A Systematic Review of Augmented Reality In Mathematics Education In The Last Decade

Zeynep Bahar ERŞEN [1], Yasemin ALP [2]

[1] zbahar.ozdogan@hotmail.com, orcid.org/0000-0002-7928-2535, Selçuk University, Türkiye

[2] alpalpy@hotmail.com, orcid.org/0000-0002-4146-7374, Selçuk University, Türkiye

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ABSTRACT

The goal of the study is to examine a comprehensive review of research involving augmented reality (AR) in mathematics teaching during the previous 10 years. For this purpose, the research was conducted using a systematic review technique. It synthesized a set of 60 articles from 2012 to 2021. Two researchers used content analysis to analyze the data. According to the findings, the majority of publications were published in 2019, with studies mostly aiming at assessing the influence of AR applications on mathematical achievement and exposing viewpoints on AR applications used in mathematics education. Also, secondary school students were mostly preferred as participants. Furthermore, most of the studies found that mathematics teaching with AR applications had a positive impact on academic standing and the teaching process, and that AR applications positively affected attitudes in mathematics lessons, increased the motivation of individuals towards mathematics lessons, and improved three-dimensional thinking skills.

Keywords: Augmented reality, interactive learning environments, mathematics education, systematic review

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INTRODUCTION

Reasons such as developments in science and technology, globalization, and rapid information flow through social media create the need for continuous updating of education systems. Therefore, it becomes necessary to redefine the goals in the curriculum in order to create individuals who meet the necessities and requirements of the time they live in (Maričića, 2016). In this context, one of the important topics in the curriculum is undoubtedly the usage of information and communication technologies in lessons. The significance of using digital resources in mathematics education, which is one of the areas where information and communication technologies are integrated, has begun to be accepted (Drijvers, Tacoma, Besamusca, Doorman, & Boon, 2013). As a matter of fact, in the NCTM Statement on Technology (2008), it is remarked that technologies to be used for mathematics education are important tools in supporting and expanding mathematical reasoning, in mathematical reflection, and in making sense of and solving problems. One of the technologies that has been used for mathematics education is augmented reality technology.

AR [augmented reality], which emerged in the 1960s and started to be used in the military and health fields, has also begun to be used in entertainment and education environments with the cheapening and widespread use of technology (Somyurek, 2014). In the 2008 Horizon report published by the NMC [New Media Consortium], AR technology was foreseen among the technologies that will have an impact on education in the near future, and it has been estimated that it will play an essential role in education with

mobile devices since 2010 and with wearable technologies since 2013 (İbili & Şahin, 2015). Augmented reality is a technology that offers the simultaneous display of computer-created virtual things in the actual environment. Its structure is similar to virtual reality (Rochlen, Levine, & Tait, 2017). Another definition of AR is a technology that allows users to experience the actual world as enhanced, enriched, or augmented by adding information such as text, photos, voice, etc. to the real image simultaneously (Gonzato, Arcila, & Crespin, 2008). With augmented reality, it can be ensured that students see virtual drawings on real objects and interact with them directly in teaching environments, increasing their interest in educational activities and avoiding the distraction that may arise from using input tools such as keyboard and mouse to interact with traditional technology (Kaufmann & Schmalstieg, 2003).

When the research in the literature on AR applications in mathematics education are analyzed, it was shown that teaching using AR applications increased academic achievement (Lin, Chen & Chang, 2015; Lozada-Yánez, La-Serna-Palomino & Molina-Granja, 2019; Özçakır, 2017; Saundarajan et al., 2020), improved three-dimensional thinking (Gün & Atasoy, 2017; İbili, 2013; Salinas, 2017), increased motivation in mathematics lessons (Kaufmann & Dünser, 2007; Martín-Gutiérrez et al., 2010; Pérez-López & Contero, 2013), and provided meaningful learning (Flores-Bascuñana, Diago, Villena-Taranilla & Yáñez, 2019; Hsiao & Rashvand, 2011), and that participants had positive views on AR applications (Buchori, Setyosari, Dasna & Ulfa, 2017; Cai et al., 2020; Martin-Gonzalez, Chi-Poot & Uc-Cetina, 2016).

