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How Does the Use of the Augmented Reality Technology in Mathematics Education Affect Learning Processes?: A Systematic Review

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Abstract

This study aimed to examine the methodological trends of studies using the Augmented Reality (AR) technology in mathematics education and reveal basic findings obtained from the studies. In this context, a systematic review process was conducted in the Web of Science database and 86 studies obtained as a consequence were reviewed. In this systematic review study, the content analysis method has been used to analyze the data. As a result of analyzing the studies reviewed, it was observed that related studies increased as from 2010, and the qualitative method was the most frequently used. It was determined that materials in the studies were usually designed using the Unity3D and Vuforia platforms. In the studies reviewed, it was seen that the most frequently faced advantages of AR in mathematics education were that it supported learning and motivation and enhanced the spatial abilities of students. Additionally, the most frequent disadvantages of AR in mathematics education were that it caused technical inconveniences and it is difficult to develop materials through AR. Students show resistance against new technology, and it causes health problems in extended use. Finally, recommendations for researchers and practitioners have been presented based on the findings obtained from this systematic review.

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Introduction

Mathematics is a crucial course because of the acquisitions it provides to students to solve their daily life problems and its effects on their academic achievement throughout their education life (Durksen, Way, Bobis, Anderson, Skilling, & Martin, 2017; Lein, Jitendra, Starosta, Dupuis, Hughes-Reid, & Star, 2016). Studies have revealed that mathematical skills are acquired during school years (Koponen, Aunola, & Nurmi, 2019). Yaşar and Papatğa (2015) stated that mathematics lesson, which plays a crucial role in determining students' academic achievement throughout their education life, is among the top courses in which students fail, have anxiety and difficulty, and develop negative attitudes the most. Additionally, many students from all educational levels face problems when learning mathematics and these problems are usually associated with abstract thinking skills (Bishop, 1986). In addition, the self-induced difficulty of mathematics arises from an epistemological reason

and students are likely to have a misconception regarding almost every subject in mathematics (Gürel & Okur, 2016).

Jackson (2008) suggests that negative perceptions related to mathematics and mathematics difficulty affect students' learning. The skill of doing mathematics is primarily influenced by the mathematics learning attitudes of students rather than their cognitive skills. Accordingly, it can be asserted that arousing positive beliefs and emotions in students regarding their competence in mathematics will lead to learning mathematics better (Timmerman, Toll, & Van Luit, 2017). Today, students who fear learning mathematics commonly have feelings such as disliking mathematics, being unwilling to study and even hating mathematics (Aldalalah, Ababneh, Bawaneh, & Alzubi, 2019). These feelings concerning mathematics result from the tension preventing students from solving mathematical problems, reasoning, and being appreciated (Salinas & Pulido, 2017). As a result of these negative feelings, it becomes inevitable for students to fail in a mathematics lesson. To overcome this failure in mathematics, help students objectify their abstract knowledge and predict potential problems, multimedia applications like Augmented Reality (AR) that may enhance students' knowledge are used (Rohendi, Septian, & Sutarno, 2018). Indeed, according to the National Council of Teachers of Mathematics [NCTM] (2015), technology use is essential for developing students' mathematical skills, encouraging them to learn more profoundly and increasing their interest in mathematics. Technology is crucial in the teaching and learning of mathematics (Juhan & Halkias, 2017). Several studies on technology use in mathematics lessons have discussed the beliefs and successes of students and teacher (Aytekin & Isiksal-Bostan, 2019). It is seen that mobile technologies have the power of developing productivity, creativity, and collaboration among students from all age groups alongside learning mathematics, but also build productivity, creativity and collaboration among students from all age groups (Hu & Samuels, 2007; Khaddage, Knezek, & Baker, 2012). There has been an increase in AR technology, the final wave of mobile technologies (Solano, Ugalde, Gómez, & Sánchez, 2017).

AR is an interactive presentation of virtual objects or materials in real environments by being transferred to the virtual environment (Azuma, 1999). When examining the definitions of augmented reality in general, it can be concluded that it is a method in which elements like a virtual object, animation, video, sound, and image are added to the real world via glasses, camera, or 3D screen (Aldalalah et al., 2019). AR is one of the developing technologies used in many fields like medicine, education, architecture, commerce, sports, and entertainment (Gecu-Parmaksiz & Delialioglu, 2019). Various studies have investigated the effects of AR technology on educational processes in different fields. For example, Martín-Gutiérrez et al. (2010) have stated that using augmented reality technology in engineering education positively affects students' spatial ability and satisfaction. As a result of a study conducted by Turan, Meral, and Sahin (2018) examining the effects of AR technology on geography education found that this technology increased student success, decreased their cognitive load level, and positively affected their views.

Studies on the use of AR in mathematics education have suggested that it enables students to display a positive attitude toward learning contents, provides an interesting learning experience, provides a teacher-student collaboration and enhances both geometry and mathematics learnings (Billinghurst & Duenser, 2012; Lin, Chen, & Chang, 2013; Kaufmann & Schmalstieg, 2003).

The AR technology helps students understand complex subjects by providing 3D simulations of invisible situations that are hard to visualize (Cai et al., 2020). In the study conducted by Sun and Chen (2019) on AR technology in mathematics education, they observed that the AR technology positively affected interaction besides encouraging students to participate in learning activities with less cognitive effort and enhance their learning performance. In a study which was conducted using a traditional method and the AR technology for students to learn manipulated and mental rotation questions via image pointers, it was found that the AR technology-facilitated understanding mathematical concepts for students, compared to the traditional method (Nakano, Matsubara,

Okamoto, & Iwane, 2017). Furthermore, in the literature, it is indicated that AR technology can positively affect students' learning levels and motivations (Chang, Chung, & Huang, 2016).

Accordingly, in the study conducted by Estapa and Nadolny (2015) examining the effect of AR technology on the success and motivation of students in a mathematics lesson, they found that AR had a positive impact on the success and motivation of students. In addition, Liao, Yu, and Wu (2015) found that using the AR application, which they developed for students to learn geometry concepts, might build their attitudes in learning geometry and their spatial ability, geometry success, and attitudes toward learning mathematics. Thus, it can be asserted that using the AR technology in mathematics teaching can develop student motivation and both technical and conceptual types of mathematical activity (Estapa & Nadolny, 2015). In another experimental study comparing the effects of the traditional methods and AR applications, it was found that students had a positive learning attitude; their success increased, and their reasoning abilities developed (Cai, 2018). In the light of all these findings, it can be stated that the AR technology has significant potential in mathematics education (Kellems et al. 2020). Consequently, AR is a highly attention-grabbing technology in terms of the learning environments it provides to students due to its visualizing abstract concepts.

