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Content Analysis of Augmented Reality in STEM Education

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Abstract: *This study aims to comprehensively examine academic studies conducted on the use of augmented reality (AR) technology in STEM education in the last five years (2020-2024). A total of 23 studies were analysed in different dimensions such as publication type, year, location, number of authors, discipline and country. The main purpose of the research is to compile current literature on the use of AR in STEM education, determine trends in this field and guide future studies. In this way, educators, researchers and policy makers will have a more in-depth understanding of the use of AR technology in education and will be able to contribute to developments in this field. Augmented reality is a technology that revolutionises education by enriching learning experiences. Especially in fields where abstract concepts are intense such as STEM, AR enables students to better understand and apply these concepts. It also plays an important role in the development of 21st century skills such as problem solving, critical thinking and creativity. In this study, the data obtained from the Google Scholar database was examined using the content analysis method. The analysis results show that the use of AR in STEM education has attracted increasing interest, especially increasing students' motivation and positively affecting their academic success. In addition, applications and comparative analyses of AR in different STEM disciplines are also presented.*

Keywords: *augmented reality; STEM education; literature review; educational technologies.*

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1. Introduction

With the rapid advancement of technology today, the education system must adapt to this change along with the new generation. Especially STEM education (Science, Technology, Engineering, and Mathematics) has an important role in providing the skills of the 21st century. In this process, Augmented Reality (AR) technology, which provides an effective dimension in education, has great potential to increase the quality and efficiency of STEM education. Nowadays, AR, which plays a major role in the concretisation stage of abstract concepts in education as a system based on the integration of non-physical objects into the environment through technology, emerges (Sırakaya, & Seferoğlu, 2016). According to Arslan, Kofoğlu & Dargut, (2020), the use of AR in education continues to grow in the field of AR with the recognition of its potential to increase the quality in the field of learning.

AR not only provides a more interactive learning experience but also creates new opportunities in the presentation of information and complex concepts. New methods are being sought every day to improve the difficulties experienced by students and teachers. Especially to increase students' attention, it is drawn to AR in education. Studies show that AR provides many benefits in education. Since AR adds digital content to the real image, it not only adds a difference to students' learning experiences but also provides an effective learning experience. AR makes abstract concepts concrete and facilitates learning (Bressler, & Bodzin, 2013; Bujak et al., 2013; Huang, Chen, & Chou, 2016; Sirakaya & Sirakaya, 2022). In addition, it has been shown that it increases students' motivation for the lesson (Chen, & Wang, 2018; Ibáñez et al., 2015) and they are more attentive to their lessons (Bressler, & Bodzin, 2013; Bujak et al., 2013; Huang, Chen, & Chou, 2016). In addition, research shows that lessons are much more fun and enjoyable with AR compared to normal lessons (Gun, & Atasoy, 2017), and students' participation in the lesson is increased and they are full of fun. To exemplify this, the study by Wojciechowski and Cellary (2013) emphasised the importance of using AR in physics education. In particular, the importance of abstract concepts such as electromagnetics in teaching was emphasised. In the study, an AR system called ARIES (Augmented Reality for Interesting Engineering Simulations) was used. The system in question allowed students to visualise electromagnetic fields and their effects on audio speakers. Students first started the training by examining a real speaker, and then they had the opportunity to observe the electromagnetic fields inside the speaker and the formation of sound waves in three dimensions with AR applications. In the AR environment, it enabled students to see magnetic fields, which they normally cannot see, in the form of coloured lines and vectors. With AR technology, processes that are complex and difficult for students to understand, such as how electric current creates a magnetic field and how this field produces sound waves, become concrete and easily understandable for students. (Giasiranis & Sofos, 2017; Wojciechowski, & Cellary, 2013).