Although studies on AR in mathematics teaching have increased in recent years, there are very few review studies (Ahmad & Junaini, 2020; Palancı & Turan, 2021). In the study conducted by Ahmad and Junaini (2020), from 2015 to 2019, 19 research publications on AR in mathematics education were analyzed. In the study conducted by Palancı and Turan (2021), 86 studies published between 2010 and 2020, 35 of which were articles and 51 of which were conference proceedings, and in which AR was used in mathematics education, were examined. This research, on the other hand, provides a more comprehensive framework than other studies with the number of articles found and the sub-headings analyzed. Considering that systematic reviews have significant benefits over traditional methods in terms of examining all available data (Bown & Sutton, 2010), this study is expected to guide academics and contribute to the literature. In this regard, the study's goal is to conduct a comprehensive examination of studies in which AR was utilized in mathematics education throughout the previous 10 years in terms of different factors. According to the goal of the research, responses to the following research questions were sought:

1. How are the conducted studies distributed in terms of years and journals?
2. How are the conducted studies distributed in terms of number and country of authors?
3. How are the conducted studies distributed in terms of indexes?
4. What are the aims of the conducted studies?
5. What are the research topics of the conducted studies?
6. Which methodologies are used in the conducted studies?
7. How are the types and numbers of participants in the conducted studies distributed?
8. What are the data collection tools and data analysis types in the conducted studies?
9. How are the conducted studies distributed in terms of reference numbers?
10. What do the results of the conducted studies reveal?

RESEARCH METHOD

Research Design

This study is a systematic review. The systematic review approach is a thorough screening method for evaluating and synthesizing studies on a subject (Uman, 2011). In this study, articles on the topic of AR in mathematics education were considered. The current status of the studies carried out around the world on this subject in the last decade is stated.

Collection of Data

The research was done using databases. The keywords “augmented reality in mathematics education” and “matematik eğitiminde artırılmış gerçeklik” were used while searching. Studies to be included in the research were accessed through Google Scholar, Web of Science, TÜBİTAK ULAKBİM, DergiPark, Scopus, and ScienceDirect. Only articles published between the years 2012 and 2021 were included in the study. Inaccessible studies were not included in this research. Under the specified conditions, a total of 60 articles based on augmented reality in mathematics education were accessed.

Data Analysis

First of all, the articles suitable for the purpose of the research were examined in detail. Then, the data to be used in the study was recorded in the computer environment. Note that, while considering the data, the criteria were inspired by those of Tezer (Tezer et al., 2019). When examining the articles on augmented reality in mathematics education, the number of authors, publication year, countries of the authors, research method, sample group, number of samples, number of references, purpose of the study, topic of the study, results of the study, data collection tool used, analysis technique used, journals in which the studies were published, and the indexes of the journals were taken into account. The data obtained is shown in the tables. The research findings were evaluated using percentages and frequencies. The similarities and differences between the studies are explained in the tables. The data used in the investigation is shown in Table 1.

Table 1. *The Data Used in the Study*

Name of the journal in which the study was published
Index of the journal in which the study was published
Year which the study was published
Number of authors of the research
Authors’ countries
Method of the research
Preferred sample group in the study
Number of the sample group
Data collection tool used in the research
Analysis technique used in the research
Number of references
Purpose of the research
Topic of the research
Results of the research

Validity and Credibility

In order to ensure the validity and reliability of the study, the authors evaluated whether the articles to be considered were suitable for the purpose of the research. The researchers determined the articles to be reviewed by consensus. In addition, the data to be used in the findings section was examined separately by the researchers. Then, the obtained data were compared, and it was seen that the researchers mostly agreed. In case of any inconsistency, the data were re-examined by the researchers together. In addition, this article includes all of the data analyzed during this investigation.

FINDINGS

Table 2. *Distribution of Publications on Augmented Reality in Mathematics Education by Year*

Publication Year	f	%
2012	1	1,6
2013	2	3,3
2014	2	3,3
2015	5	8,4
2016	1	1,6
2017	8	13,4
2018	1	1,6
2019	16	26,7
2020	14	23,4
2021	10	16,7
Total	**60**	**100**

As seen in Table 2, more studies on augmented reality in mathematics education have been conducted in recent years. In the distribution of publications on augmented reality in mathematics education by year, it is seen that the most publications were made in 2019 (26.7%). The number of publications in this field was 14 (23.4%) in 2020. Furthermore, it is observed that the number of studies on augmented reality in mathematics education in 2021 was 10. (16.7%). The years with the least number of studies on augmented reality in mathematics education are 2012, 2016, and 2018 (1.6%). There was a rise in the number of publications on this subject between 2012 and 2015. In 2017, there were 8 (13.4%) publications about augmented reality in mathematics education.