Although many studies in which AR technology is used in mathematical education, only a few studies have systematically examined relevant studies on this subject. None, however, have provided a comprehensive analysis (Ahmad & Junaini, 2020). Therefore, examining the studies conducted within the scope of AR technology mathematical subjects is important in determining the current situation (Korucu, Usta, & Yavuzarslan, 2016; Altinpulluk, 2019). Therefore this study, which examines the results of studies in the literature, is important in offering instructive findings to further studies and practitioners. Also, it is thought that this study will guide researchers and contribute to the literature. Accordingly, the purpose of the study is to review scientific studies on the use of AR technology in mathematics education. In line with this purpose, answers were sought to the following research questions:

1. What are the methodological and application-oriented trends of the scientific studies conducted regarding AR technology in mathematics education?

- How is the distribution of the studies according to the types of publication?
- How are the studies distributed based on the years?
- How are the research methods used in the studies distributed?
- How are the studies distributed based on the sample groups?
- How are the studies distributed based on the countries where they are conducted?
- How are the AR technology types used in the studies distributed?
- How is the distribution of studies according to the sub-branches of mathematics?
- How are the variables examined in the studies distributed?
- How are the applications and development kits used in the studies distributed?

2. What are the basic findings obtained from the scientific studies conducted regarding AR technology in mathematics education?

- What are the advantages and disadvantages of using the AR technology in mathematics education?
- Is the use of AR technology in mathematics education effective in students' learning processes?

Method

This study aims to review scientific studies on using AR technology in mathematics education, the systematic review method used. The systematic review method is a comprehensive screening method through evaluating and synthesising studies on a subject (Uman, 2011). A systematic review is a valuable method for creating research results and presenting findings, adding value to discussions in educational research (Bennett, Lubben, Hogarth, & Campbell, 2005). Systematic reviews enhance a study process and outcome using transparent and repeatable procedures (Tranfield, Denyer, & Smart, 2003). The systematic review method usually comprises of three sections: data collection, analysis, synthesis, and each step must be taken cautiously (Crossan & Apaydin, 2010).

Data Collection

In this systematic review, the studies using the AR technology in mathematics education in the Web of Science database screened to determine the studies to be evaluated. The review process completed on 9 July 2020. Keywords used in the review process were as follows: “Augmented reality AND math”, “Augmented reality AND maths”, “Augmented reality AND mathematical”, “Augmented reality AND mathematics”, “Augmented reality AND algebra”, “Augmented reality AND geometry”, “Augmented reality AND trigonometry”, “Augmented reality AND statistics”, “Augmented reality AND calculus”, “Augmented reality AND math learning”, “Augmented reality AND math education” and “Augmented reality AND math teaching”.

Data Analysis

The studies reviewed within the scope of this study were analyzed by one of the researchers. The other researcher also examined the analyses to increase the reliability of the study. For this purpose, a form created in Microsoft Office Word for each study and the content analysis method used for data analysis. This form had sections that answer the research questions. These sections were number, name, database, type, publication year, publication type (journal article/conference proceedings), method, data collection tools, sample, country of the study, platforms where the application developed, type of augmented reality used, field/subject studied, advantages and disadvantages of augmented reality in mathematics education, effectiveness level of augmented reality in mathematics education, and variables examined in the study. The studies included in the present systematic review read carefully, and the form prepared was completed separately for each study. Then, the data in the forms were turned into codes, categories, and graphics using the Microsoft Office Excel program. The data acquired from the studies reviewed presented descriptively.

As a result of the Web of Science database review with the search mentioned above terms, 1077 studies reached totally, as shown in Figure 1. As a result of excluding the repeated copies, a total of 785 studies left. Upon reviewing the 785 studies according to their title and abstract sections, it was determined that 92 studies were not related to AR, 15 studies were not written in English, and 575 studies were not related to mathematics education. These papers excluded. Full texts of the remaining 103 studies reviewed in terms of convenience found that ten studies were not related to mathematics education. Seven studies presented the augmented reality technology; however, they were excluded because they did not focus on AR in the study. As a result of all these reviews, a total of 86 papers have been included in this systematic review.

