). Similarly, the first real AR/VR experience was with the "Sword of Damocles," invented by Ivan Sutherland and his student Bob Sproull at Harvard University in 1968 (Billinghurst et al., 2015; Wikipedia, 2024). On the other hand, Turkey ranked third among the countries where these technologies were integrated into educational research. In a systematic review conducted in Turkey, it was found that studies on educational technology indexed in SSCI, SCI, and ERIC indexes have increased since the beginning of the 21st century (Kucuk et al., 2013). Finally, it was found that there were almost no studies on educational technologies on the African continent, while on the European continent, countries had a more balanced distribution in the number of publications on related technologies.

The findings showed that AR, VR, and MR studies were published more in "Education and Information Technology" and "Interactive Learning Environment" journals, respectively. Following these journals, "Education Sciences," "Computers and Education" and "Journal of Chemical Education" journals included more educational research on related technologies. Likewise, Irwanto et al. (2022) suggested that AR articles in science education are mostly published by the "Journal of Chemical Education" and "Computers and Education". Karakus et al. (2019) also determined that the most important journal in AR-supported education studies is "Computers and Education," according to the bibliographic analysis of journals. Similarly, Rashid et al. (2021) found that "Computers

and Education" is the most influential journal in VR technology, with 39 publications and 3968 citations. Finally, evaluating the number of publications by journal and country together can help to understand the scientific contributions of countries in more depth. In this context, the fact that the first authors of the articles published in the journal "Computer and Education" are generally citizens of the United States or China supports the number of publications determined on a country basis (Hsu et al., 2013). On the other hand, when the journals were compared, it was seen that "Computers and Education" received more citations than the others despite having 51 articles. Therefore, it can be claimed that each article published in the mentioned journal receives an average of thirty-nine citations and this number is higher than the average number of citations per article in other journals.

In the present research, it was determined that three publications by Guido Makransky ranked in the top ten regarding the number of citations. It was seen that the researcher published these studies in 2019. The citation relationships of VR-supported research in the literature from 2015 to 2020 were examined, and it was found that Makransky was the most frequently cited researcher (Cheng et al., 2022). A bibliometric analysis of the Metaverse also emphasized that Makransky is the most cited author (Tas & Bolat, 2022). Similarly, Makransky ranked first among the authors who published the most articles. In addition, when all the studies of the authors included in the systematic review are multiplied by the proportion of first authors, Makransky stands out as the second researcher with the highest number of first authors. Guo et al. (2021) also concluded in their extended reality study that Makransky has the highest number of articles as the first author. On the other hand, Christian Moro was the first in the first author ranking. However, it is remarkable that Moro ranks third in terms of the total number of studies. In line with these results, Guido Makransky, Bruce C. Wainman, Oliver A. Meyer, and Christian Moro, respectively, scored higher than the others in terms of h-index. On the other hand, due to the bibliometric analysis, it is important that there are three articles from Turkey in the top ten, and these studies received a total of 345 citations. In another study, the distribution of AR studies according to the number of citations between 2007 and 2022 was analyzed and it was stated that one study from Turkey ranked in the top ten (Irwanto et al., 2022).

As a result of the examinations, it was seen that AR, VR, and MR studies were mostly conducted with two, three, and four authors. It is also remarkable that there are two studies with six authors and one study each with eight, twelve, and fifteen authors. In another study, AR studies were evaluated regarding the number of authors, and it was determined that the studies generally had two authors (Tezer et al., 2019). In the same study, it was found that the number of studies conducted with at least six authors was high. Four of the studies included in this study cover MR, and one study covers AR. From this point of view, teamwork is needed when implementing applications for MR technology. This may be because MR applications are a very new technology and are less known than AR and VR technologies. Speicher et al. (2019) support this inference by stating that MR was first proposed in 1994 and that discussions about this technology have become more complex as time goes on. On the other hand, it was determined that

some of the related studies emerged as a result of the cooperation of different countries, universities, and departments. In this direction, the findings suggest that research integrating education and technology requires expertise, and more effective results can be obtained with teamwork and cooperation.