Table 3. *Distribution of Publications on Augmented Reality in Mathematics Education by Number of Authors*

Author Numbers	f	%
1 author	6	10
2 authors	22	36,6
3 authors	18	30
4 authors	7	11,7
5 or more authors	7	11,7
Total	**60**	**100**

When the publications on augmented reality in mathematics education are investigated, it is observed that there are 22 (36.6%) publications that have been written by two authors. According to Table 2, 18 of the examined articles (30%) have been written by three authors. In addition, the number of articles with a single author is 6 (10%). It is clear from the above table that 4 authors wrote 7 publications (11.7%), and 7 publications (11.7%) were written by 5 or more authors on augmented reality in mathematics education. Also, the distribution of the number of authors of publications with 5 or more authors is: 5 of them (8.3%) have 6 authors, 1 of them (1.6%) has 5 authors, and 1 of them (1.6%) has 11 authors.

Table 4. *Distribution of Publications on Augmented Reality in Mathematics Education by Country*

Countries	f	%
Australia	4	2,2
Brazil	5	2,9
China	8	4,5
Cyprus	3	1,7
Ecuador	3	1,7
Germany	12	6,7
Greece	2	1,1
Indonesia	27	15,2
Jordan	1	0,6
Liechtenstein	2	1,1
Malaysia	12	6,7
Mexico	18	10,1
Saudi Arabia	4	2,2
Spain	15	8,4
Sweden	1	0,6
Taiwan	8	4,5
Turkey	32	18
Ukraine	6	3,4
United Arab Emirates	2	1,1
United States of America	13	7,3
TOTAL	**178**	**100**

Publications on augmented reality in mathematics education were made in 20 different countries by 178 authors from 2012 to 2021. In the 60 articles analyzed, it is seen that Turkish writers are found to be the most common in terms of author distribution by country (18%). Indonesian authors follow Turkish authors with 27 authors (15.2%). The number of Mexican authors working on augmented reality in mathematics education is 18 (10.1%). It is seen in Table 4 that there are a lot of American (7.3%), Spanish (8.4%), Malaysian (6.7%), and German (6.7%) authors working on augmented reality in mathematics education. The countries of other authors publishing in this context are as follows: Taiwan (4.5%), China (4.5%), Brazil (2.9%), Saudi Arabia (2.2%), Ukraine (3.4%), Australia (2.2%), Cyprus (1.7%), Ecuador (1.7%), United Arab Emirates (1.1%), Greece (1.1%), Liechtenstein (1.1%), Jordan (0.6%), and Sweden (0.6%).

Table 5. *Distribution of Publications on Augmented Reality in Mathematics Education by Index of Journals*

Index of publications	f	%
SSCI and SCI-Expanded	17	28,3
Area Index (ERIC)	16	26,6
ESCI	8	13,4
TR index	6	10
Others	13	21,7
TOTAL	**60**	**100**

The distribution of publications on augmented reality in mathematics education according to the index of journals is given in Table 5. It is clear that most of the studies were published in SSCI (18.3%) and SCI-Expanded (10%). In addition, the ERIC database has 16 publications on augmented reality in mathematics education. The number of articles in the ESCI and TR indexes is clearly shown to be 8 (13.4%) and 6 (10%),

respectively. The articles in the "others" (21.7%) section consist of journals that are not mentioned in the Web of Science and ERIC indexes.

Table 6. *Distribution of Publications on Augmented Reality in Mathematics Education by Journal*