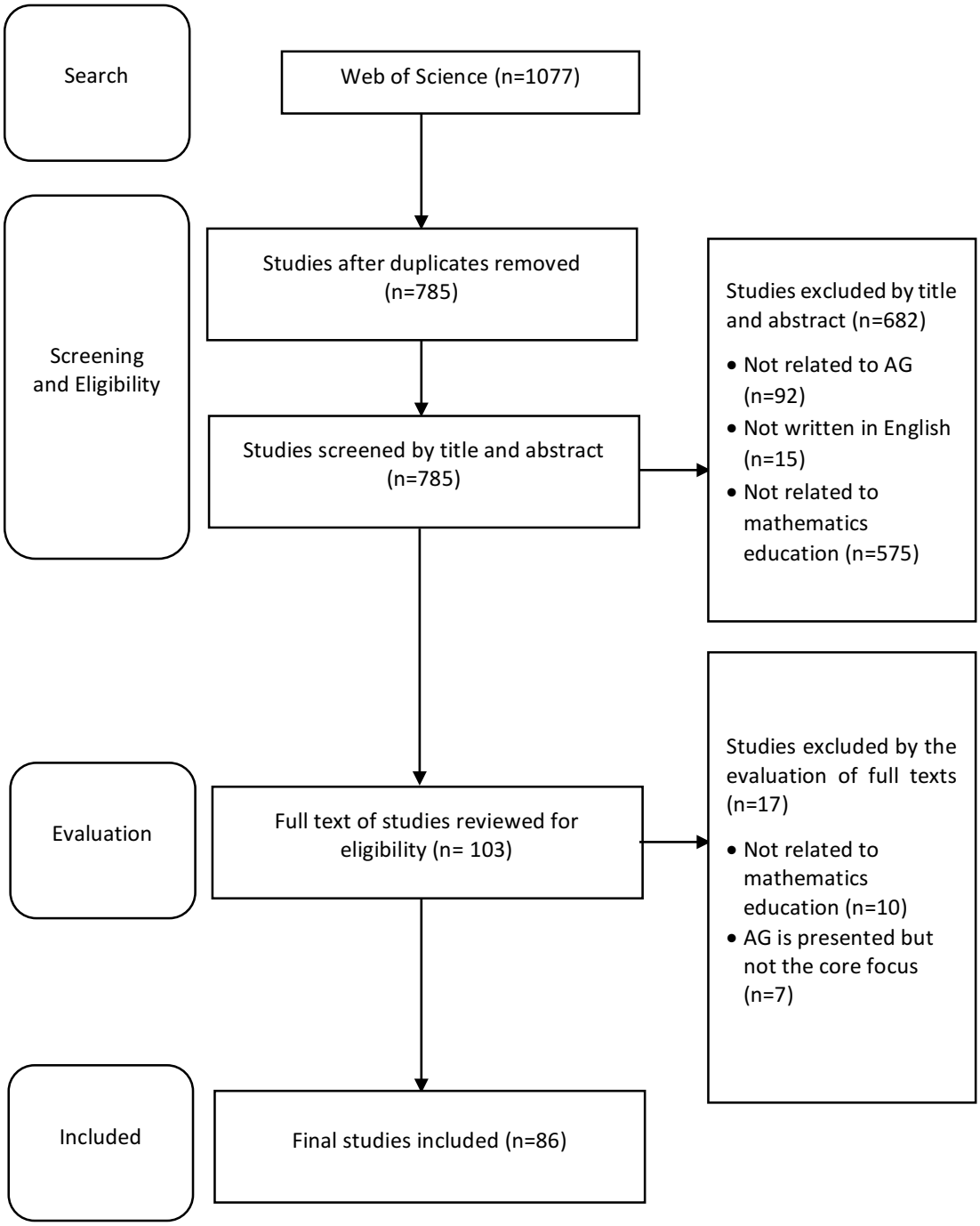


Figure 1. *Systematic review process (Liberati et al., 2009)*

Results

The studies on AR use in mathematics education, which comprise the study's data, were analyzed, and the findings obtained were presented as follows. The findings presented under two titles as trends in the studies and basic findings.

Trends in Augmented Reality and Mathematics Education Literature

Distribution of the Studies According to Their Types

Figure 2 shows the distribution of the studies on the use of AR in mathematics education based on their types. As seen in Figure 2, the studies using the AR technology in mathematics education were published mostly as conference paper (n=51), and the remaining 35 studies consisted of journal articles.

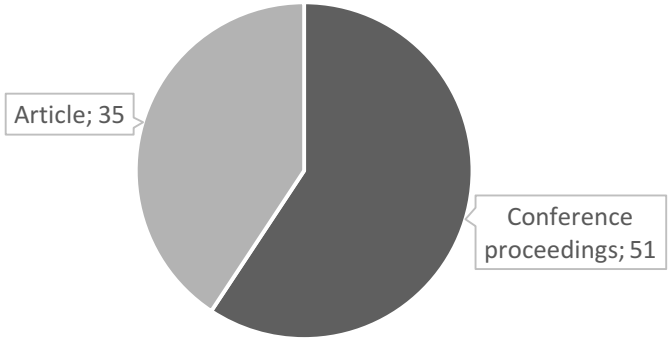
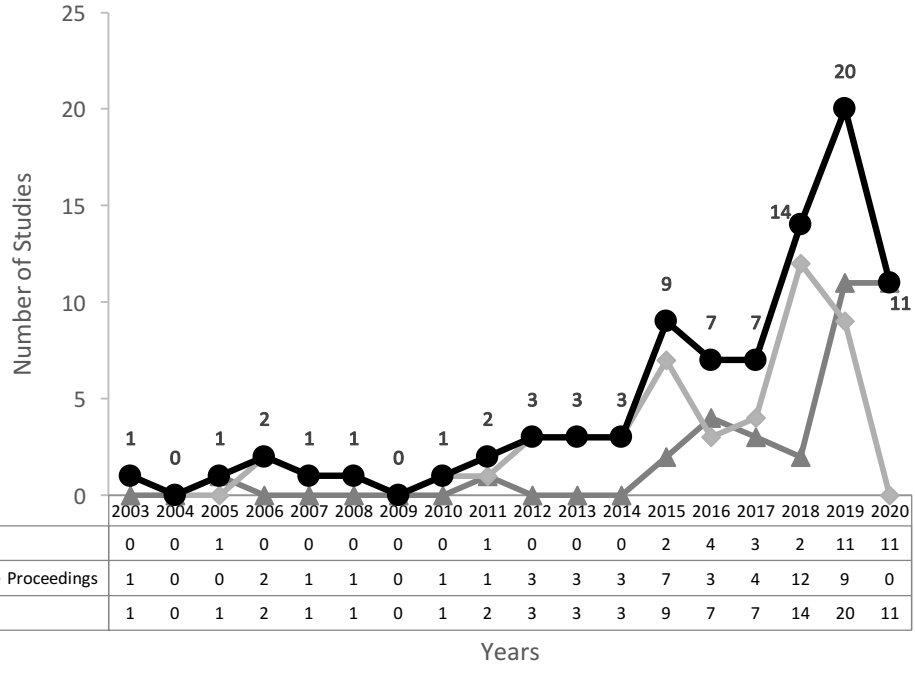


Figure 2. *Distribution of the studies based on their types*

Distribution of the Studies Based on the Years

Figure 3 shows the distribution of studies by years as articles, conference proceedings and the total number of studies. As shown in Figure 3, the first study on the subject was published in 2003 as a conference proceeding. There has been an increase in the number of related studies since 2010. When considering the studies conducted until 2020, it was observed that the studies conducted mostly in 2019 (n=20).



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Article	0	0	1	0	0	0	0	0	1	0	0	0	2	4	3	2	11	11
Conference Proceedings	1	0	0	2	1	1	0	1	1	3	3	3	7	3	4	12	9	0
Total	1	0	1	2	1	1	0	1	2	3	3	3	9	7	7	14	20	11

Figure 3. *Distribution of the studies based on the years*

Distribution of the Methods Used in the Studies

Figure 4 shows the distribution of the methods used in the reviewed studies. As shown in Figure 4, the studies used primarily qualitative (n=47) and mixed (n=29) methods and then quantitative (n=9) and literature review (n=1) methods.

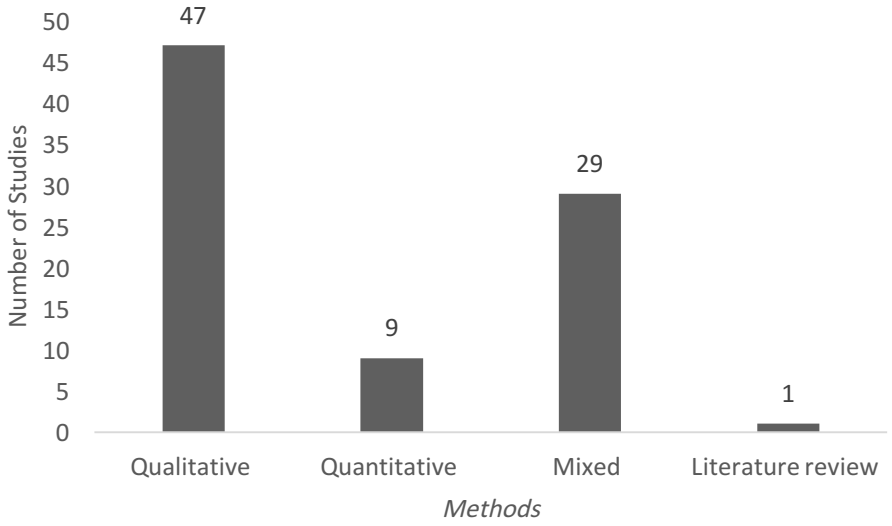


Figure 4. *Distribution of methods used in the studies*

Distribution of the Studies According to the Sample Group

Figure 5 shows the distribution of the studies on the use of AR in mathematics education based on the sample group. As shown in Figure 5, related studies were conducted mostly with secondary school students (n=18) and primary school students (n=18). However, in 18 studies, the sample group was not specified. It was observed that following the secondary and primary school levels, the most studied sample group was university students (n=16).