Limitations and Recommendations

Although this study has many contributions to the literature, some limitations need to be addressed. The main limitation of this study is that it focuses only on the analysis of studies published in Web of Science. Therefore, it is recommended to expand the documents to be analyzed in further studies with other databases. In other words, the use of databases, such as Scopus or Google Scholar, may lead to different results. In this study, theses, books, or articles were not added to the inclusion criteria. Furthermore, the present study only examined publications in English and did not include research in other languages. Thus, bibliometric studies involving different languages and various types of publications can be conducted in the future. The keywords augmented reality, virtual reality, and mixed reality were used in the study. For a broader analysis of bibliometric data on these technologies, new search terms can be defined that allow the inclusion of other studies related to the field of education. Similarly, inclusion of the keywords mentioned in the present study in the title was accepted as a criterion. However, studies using AR, VR, and MR research as secondary teaching methods or techniques can also increase the knowledge in this field. Hence, scanning the abstract and the title in further studies can provide rich data. Finally, the data sources included in the present study were limited to the field of education. In this direction, multidisciplinary research can be conducted by selecting different fields where AR, VR, and MR technologies are used.

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Genişletilmiş Türkçe Özet

Alan yazın incelendiğinde eğitim alanında AG, SG ve KG teknolojileriyle ilgili ayrı ayrı birçok bibliyometrik analiz çalışması yapıldığı görülmüştür (Arici vd., 2019; Hincapie vd., 2021; Liu vd., 2017; Mani & Madhusudan, 2022; Rojas-Sánchez vd., 2023; Soto vd., 2020; Talan, 2021). Benzer şekilde alan yazınında bahsi geçen teknolojileri ikili olarak ele alan ve bibliyometrik analiz kapsamında gerçekleştiren eğitim araştırmalarına rastlanmıştır (Calabuig-Moreno vd., 2020; Zhao vd. 2023). Ancak AG, SG ve KG teknolojilerini bütüncül bir şekilde ele almamak pedagoji oluşturma fırsatını sınırlamaktadır (Maas & Hughes, 2020). Bu yüzden Zhang vd. (2022) tarafından üç teknolojiyi de içerisinde barındıran bir bibliyometrik analiz yapılmıştır. Ancak bu araştırmada yalnızca cerrahi çalışmalara odaklanılmış ve diğer alanlar göz ardı edilmiştir. Buradan hareketle bu araştırmada üç teknoloji birlikte değerlendirilmiş ve eğitim teknolojilerine yönelik bilgilerin kapsamı artırılmaya çalışılmıştır. Bu durumun eğitimde AG, SG ve KG uygulamalarını inceleyen araştırmacılara, eğitim politikacılarına ve öğretmenlere önemli katkı sağlayacağı düşünülmektedir. Ayrıca bu çalışmanın araştırmacılar için yararlı bir kaynak olacağı öngörülmektedir. Belirtilen gerekçeler doğrultusunda çalışmanın amacı, eğitim alanındaki AG, SG ve KG araştırmalarına yönelik yayınlanan makalelerin bibliyometrik analizini gerçekleştirmektir. Bununla birlikte çalışmada, bibliyometrik analiz verilerine dayalı olarak bir sistematik inceleme yapılarak araştırma eğilimlerine ilişkin daha kapsamlı bilgilere ulaşılması amaçlanmaktadır.

Bu çalışma, çoklu araştırma yöntemine göre tasarlanmıştır. Çoklu araştırma yöntemi, araştırma probleminin incelenmesinde iki veya daha fazla veri toplama yönteminin birlikte kullanılması olarak tanımlanabilir (Cohen vd., 2007). Bu doğrultuda araştırmada iki farklı nitel yöntemden yararlanılmış ve öncelikle bibliyometrik analiz yapılmıştır. Bibliyometrik analizden sonra en fazla atıf alan çalışmaları değerlendirmek amacıyla sistematik inceleme tekniğinden yararlanılmıştır. Araştırmada, tarama yapmak için "augmented reality", "virtual reality" ve "mixed reality" anahtar kelimeleri kullanılmıştır. İlgili anahtar kelimelere göre başlık kategorisi göz önünde bulundurularak 01.10.2023 tarihinde Web of Science veri tabanında bir tarama gerçekleştirilmiştir. Bu kapsamda AG (n=531), SG (n=685), KG'ye (n=71) yönelik toplam 1287 çalışma .txt formatında indirilmiştir. Sistematik incelemeye dâhil edilen makalelerin seçiminde atıf sayıları dikkate alınmıştır. Böylece toplam yirmi doküman gözden geçirilmiştir. Araştırma kapsamında ulaşılan bibliyometrik verilerin analizi, van Eck ve Waltman (2010) tarafından geliştirilen VOSviewer programıyla gerçekleştirilmiştir. Sistematik incelemeye dâhil edilen dokümanlar MaxQda 20 programına aktarılmıştır. Bu kapsamda dokümanlar, yazar sayıları açısından incelenmiştir.