Journals	f	%
Journal of the Human and Social Science Researches	1	1,6
Inonu University Journal of the Graduate School of Education	1	1,6
Inonu University Journal of the Faculty of Education	1	1,6
Education and Science	1	1,6
Eurasia Journal of Mathematics, Science and Technology Education	3	5
Afyon Kocatepe University Journal of Science and Engineering	1	1,6
Research and Practice in Technology Enhanced Learning	1	1,6
Necatibey Faculty of Education, Electronic Journal of Science and Mathematics Education	1	1,6
Creative Education	1	1,6
Journal of STEM Education	1	1,6
Revista Iberoamericana de Informatica Educativa	1	1,6
Educational Dimension	1	1,6
Interactive Learning Environments	2	3,3
Education and Information Technologies	3	5
Journal on Mathematics Education	1	1,6
Education Sciences	2	3,3
International Journal of Emerging Technologies in Learning	3	5
Universal Journal of Educational Research	2	3,3
Indonesian Journal of Educational Studies	1	1,6
Jurnal Riset Pendidikan Matematika	1	1,6
Applied Sciences	1	1,6
International Journal on Interactive Design and Manufacturing	1	1,6
International Education Studies	1	1,6
International Journal of Mathematical Educational in Science and Technology	1	1,6
Journal of Educational Computing Research	1	1,6
Journal of Education and Practice	1	1,6
Journal of Internet Technology	1	1,6
Computers and Electrical Engineering	1	1,6
British Journal of Educational Technology	1	1,6
Turkish Journal of Mathematics Education	1	1,6
Adıyaman University Journal of Educational Sciences	1	1,6
Educational Technology Theory and Practice	1	1,6
Pixel-BIT Revista de Medios y Educacion	1	1,6
Campus Virtuales	1	1,6
Mathematics	1	1,6
International Journal of Advanced Computer Science and Applications	1	1,6
Journal of Universal Computer Science	1	1,6
Career Development and Transition for Exceptional Individuals	1	1,6
International Journal of Instruction	1	1,6
International Journal of Curriculum and Instructional Studies	1	1,6
The Mathematics Enthusiast	1	1,6
Advances in Social Sciences Research Journal	1	1,6
Computers & Education	2	1,6
International Journal of Applied Engineering Research	1	1,6
Innovations in Education and Teaching International	1	1,6
Teaching Mathematics and Computer Science	1	1,6
The Journal of Information Technologies	1	1,6
Mathematical Problems in Engineering	1	1,6
International Journal of Interactive Mobile Technologies	2	3,3
TOTAL	**60**	**100**

When reviewing the 60 papers on augmented reality in mathematics education between 2012 and 2021, it was observed that these studies were published in 49 different journals. "Education and Information

Technologies," "International Journal of Emerging Technologies in Learning," and "Eurasia Journal of Mathematics, Science, and Technology Education" each published 3 articles (5%). Moreover, "Interactive Learning Environments," "Education Sciences," "Universal Journal of Educational Research," and "Computers & Education" each published 2 articles (3.3%). Table 15 shows that one article was published in each of the remaining journals.

Table 7. *Distribution of Publications on Augmented Reality in Mathematics Education by Purpose of Articles*

Purpose of publications	f	%
The effect of AR-based learning applications on academic success	19	22,9
The effect of augmented reality on attitude, opinions and perception	19	22,9
To develop AR-based learning applications and overview tools	15	18
The effect of AR-based learning applications on motivation	11	13,4
The effect of AR-based learning applications on spatial ability, visual thinking and 3D thinking skills	7	8,4
Document Review	5	6
The effect of augmented reality on self-efficacy	3	3,6
To develop scale	1	1,2
To explain the challenges of teachers in developing AR-based learning applications	1	1,2
The effect of augmented reality on math anxiety	1	1,2
To determine success in informal learning environment	1	1,2
TOTAL	**83**	**100**

Table 7 shows the distribution of publications on augmented reality in mathematics education by purpose. The influence of augmented reality applications in mathematics education on academic success was clearly investigated in the majority of research (22.9%). The impact of augmented reality on attitude and opinion was the most researched topic after academic performance (22.9%). Another topic that received the most attention was the creation of augmented reality-based learning applications and providing information about current applications (18%). The effect of augmented reality on motivation (13.4%) and spatial ability and visual thinking (8.4%) are other purposes considered. Document analysis was performed in 6% of the publications on augmented reality in mathematics teaching. Other studies using augmented reality in mathematics education aim to develop scales (1.2%), identify the difficulties experienced by teachers in developing an AR-based application (1.2%), determine success in an informal learning environment (1.2%), and determine the effect of augmented reality on math anxiety (1.2%) and on self-efficacy (3.6%).