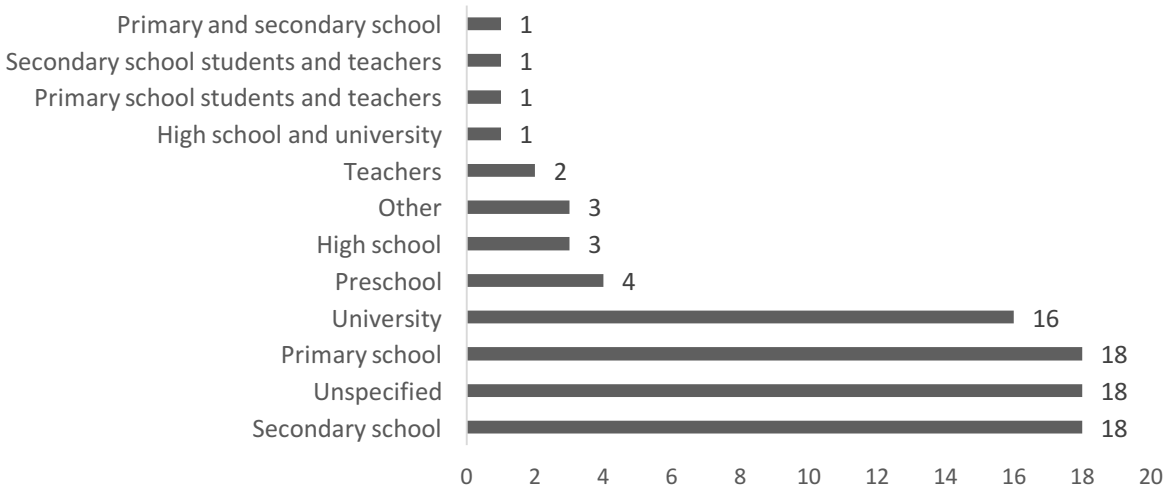


Figure 5. *Distribution of the studies based on the sample group*

Distribution of the Countries Where the Studies Conducted

Figure 6 shows the distribution of the studies on the use of AR in mathematics education based on the countries where they were conducted. As seen in Figure 6, related studies were conducted mainly in Mexico (n=11) and then Taiwan (n=9) and Spain (n=7).

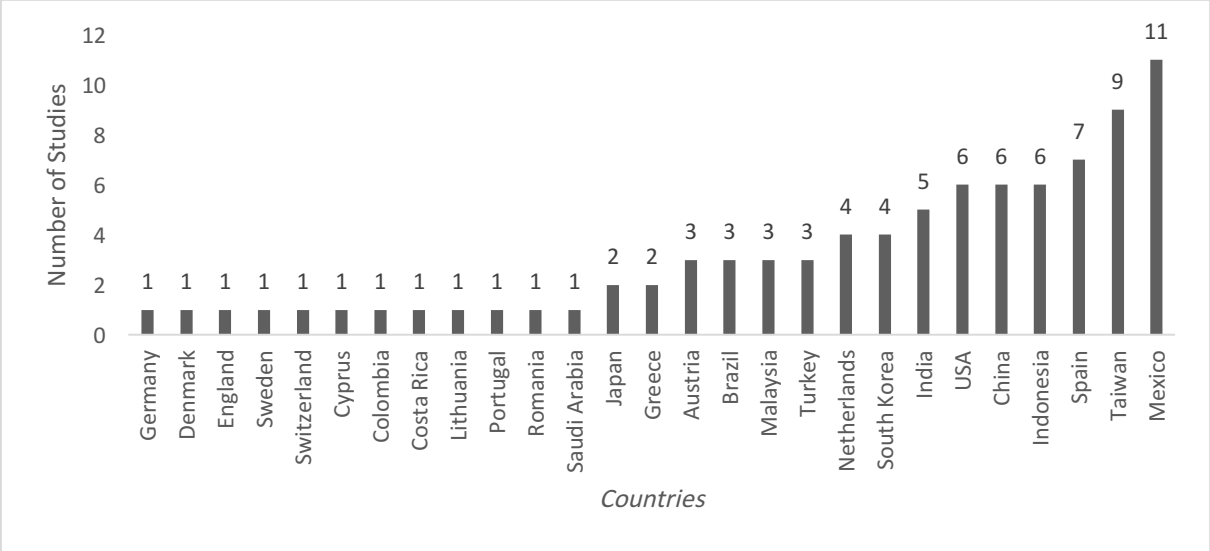


Figure 6. *Distribution of the countries where the studies conducted*

Distribution of the AR Technology Types Used in the Studies

Figure 7 shows the distribution of the AR technology types used in applications developed in the studies on AR in mathematics education. As seen in Figure 7, it can be asserted that the most frequently used AR-type was picture/image-based (n=71).

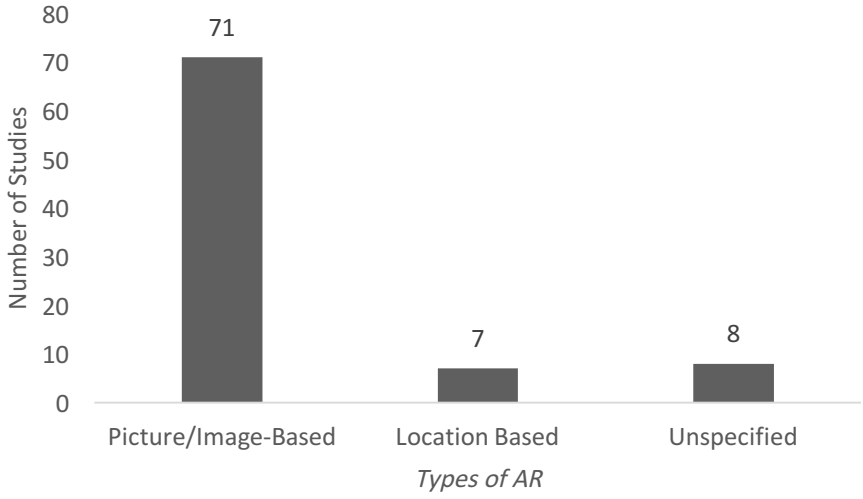


Figure 7. *The AR technology types used in the studies*

Distribution of the Sub-Branches of Mathematics Focused in the Studies

Figure 8 shows the fields and subjects focused in the studies on the use of AR in mathematics education. As seen in Figure 8, the studies were conducted mostly in mathematics (n=52) and geometry (n=31).