Araştırmada, AG ve SG teknolojisiyle gerçekleştirilen eğitim araştırmalarının 1990'lı yıllarda yapılmaya başlandığı tespit edilmiştir. Bu sonuçlarla benzer olarak alan yazınındaki bazı çalışmalarda AG'ye yönelik ilk eğitim araştırmasının 1999'da yapıldığı görülmektedir (Karakus vd., 2019). Öte yandan Rashid vd. (2021) tarafından yükseköğretimde SG'ye ilişkin ilk yayının 1994 yılında yapıldığının belirtilmesi

araştırmanın sonuçlarıyla tutarlık göstermektedir. Buna karşın KG araştırmalarının eğitimle bütünleştirilmesinin 2000'li yılların ortalarına denk geldiği belirlenmiştir. Buradan hareketle AG, SG ve KG'nin başta eğitim olmak üzere çeşitli disiplinler için nispeten yeni teknolojiler olduğu söylenebilir. Diğer taraftan bu teknolojiler karşılaştırıldığında SG'nin diğer gerçeklik teknolojilerine nazaran eğitimde daha çok kullanıldığı görülmüştür. Bu durum SG teknolojsiyle gerçekleştirilen çalışmaların hem yıl olarak daha önce başlamasından hem de araştırmacıların bu teknolojiye daha fazla aşina olmasından kaynaklanıyor olabilir. Öyle ki AG, sanal ortamların veya daha yaygın olarak adlandırılan SG teknolojisinin bir varyasyonu olarak öngörülebilir (Azuma, 1997).

Web of Science'da bulunan çalışmalarda sırasıyla virtual reality, augmented reality, education, medical education, simulation, mixed reality, mobile learning, educational technology ve computer-based learning anahtar kelimelerinin daha fazla kullanıldığı saptanmıştır. Bu durumun nedeni, alan yazınındaki çoğu araştırmada anahtar kelimeler ile başlık veya konunun uyumlu seçilmesi olabilir (Lin vd., 2017; Mirault vd., 2021; Tiwari vd., 2024; Tosik-Gün & Atasoy, 2017). Çünkü bazı araştırmacılar, iyi bir başlığın anahtar kelimeleri içermesi gerektiğini öne sürmektedir (Gemayel, 2016; Lippi, 2017; Sharma, 2019).

AG, SG ve KG araştırmalarının sırasıyla daha çok Amerika Birleşik Devletleri ve Çin'de yapıldığı tespit edilmiştir. Ayrıca AG, SG ve KG teknolojileriyle alakalı en fazla araştırma yapan üniversitelerin Çin'de yer alması ve ilk beş sıra içerisinde dört farklı Çin üniversitesinin bulunması bu durumu destekler niteliktedir. Bu kapsamda "National Taiwan Normal University"nin AG, SG ve KG teknolojileriyle alakalı en fazla araştırma yapan üniversite olduğu görülmüştür. İlgili üniversiteyi yayın sayısı açısından "National Taiwan University of Science and Technology"nin takip ettiği tespit edilmiştir. Dolayısıyla Asya ülkelerinde yapılan çalışmaların belirli üniversitelerde gerçekleştirildiği ifade edilebilir. Ancak Amerika Birleşik Devletleri'nde yapılan araştırmaların tek bir üniversitede yığılmadığı, böylece yayın açısından farklı üniversitelere yönelik bir dağılım olduğu söylenebilir. Cannizzaro vd. (2022) tarafından gerçekleştirilen sistematik incelemede, ülke başına düşen AG yayınlarında Amerika Birleşik Devletleri'nin birinci, Çin'in üçüncü sırada olduğu görülmüştür. Benzer şekilde Agbo vd. (2021), bilgisayar bilimleri eğitiminde SG ile ilgili makalelerin yayınlanması açısından Amerika Birleşik Devletleri'nin en üretken ülke olduğunu öne sürmektedir. Diğer taraftan bahsi geçen teknolojilerin eğitim araştırmalarıyla bütünleştirildiği ülkeler arasında Türkiye üçüncü sırada yer almıştır. Türkiye'de yapılan bir sistematik incelemede SSCI, SCI ve ERIC indekslerinde taranan eğitim teknolojisine yönelik çalışmaların 21. yüzyılın başlangıcından itibaren artış gösterdiği saptanmıştır (Kucuk vd., 2013).