Table 8. *Distribution of Publications on Augmented Reality in Mathematics Education by Research Topic*

Research trends of publications	f	%
Academic success	16	30,8
Attitude, opinion	14	26,9
Motivation	11	21,2
Spatial ability, visual thinking skill, 3D thinking skill	7	13,5
Self-efficacy	3	5,7
Math anxiety	1	1,9
TOTAL	**52**	**100**

When looking at publications by study subject, Table 8 shows that the influence of augmented reality in mathematics education on academic success is the most investigated (30.8%). According to the publications analyzed, the researchers investigated the influence of augmented reality on the sample group's views and opinions (26.9%). The impact of augmented reality on motivation is also one of the most investigated subjects (21.2%). It is clearly seen that the other topics that researchers consider are spatial ability, visual thinking skills, and 3D thinking skills (13.5%), self-efficacy (5.7%), and math anxiety (1.9%). It

should also be emphasized that the impact of augmented reality on different types of research trends in any one publication is examined.

Table 9. *Distribution of Publications on Augmented Reality in Mathematics Education by Research Method*

Method	f	%
Quantitative Research Methods	27	45
Others	12	20
Qualitative Research Methods	9	15
Mixed Model	7	11,7
Literary Review	5	8,3
TOTAL	**60**	**100**

It is clear from Table 9 that in the publications on augmented reality in mathematics education, the authors mostly prefer quantitative research methods (45%). Furthermore, an experimental design was selected in the majority of the publications in which a quantitative research method was used. A qualitative research method was used in 9 (15%) of the analyzed articles. In studies using a qualitative research method, it is seen that phenomenological and case studies were used as designs. A mixed method was used in 7 (11.7%) publications in the reviewed articles. A literature review was conducted on five (8.3%) publications. 12 (18.8%) of the studies using an “other” research method in publications on augmented reality in mathematics education are theoretical studies. The remaining 1 (1.6%) study is a scale development study.

Table 10. *Distribution of Publications on Augmented Reality in Mathematics Education by Sample Group*

Sample Groups	f	%
Secondary School	19	41,3
University	13	28,3
High School	5	10,9
Primary School	3	6,6
Special Education	2	4,3
Teachers	2	4,3
Others	2	4,3
TOTAL	**46**	**100**

When articles on augmented reality in mathematics education are analyzed in terms of sample groups, it is shown that secondary school students are preferred the most (41.3%). Following secondary school students, university students are the most preferred sample group (28.3%). Primary and high school students were selected as sample groups in 3 (6.6%) and 5 (10.9%) publications, respectively. The least preferred sample groups are special education (4.3%) and teachers (4.3%). In the sample group stated as "others," there are parents (2.15%) and visitors to the mathematics exhibition (2.15%).

Table 11. *Distribution of Publications on Augmented Reality in Mathematics Education by Sample Number*

Sample Numbers	f	%
1-20	6	13
21-40	13	28,3
41-60	6	13
61-80	6	13
81-100	6	13
101 or more	9	19,7
TOTAL	**46**	**100**

Table 11 shows that the greatest number of samples in research on augmented reality in mathematics education ranges from 21 to 40 (28.3%). The number of publications with a sample number of 101 or more is 9 (19.7%). The number of publications with samples between 1-20, 41-60, 61-80, and 81-100 is 6 (13%) each.

Table 12. *Distribution of Publications on Augmented Reality in Mathematics Education by Data Collection Tool*

Data Collection Tools	f	%
Questionnaires	13	18,8
İnterviews	13	18,8
Achievement tests	12	17,5
Skill tests (visual thinking tests, 3D thinking tests, spatial thinking, computer skills test)	8	11,6
Scale	7	10,1
Document Analysis	5	7,2
Video recordings and audio recordings	4	5,8
Observations	4	5,8
Attitude tests, opinion forms	2	2,9
Self-efficacy test	1	1,5
TOTAL	**69**	**100**

As can be seen in Table 12, questionnaires and interviews were mostly preferred as a data collection tool in publications on augmented reality in mathematics education (18.8%). Another two of the most commonly used data gathering tools in the research studied are achievement tests (17.5%) and skill tests (11.6%). It is seen that document analysis (7.2%), video recordings (5.8%), observations (5.8%), and attitude tests (2.9%) are less preferred by researchers compared to other data collection tools. It is seen from Table 12 that the least preferred data collection tool in the publications on augmented reality in mathematics education is the self-efficacy test (1.5%). It should also be noted that more than one different type of data gathering tool has been used in any one publication on augmented reality in mathematics education.