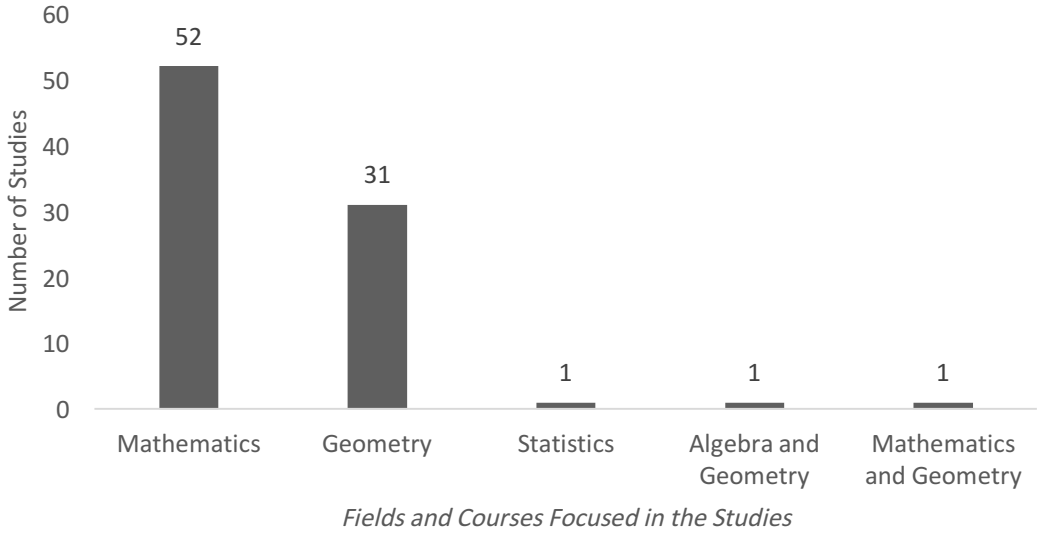


Figure 8. *Fields and courses focused in the studies*

The Variables Examined in the Studies

Figure 9 shows the variables examined in the studies on the use of AR in mathematics education. As seen in Figure 9, the studies investigated primarily cognitive and affective variables (n=29).

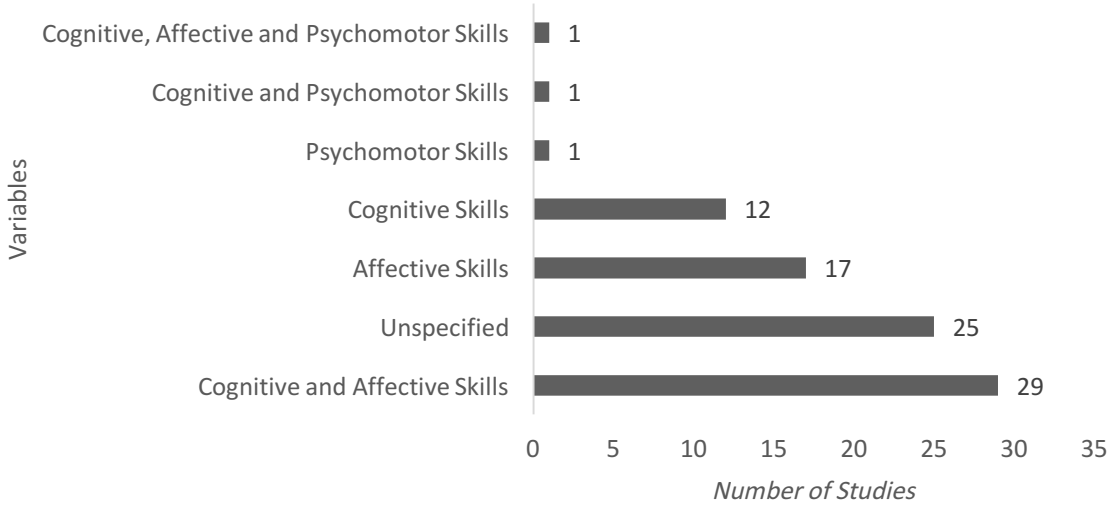


Figure 9. *The variables examined in the studies*

The Applications and Development Kits Used in the Studies

Figure 10 shows the applications used in the development period of AR materials in the reviewed studies. As shown in Figure 10, the most frequently used application was Unity3D (n=23).

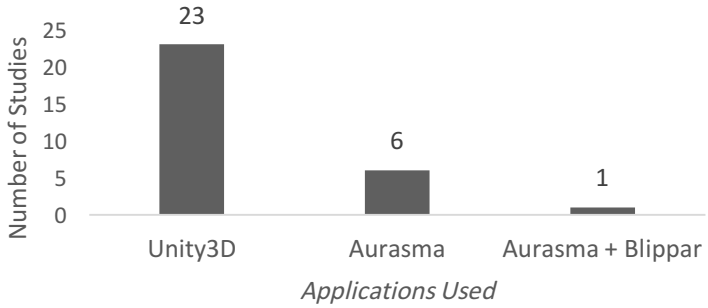


Figure 10. *The applications used in the studies*

Figure 11 shows the development kits used besides software or externally. As seen in Figure 11, the studies on the use of AR in mathematics education used mostly the Vuforia (n=21) development kit.

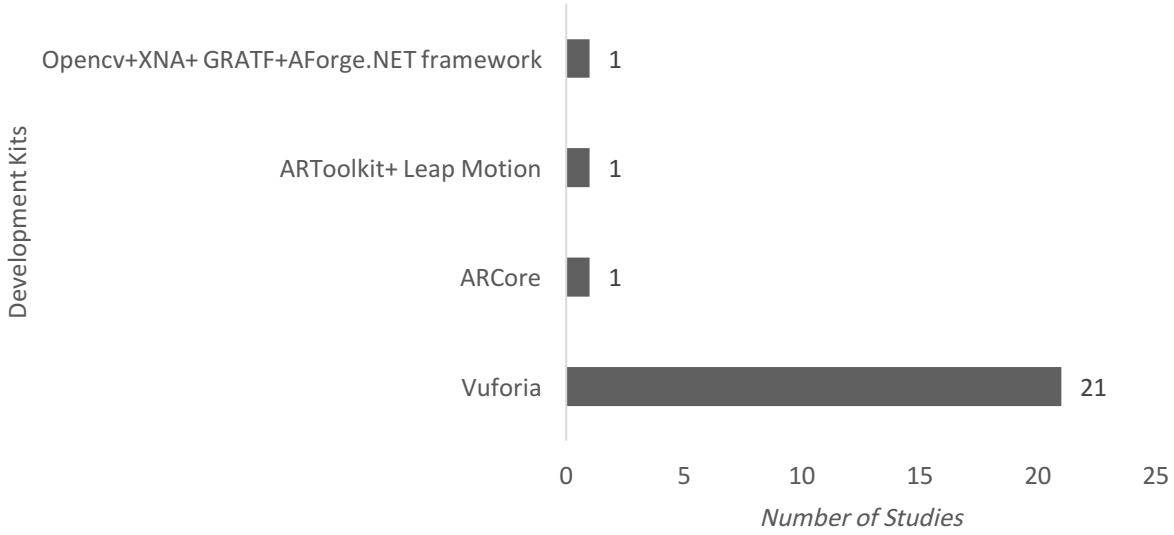


Figure 11. *The development kits used in the studies*

The Main Findings of Augmented Reality and Mathematics Education Literature

The Advantages of AR Mentioned as a Result of the Study

Table 1 shows the advantages of using the AR technology in mathematics education in the studies reviewed within the scope of this systematic review. As shown in Table 1, the studies reviewed mostly mentioned the supportive impact of the augmented reality technology on learning in mathematics education as an advantage (n= 34). The other most specified advantages were that AR motivated students in mathematics lessons (n= 27), developed their spatial ability (n= 16) and enabled them to create positive attitudes (n=11).