AG, SG ve KG araştırmalarının sırasıyla "Education and Information Technology" ve "Interactive Learning Environment" dergilerinde daha çok yayınlandığı tespit edilmiştir. Bu dergilerin ardından "Education Sciences", "Computers and Education" ve "Journal of Chemical Education" dergilerinde ilgili teknolojilere yönelik eğitim araştırmalarına daha fazla yer verildiği görülmüştür. Aynı şekilde Irwanto vd. (2022), fen eğitiminde AG

makalelerinin çoğunlukla "Journal of Chemical Education" ve "Computers and Education" tarafından yayınlandığını öne sürmüştür. Karakus vd. (2019) de dergilerin bibliyografik analizine göre, AG destekli eğitim çalışmalarında en önemli derginin "Computers and Education" olduğunu belirlemiştir. Benzer olarak Rashid vd. (2021), "Computers and Education"ın 39 yayın ve 3968 atıf sayısıyla SG teknolojisinde en etkili dergi olduğunu saptamıştır.

Araştırmada, Guido Makransky tarafından gerçekleştirilen üç yayının atıf sayısı açısından ilk on sırada yer aldığı belirlenmiştir. Araştırmacının bu çalışmaları 2019 yılında yayınladığı görülmüştür. Alan yazınında 2015'ten 2020'ye kadar SG destekli araştırmaların atıf ilişkileri incelenmiş ve Makransky'nin en sık atıfta bulunulan araştırmacı olduğu tespit edilmiştir (Cheng vd., 2022). Metaverse üzerine gerçekleştirilen bir bibliyometrik analizde de Makransky'nin en çok atıf alan yazar olduğuna vurgu yapılmıştır (Tas & Bolat, 2022). Benzer şekilde en fazla makale yayınlayan yazarlar sıralamasında Makransky ilk sırada yer almıştır. Ayrıca sistematik incelemeye dâhil edilen yazarların tüm çalışmaları, ilk yazar olma oranlarıyla çarpılınca Makransky, en çok ilk yazar olan ikinci araştırmacı olarak öne çıkmaktadır. Guo vd. (2021) de genişletilmiş gerçeklik çalışmalarında Makransky'nin ilk yazar olarak en fazla sayıda makaleye sahip olduğu sonucuna ulaşmışlardır.

İncelemeler sonucunda AG, SG ve KG araştırmalarının çoğunlukla iki, üç ve dört yazar ortaklığında gerçekleştirildiği görülmüştür. Ayrıca altı yazarlı iki çalışma; sekiz, on iki ve on beş yazarlı birer çalışma olması dikkat çekmektedir. Başka bir araştırmada AG çalışmaları yazar sayısı açısından değerlendirilmiş ve çalışmaların genellikle iki yazarlı oldukları belirlenmiştir (Tezer vd., 2019). Aynı araştırmada en az altı yazarla birlikte yürütülen çalışma sayısının fazla olduğu saptanmıştır. Bu araştırmaya dâhil edilen çalışmaların dördü KG'yi, biri ise AG'yi kapsamaktadır. Buradan hareketle KG teknolojisine yönelik uygulamalar gerçekleştirilirken ekip çalışmasına ihtiyaç duyulduğu düşünülebilir. Bu durum KG uygulamalarının çok yeni bir teknoloji olmasından ve AG ile SG teknolojilerine göre daha az bilinmesinden kaynaklanıyor olabilir. Öyle ki Speicher vd. (2019) tarafından KG'nin 1994'te ilk kez önerildiğinin ve gün geçtikçe bu teknolojiye yönelik tartışmaların karmaşık hale geldiğinin söylenmesi bu çıkarımı destekler niteliktedir.

Ethics Committee Approval: All the rules in the Scientific Research and Publication Ethics Directive were complied with, and none of the "Actions Contrary to Scientific Research and Publication Ethics" in the second part of the Directive were applied.

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