Table 13. *Distribution of Publications on Augmented Reality in Mathematics Education by Analysis Technique*

Analysis Technique	f	%
t-test	21	30,5
Descriptive analysis	20	29
Content analysis	6	8,7
ANOVA	5	7,2
ANCOVA	5	7,2
Others	5	7,2
Descriptive statistics	4	5,9
Mann-Whitney U test	3	4,3
TOTAL	**69**	**100**

When the publications on augmented reality in mathematics education are analyzed in terms of analysis technique, it is clearly seen in Table 13 that researchers mostly use t-tests (30.5%) and descriptive analysis (29%). In addition, content analysis (8.7%), ANOVA (7.2%), and ANCOVA (7.2%) are seen as other preferred analysis techniques. The least preferred analysis techniques are descriptive statistics (5.9%) and the Mann-Whitney U test (4.3%). The analysis techniques specified as “others” in the table are sequential analysis (1.44%), inferential statistics (1.44%), Pearson correlation coefficients (1.44%), Bogdan & Biklen model (1.44%), and statistical analysis (1.44%). It should also be noted that more than one different type of analysis has been used in any one publication on augmented reality in mathematics education.

Table 14. *Distribution of Publications on Augmented Reality in Mathematics Education by Results of Articles*

Results of publications	f	%
Positive effect on academic success and learning process	26	48,1
Positive effect on attitude, opinions and perception	10	18,5
Positive effect on motivation	5	9,2
Positive effect on spatial ability, visual thinking and 3D thinking skills	5	9,2
Positive effect on self-efficacy	2	3,6
No effect on learning process	1	1,9
A scale with validity and reliability was developed	1	1,9
No effect on self-efficacy	1	1,9
The teachers overcome the difficulties faced to develop AR aplications	1	1,9
Increasing performance of sample group with high anxiety	1	1,9
Positive effect on informal learning environment	1	1,9
TOTAL	**54**	**100**

When the findings of research on augmented reality in mathematics education are analyzed, it is clear that augmented reality has a favorable impact in many of the publications. As shown in Table 14, AR-based learning applications have a beneficial impact on achievement and the learning process (48.1%). In the evaluated publications, AR-based learning applications have been shown to increase the dynamic nature of the learning process. However, other studies find that augmented reality-based learning applications have no substantial impact on the learning process (1.9%). In many publications, the sample group has a positive attitude and opinion about augmented reality (18.5%). Furthermore, papers on augmented reality in mathematics education reveal that it boosts the sample group's motivation (9.2%). As a result of the publication aimed at scale development, a scale with validity and reliability was developed (1.9%). In some research, augmented reality had a positive effect on self-efficacy (3.6%), whereas in others, it had no effect (1.9%). As a result of the study, which aims to explain the difficulties of teachers in developing AR-based learning applications, it was concluded that teachers overcame their difficulties (1.9%). Additionally, AR-based learning applications have a favorable effect in an informal learning setting (1.9%) and improve the performance of a sample group with high anxiety (1.9%).

Table 15. *Distribution of Publications on Augmented Reality in Mathematics Education by Bibliographic Number*

Bibliographic Numbers	f	%
1-20	5	8,3
21-40	32	53,3
41-60	17	28,3
61-80	4	6,7
81-100	2	3,4
TOTAL	**60**	**100**

Table 15 shows that the number of references in half of the papers on augmented reality in mathematics education ranges between 21 and 40 (53.3%). The number of publications with a number of references between 41 and 60 is 17 (28.3%). The number of publications with 1–20 and 61–80 references is 5 (8.3%) and 4 (6.7%), respectively. In addition, the number of publications with references between 81 and 100 is the least, with 2 (3.4%).

DISCUSSION AND CONCLUSION

When the distribution of publications on the use of AR in mathematics education, which is the first sub-problem of the research, was evaluated by year, it was noted that the number of articles rose, notably in 2019 (Altıok, 2019; Demitriadou, Stavroulia & Lanitis, 2019; Ibili, Resnyansky & Billinghurst, 2019; Kramarenko, Pylypenko & Zaselskiy, 2019). Although recent technical advancements have boosted the amount of research on AR applications, it was seen that there was a slight decrease in the number of publications, probably due to the COVID-19 outbreak. Furthermore, it was discovered that the investigations were mostly undertaken by two researchers (Chao & Chang, 2018; Elsayed & Al-Najrani, 2021; Sommerauer & Müller, 2014). While the majority of the authors who conducted research on AR applications in mathematics education were Turkish (18%), this is followed by Indonesian (about 15%), Mexican (about 10%), and Spanish (about 8%) researchers. The reason why an important majority of the studies on this subject were carried out by Turkish researchers may be the 2018 curriculum announced by the Higher Education Council (HEC). As a matter of fact, the frequent emphasis on the use of technology in the mathematics curriculum (Ministry of National Education [MoNE], 2018) may have led the researchers to AR applications, which are newly used in mathematics education.