Table 1. *Advantages of the use of augmented reality in mathematics education*

Advantages	*f*	*Sample study*
Supports learning	34	İbili, Çat, Resnyansky, Şahin and Billinghurst (2019)
Motivates students	27	Demitriadou, Stavroulia and Lanitis (2019)
Improves students' spatial abilities	16	de Ravé, Jiménez-Hornero, Ariza-Villaverde and Taguas-Ruiz (2016)
Provides a positive learning attitude	11	Lin et al. (2013)
Supports intuitive and interesting learning processes	7	Lin et al. (2016)
Makes learning environments more interactive and enjoyable	7	Correa et al. (2013)
Materials prepared with AR are easy to use	5	Quintero, Salinas, Gonzalez-Mendívil and Ramírez (2015)
Supports collaborative learning	5	Kaufmann, Steinbugl, Dunser and Gluck (2005)
Increases students' engagements	5	Sun and Chen (2019)
Impacts students' views positively	3	Kellems et al. (2020)
Provides the opportunity to explore and learn in-depth the geometric properties of different shapes	2	Le and Kim (2017)
Improves problem-solving skills	1	Demitriadou et al. (2019)
Decreases students' anxiety levels	1	Chen (2019)

The Disadvantages of AR Mentioned as a Result of the Study

Table 2 shows the disadvantages of using the augmented reality technology in mathematics education in the studies reviewed within the scope of this study. As seen in Table 2, the studies mainly mentioned technical problems using the AR applications as a disadvantage (n= 10). Also, the studies said necessities like the higher skill of computer use, money and time to develop the AR applications as disadvantages (n= 3). Other disadvantages were that users rejected and resisted using AR, a new technology (n= 2), and it caused health problems in the long-term use (n= 1).

Table 2. *Disadvantages of the use of augmented reality in mathematics education*

Disadvantages	*f*	*Sample study*
Technical problems in the use of AR applications	10	Coimbra, Cardoso, and Mateus (2015)
Production of materials requires a high level of technical skill, money and time	3	Chen (2019)
User resistance to the use of AR as a new technology	2	Barraza Castillo, Cruz Sánchez and Vergara Villegas (2015)
The emergence of health problems (headache, eye strain) in long-term use	1	Kaufmann, Steinbugl, Dunser and Gluck (2005)

Effectiveness of Augmented Reality in Mathematics Education

Table 3 shows the effectiveness levels specified in the experimental studies on AR in mathematics education. It was seen that in 15 out of 16 studies comparing the traditional method and AR, the AR method was more effective in all variables compared to the traditional method. In one study, however, it was observed that some of the variables were not different in the traditional method and the AR method or the AR method was more effective.

Table 3. *Findings of the studies about the effectiveness of augmented reality in mathematics education*

Findings	*f*	*Studies*
AR is more effective	*15*	*Nakano et al. (2017), Cai (2018), Demitriadou et al. (2019), de Ravé et al. (2016), Cheng et al. (2018), Conley, Atkinson, Nguyen and Nelson (2020), Flores-Bascuñana et al. (2020), Alves et al. (2017), Cai et al. (2020), Sarkar, Pillai and Gupta (2018), Arvanitaki and Zaranis (2020), Liao et al. (2015), Sun and Chen (2019), Sun and Chen (2020), Manisha and Mantri (2019)*
AR is more effective and/or makes no difference	*1*	*Cai, Liu, Yang and Liang (2019)*

Discussion

In this study, 86 studies consisting of conference proceedings and journal articles obtained from the Web of Science database were analyzed in terms of research trends and main findings. Results yielded that a great majority of the studies were published as conference paper. It was concluded that the first AR-relevant study has been carried out in 2003, and the number of studies increased after 2010, in the least. This finding can be explained depending on technological developments and the proliferation of mobile devices and the internet (İçten & Bal, 2017). In the studies reviewed, it was observed that the most frequently used method was the qualitative method. Even though studies are using experimental and quantitative methods to determine the effects of AR in mathematics education, it can be asserted that the studies are still inadequate in number. Accordingly, it can be stated that increasing the number of experimental studies will enable using AR more effectively in mathematics education. In the studies, it was determined that the most frequently preferred sample group was secondary school students. Accordingly, it is possible to assert the necessity of increasing the number of studies conducted, especially with university students who commonly use smartphones and the internet. Conducting studies, especially on engineering faculty students who study mathematics may enable them to understand abstract concepts and develop their spatial thinking ability. When the countries where the studies have been conducted were examined, it was seen that the scientific studies on the use of AR in mathematics education were conducted in 27 countries which is quite limited in scope. It was observed that the country with the highest number of studies was Mexico. Accordingly, it can be asserted that related studies were actually conducted worldwide; however, it is safe to say that they were not enough in number in order to generalize the findings and understand the effects entirely.

It was observed that the studies used mainly the image-based AR type. According to detection techniques, there are two types of AR as image-based and location-based (Cheng & Tsai, 2013). Cheng and Tsai (2013) stated that the image-based AR type is more appropriate for learning spatial ability, conceptual learning and practice skills. The location-based AR is more suitable for inquiry-based scientific activities. Accordingly, the fact that the studies using AR technology in mathematics education used mostly the image-based AR type is not surprising. It was seen that the studies focus mainly on the fields of mathematics and geometry. In addition, the studies primarily examined cognitive and affective skills together. Within this scope, it can be asserted that conducting new studies investigating different skills in different mathematics subjects would be important. Different sample levels will make essential contributions to the field to reach more accurate results regarding AR technology in mathematics education (Aldalalah et al., 2019; Flores-Bascuñana et al., 2020). Furthermore, considering the importance of affective skills in the mathematics learning process, increasing the number of studies aimed at affective skills is essential. The most frequently used application in developing AR applications in mathematics education was Unity3D, and the

development kit was Vuforia. This result confirms the increase in the number of studies on the use of AR in mathematics education. Qualcomm Connected Experiences purchased Vuforia in 2015 and constantly invested and supported the developers in this direction (PTC, 2015). AR technology is beginning to mature (Garzón, Pavón, & Baldiris, 2019). Considering the use of AR technology, especially in mathematics, it is predicted that its potential can expand and more accepted in education (Phon, Ali, & Halim 2014). In the present paper reviewing the studies on the use of AR technology in mathematics education, it was observed that the AR method was more effective than the traditional method. In addition, it can be said that the problems experienced in the traditional method can be reduced with AR (Tosik Gün, & Atasoy, 2017). It can be asserted that AR technology increased visual thinking skills in the mathematics field, made the learning environment interactive and fun and supported to increase students' participation in the learning process (Aldalalah et al., 2019; Sarkar et al. 2018; Sun & Chen, 2019). In short, it can be concluded that AR is a technology that will facilitate access to information and provide effective use (Coimbra et al., 2015).

In the studies on AR applications, it is possible to summarize the advantages of AR as learning/academic achievement, motivation, and attitude in general (Arici, Yildirim, Caliklar, & Yilmaz, 2019; Cahyono et al., 2020). However, the use of AR in mathematics has some disadvantages such as costly application, the resistance of students against using and health problems such as headache and eye strain, especially in AR devices put on the head (Barraza Castillo et al., 2015; Chen, 2019; Kaufmann et al., 2005). Overall, however, AR has a promising trend in mathematics education (Ahmad & Junaini, 2020).

Conclusion, Implications and Limitations

This review showed that the studies published as conference papers were larger in number than articles. AR technology has gained interest in mathematics education in recent years; it can be said that it is more effective than the traditional method on variables such as motivation, academic achievement and attitude. Consequently, the paper reviewing the studies on the use of AR in mathematics is crucial since it is a pioneer in the field and may guide further researchers. This research is limited to the search terms used and the Web of Science database. In addition, the studies included in the research cover mathematics education. Based on the findings of the study, the following recommendations can be made.

Recommendations for further research

• The reviewed studies used qualitative methods commonly, and the sample group was mainly at the secondary school level. It is necessary to conduct extensive studies on AR technology, especially with special education students and those suffering from learning disability, in different sample types based on quantitative and mixed methods, considering other gains in mathematics education.

• In the study, it was determined through content analysis that many studies suggest that the AR technology was more effective than the traditional methods. Meta-analysis studies need to be conducted in the future to quantitatively determine the effects of using AR technology in mathematics education.

• Further studies may examine the materials supported by AR in mathematics education in terms of instructional design.

Recommendations for practitioners

• Considering the better learning of mathematics and its effect on visual thinking skills, AR can integrate into all educational software related to mathematics education. Moreover, interactive AR applications can develop for subjects containing more misconceptions in the mathematics field.

• Mathematics problem-solving books supported by AR can be designed for students to make operations on paper and examine problems in the virtual environment audibly and visually outside the class.

• Since the design of materials supported by AR requires a higher technical skill and disadvantages in terms of time and money opportunities, free Web 2.0 tools can be provided to mathematics teachers to create AR materials easily.

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TÜRKÇE GENİŞ ÖZET

Matematik Eğitiminde Artırılmış Gerçeklik Teknolojisinin Kullanımı Öğrenme Süreçlerini Nasıl Etkiler?: Sistematik Bir İnceleme

Giriş

Matematik dersi, öğrencilerin günlük hayatlarında yaşadıkları problemleri çözmeleri konusunda sağladığı kazanımlar ve öğrenim hayatları boyunca akademik başarılarına olan etkileri açısından oldukça önemlidir (Durksen, Way, Bobis, Anderson, Skilling & Martin, 2017; Lein, Jitendra, Starosta, Dupuis, Hughes-Reid & Star, 2016). Alanyazında yer alan araştırmalar matematik becerilerinin okul yıllarında kazanıldığını göstermektedir (Koponen, Aunola & Nurmi, 2019). Yaşar ve Papatğa (2015) öğrencilerin eğitim hayatı boyunca akademik başarılarını belirlemede önemli bir yeri olan matematik dersinin; en çok başarısız olunan, kaygı duyulan, zorlanılan ve en çok olumsuz tutum geliştirilen derslerin başında yer aldığını belirtmiştir. Ayrıca, matematiğin kendinden kaynaklı zor olması epistemolojik bir sebeptir ve matematiğin hemen her konusunda öğrencilerin kavram yanılgısına sahip olmaları da olasıdır (Gürel & Okur, 2016).

Artırılmış Gerçeklik (AG) teknolojisi, görünmeyen ve görselleştirilmesi zor durumların 3D simülasyonlarını sağlayarak öğrencilerin zor bulduğu konuların anlaşılmasına yardımcı olur (Cai vd., 2020). Matematik eğitiminde AG teknolojisinin kullanımına yönelik yapılan araştırmalar, öğrencilerin AG destekli öğrenme içeriklerine karşı olumlu bir tutum sergilediklerini, AG'nin ilgi çekici öğrenme deneyimi sağladığını, öğretmen ve öğrenci iş birliği sağladığını, gerek geometri gerekse matematik öğrenmelerini olumlu yönde etkilediğini ortaya koymaktadır (Billinghurst & Duenser, 2012; Lin, Chen & Chang, 2013; Kaufmann & Schmalstieg, 2003).

Sonuç olarak AG, soyut kavramları görselleştirme özellikleriyle öğrenme ortamları açısından oldukça dikkat çekici bir teknolojidir. Bu nedenle alanyazında yer alan çalışmaların sonuçlarının incelendiği bu çalışma hem gelecekte yapılması düşünülen araştırmalara hem de uygulayıcılara yol gösterici bulgular sunmasından dolayı önemlidir. Bu doğrultuda, bu çalışmanın amacı AG teknolojisinin matematik eğitiminde kullanımına ilişkin gerçekleştirilen bilimsel çalışmaların incelenmesidir. Bu doğrultuda aşağıdaki araştırma sorularına yanıt aranmıştır:

1. Matematik eğitiminde AG kullanımına ilişkin gerçekleştirilen bilimsel çalışmaların metodolojik ve uygulamaya yönelik eğilimleri nelerdir?

- Çalışmaların yayınlanma türlerine göre dağılımı nasıldır?
- Çalışmaların yıllara göre dağılımı nasıldır?
- Çalışmalarda kullanılan araştırma yöntemlerinin dağılımı nasıldır?
- Çalışmaların örneklem gruplarına göre dağılımı nasıldır?
- Çalışmaların gerçekleştirildiği ülkelere göre dağılımı nasıldır?

- Çalışmalarda kullanılan AG teknoloji türlerine göre dağılımı nasıldır?
- Çalışmalarda odaklanılan matematik alt branşlarının dağılımı nasıldır?
- Çalışmalarda incelenen değişkenlerin dağılımı nasıldır?
- Çalışmalarda kullanılan uygulamaların ve geliştirme kitlerinin dağılımı nasıldır?