Another result obtained from the research is that approximately 28% of the articles were scanned in SSCI/SCI Expanded and approximately 27% in ERIC-indexed journals. Indeed, this finding provides researchers with crucial information on the value of studies on augmented reality applications used in mathematics education. When the journals of the papers were analyzed, it was discovered that there was more research on the use of AR in mathematics education in publications that included technological usage (for example, Eurasia Journal of Mathematics, Science, and Technology Education (5%), Education and Information Technologies (5%), International Journal of Emerging Technologies in Learning (5%), and Interactive Learning Environments (3%)).

The results collected for the fifth sub-problem of the research demonstrate that the bulk of the studies were targeted at determining the impact of AR applications on mathematical success (Cheng, Wang, Cheng, & Chen, 2019; Estapa & Nadolny, 2015; Özdemir & Özçakır, 2019). This is followed by research in which opinions on AR applications utilized in mathematics education were explored (Buchori, Setyosari, Dasna, & Ulfa, 2017; Mailizar & Johar, 2021). In parallel with these results, when the studies were analyzed, it was seen that quantitative research methodologies were mostly used (Ahmad, 2021; Cai, Liu, Yang & Liang, 2019; Hernandez, Gomez & Cortes, 2019).

Another result of the research is that when the sample groups of the studies were examined, they were mostly conducted with secondary school students (Cahyono et al., 2020; Sommerauer & Müller, 2014); this was followed by university students (Chen, 2019; Hsieh & Chen, 2019). Also, it was determined by Ibáñez and Delgado-Kloos (2018) and Sırakaya and Alsancak-Sırakaya (2019) that the studies were frequently conducted with secondary school students in their compilation studies on AR applications used in STEM education. In the study by Tezer et al. (2019), in which they examined all academic studies on augmented reality, it was stated that approximately half of the studies on this subject were conducted with university-level students. This difference in the research by Tezer et al. (2019) may be due to the fact that many different disciplines (such as physics, chemistry, and engineering) and academic study types (such as articles, papers, and theses) were handled together. Moreover, when the number of samples in this study was examined, it was determined that there was a concentration in the range of 21–40 sample numbers (approximately 28%) in the studies.

While questionnaires (f = 13) and interviews (f = 13) were utilized as data collection tools in 26 of the studies reviewed, achievement tests were used in 12 of them. This is followed by skill tests (approximately 12%), scales (approximately 10%), and documents (approximately 7%). Parametric tests such as the t-test (approximately 31%), ANCOVA (approximately 7%), descriptive (29%), or content analysis (approximately 9%) were used for qualitative data analysis in the majority of studies.

The results gathered from the research carried out in mathematics education for AR applications over the previous ten years reveal that 48% of the studies concluded that mathematics teaching using AR applications had a favorable influence on academic success and the teaching process (Estapa & Nadolny, 2015; Tosik-Gün

& Atasoy, 2017; Velazquez & Mendez, 2021), and that AR applications positively affected attitudes in mathematics lessons (Cai et al., 2020; Demitriadou, Stavroulia & Lanitis, 2019; Önal, İbili & Çalışkan, 2017; Saundarajan et al., 2020), increased the motivation of individuals towards mathematics lessons (Cai, Liu, Yang & Liang, 2019; Caslales-Martinez, Martinez-Segura, Perez-Lopez & Contero, 2017; Chao & Chang, 2018), and improved three-dimensional thinking skills (Aldalalah, Ababneh, Bawaneh & Alzubi, 2019; Herrera, Perez & Ordonez, 2019; Salinas & Pulido, 2017). However, there were also studies showing that teaching with AR applications had no effect on academic success (Tosik-Gün & Atasoy, 2017) or did not contribute to an individual's self-efficacy (İbili & Şahin, 2015). Finally, when the studies' bibliographies were evaluated, it was discovered that around 53% of the references were clustered in the range of 21–40. As the number of researchers on this topic grows, it is expected that the number of sources will expand significantly.

Data availability All relevant data and material are included in the manuscript.

Code availability (software application or custom code) Not applicable.

Declarations

Conficts of interest The authors declare that there is no conflict of interest.

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