2. Matematik eğitiminde AG kullanımına ilişkin gerçekleştirilen bilimsel çalışmalarda elde edilen temel bulgular nelerdir?

- AG teknolojisinin matematik eğitiminde kullanımının avantajları ve dezavantajları nelerdir?
- AG teknolojisinin matematik eğitiminde kullanımı öğrencilerin öğrenme süreçleri açısından etkili midir?

Yöntem

Matematik eğitiminde AG teknolojisinin kullanımı ile ilgili bilimsel araştırmaların incelenmesini amaçlayan bu çalışmada sistematik inceleme yöntemi kullanılmıştır. Bu sistematik inceleme çalışmasında değerlendirilecek çalışmaları belirlemek amacıyla Web of Science veri tabanında matematik eğitiminde AG teknolojisinin kullanıldığı çalışmalar taranmıştır. Tarama işlemi 9 Temmuz 2020 tarihinde bitirilmiştir. Tarama sürecinde anahtar kelime olarak kullanılan terimler şu şekildedir: "Augmented reality AND math", "Augmented reality AND maths", "Augmented reality AND mathematical", "Augmented reality AND mathematics", "Augmented reality AND algebra", "Augmented reality AND geometry", "Augmented reality AND trigonometry", "Augmented reality AND statistics", "Augmented reality AND calculus", "Augmented reality AND math learning", "Augmented reality AND math education" ve "Augmented reality AND math teaching".

Bu arama terimleri aracılığıyla Web of Science veri tabanında yapılan tarama sonucunda toplam 1077 çalışmaya ulaşılmıştır. Mükerrer kopyaların çıkarılması sonucunda ise toplam 779 makale elde edilmiştir. Daha sonra 785 makalenin başlık ve özet bölümlerine göre incelenmesi sonucunda 92 çalışmanın AG ile ilgili olmadığı, 15 çalışmanın İngilizce yazılmadığı, 575 çalışmanın ise matematik eğitimi ile ilgili olmadığı tespit edilmiş ve tespit edilen bu çalışmalar elenmiştir. Kalan 103 çalışmanın tam metinleri uygunluk açısından incelenmiş ve yapılan inceleme sonucunda 10 çalışmanın matematik eğitimi ile ilgili olmadığı ve 7 çalışmanın ise AG teknolojisini sunduğu fakat çalışmanın odak noktasını temsil etmemesinden dolayı çıkarılmıştır. Tüm bu incelemeler sonucunda bu sistematik incelemeye nihai olarak 86 çalışma dahil edilmiştir.

Veri analiz yöntemlerinden içerik analizinin kullanıldığı bu çalışmada öncelikle analiz edilecek her bir çalışma için Microsoft Word programında bir form oluşturulmuştur. Bu doğrultuda, sistematik incelemeye dahil edilen çalışmalar dikkatli bir şekilde okunarak hazırlanan form Microsoft Word programında her bir çalışma için ayrı ayrı doldurulmuştur. Ardından formlarda yer alan veriler Microsoft Excel programı kullanılarak kodlar, kategoriler ve grafikler haline getirilmiştir.

Bulgular

Matematik eğitiminde AG kullanımı konusunda yapılan araştırmaların incelendiği bu çalışmada, Web of Science veri tabanından 86 çalışmaya ulaşılmış ve bu çalışmalar analiz edilmiştir. Yapılan incelemeler sonucunda bu çalışmaların büyük bir bölümünün konferans bildirisi şekilde yayınlandığı görülmüştür. Konu ile ilgili ilk çalışmanın 2003 yılında yapıldığı, 2010 yılından sonra az da olsa çalışma sayılarının arttığı sonucuna ulaşılmıştır. İncelenen çalışmalarda en çok kullanılan yöntemin nitel araştırma yöntemi olduğu görülmüştür. Her ne kadar AG'nin matematik eğitimindeki etkilerini belirlemek amacıyla deneysel yöntemleri kullanan çalışmalar olsa da, bu sayının halen yetersiz olduğu söylenebilir. Bu doğrultuda, deneysel çalışma sayısının artması AG kullanımının daha verimli bir şekilde

matematik eğitiminde kullanılmasını sağlayacağı söylenebilir. Çalışmalarda en çok tercih edilen örneklem grubunun ortaokul öğrencileri olduğu belirlenmiştir. Çalışmaların yapıldığı ülkeler incelendiğinde 27 farklı ülkede matematik eğitiminde AG kullanımına ilişkin bilimsel araştırma yapıldığı görülmüştür. En çok çalışma yapan ülkenin ise Meksika olduğu belirlenmiştir.

Bu araştırmada incelenen çalışmalarda en çok görüntü tabanlı AG türünün kullanıldığı görülmüştür. Çalışmalarda üzerine en çok odaklanılan alanların ise matematik ve geometri olduğu görülmüştür. Ayrıca çalışmalarda en çok bilişsel ve duyuşsal becerilerin birlikte incelendiği görülmüştür.

Matematik eğitiminde AG uygulamalarının geliştirilmesinde en çok kullanılan uygulamanın Unity3D, geliştirme kitinin ise Vuforia olduğu görülmüştür. Matematik eğitiminde AG teknolojisinin kullanıldığı araştırmaların incelendiği bu çalışmada, AG yönteminin geleneksel yönteme göre daha etkili olduğu görülmüştür. AG'nin matematik eğitiminde kullanımının sağladığı avantajlar genel olarak öğrenme/akademik başarı, motivasyon ve tutum olarak özetlenebilir. Bunun yanında matematik dersinde AG kullanımının bazı dezavantajları da bulunmaktadır. Özellikle AG teknolojisinin geliştirme ve bakım faaliyetlerinin; zaman, para ve beceri bakımından maliyetli olması, kullanımda yaşanan aksaklıklar, kullanıcıların kullanmamak için direnç göstermesi ve özellikle kafaya takılan AG cihazlarında baş ağrısı ve göz yorgunluğu gibi sağlık problemlerinin oluşması dezavantajlar olarak sayılabilir.

Tartışma, Sonuç ve Öneriler

Araştırma sonucunda konferans bildirisi olarak yayınlanan çalışmaların makalelere göre daha fazla tercih edildiği görülmüştür. AG teknolojisine son yıllarda matematik eğitiminde ilginin arttığı; AG'nin motivasyon, akademik başarı ve tutum gibi değişkenler üzerinde geleneksel yönteme göre daha etkili olduğu söylenebilir. Sonuç olarak matematikte AG kullanımına ilişkin araştırmaların incelendiği bu çalışma alanında bir ilk olması ve gelecekteki araştırmacılara rehber olabilmesi açısından önemlidir. Gelecekte yapılacak olan çalışmalarda matematik eğitiminde AG ile ilgili materyaller öğretim tasarımı açısından incelenebilir. Ayrıca matematikte öğrenme güçlüğü çeken öğrencilere yönelik AG destekli materyallerin etkisini inceleyen çalışmalar yapılabilir.