When we look at the literature, the reasons why AR is preferred especially in the field of education are as follows

- Cheap and easy access to materials related to course content,
- Easy provision of educational guidance appropriate to subject needs,
- Guidance to students in applications carried out during the education process,
- Creation of original, creative, and supportive environments that support targeted learning,
- Contributes to the development of communication and dialogue between students and between students and teachers,
- It is seen that it contributes to individuals who are inquisitive and questioning.

An illustrative case is the study by Singhal et al. (2012), which serves as a key example with a substantial impact on the application of AR in chemistry education. In the study, the Augmented chemistry system offered students the opportunity to examine and control molecules interactively. Students were able to control virtual molecule models by touching, grasping, dragging, rotating, and dropping with hand movements. One of the main features of Augmented Chemistry is that it allows multi-user interaction. With this, it supports collaborative learning environments in

education, allowing students to work together on the same virtual chemical structures. In this way, it concretises chemical concepts, ensures active participation of students in the course, and supports collaborative learning. (Kerawalla et al., 2006; Özarslan, 2011; Singhal et al., 2012; Wojciechowski, & Cellary, 2013; Sarıoğlu, 2021).

The greatest support for the lifelong learning scope targeted in the field of education is provided by AR. Especially in STEM education, where there are many abstract concepts, there are difficulties in learning and teaching. By integrating objects that do not exist in the current environment into the environment through technology, abstract concepts are made concrete and contribute greatly to the realisation of fun, effective, and permanent learning in STEM education. In addition, the use of AR in STEM education increases students' learning motivation, supports in-depth learning, and provides them with real-world problem-solving skills. (Sirakaya, & Sirakaya, 2022). This technology, which is used through easy-to-use and carry mobile devices such as smartphones and tablets, helps students perceive abstract concepts more concretely. In the study conducted by Sirakaya and Sirakaya (2022), it is observed that AR increases students' academic success in STEM education and increases students' learning motivation by making it easier for them to understand complex concepts. It is revealed that students have the opportunity to learn more deeply by experimenting in virtual environments, using simulations, and interacting with three-dimensional models, and in addition, it increases students' learning motivation. The study found that some difficulties prevent AR technology from becoming widespread in education, and these difficulties include costs, lack of technological infrastructure, teachers' technology use skills, and limited appropriate educational materials.

Nincarean (2024) systematically examined the use of mobile AR frameworks in STEM education and obtained some findings. The findings in question are that it increases students' learning success, enriches their learning experiences, and increases their learning motivation. However, it was emphasised that certain components should be taken into consideration for the design of effective mobile AR frameworks and these components are AR Systems, multimedia lessons, teaching methods, and learning outcomes. It was emphasised in the study that in the future, the quality of STEM education will increase even more with the further development of mobile AR technologies and their better integration into educational systems. In the study conducted by Hidayet and Wardat (2023), they drew attention to the importance of AR in STEM education. In the study in question, they revealed that the advantages of AR applications in STEM education are the increase in student success, the increase in the standard in the educational environment, and the support for students to take action towards learning. In addition, they argued that some difficulties such as cost, lack of technological infrastructure, teachers' technology use skills and limited appropriate educational materials should be overcome for this technology to become widespread in education. It is believed that in the future, the quality of STEM education will increase even more with the further development of AR technologies and their better integration into education systems. The study conducted by Syskowski, Wilfinger and Huwer (2024) examined experimental applications using AR technologies in science classes. This study investigated the effect of AR on science experiments and the classification of AR. The experimental studies discussed in the article are as follows, respectively: a. Experiments examining the effect of the use of AR in science laboratories on students' course performance; b. Studies measuring the effectiveness of virtual laboratories containing AR technologies compared to traditional laboratories; c. Studies comparing the use of marker-based and markerless AR applications in science experiments, d. Experiments evaluating the effect of AR technologies on student interest and motivation were examined. Wang and Li (2024) examined the effects of these technologies in the educational environment in detail. The study reveals that AR technology is of great importance in teacher education. Many studies were included in their study. It was observed that AR has many positive effects on teachers. These are: improving classroom management skills, its effect on teacher candidates' gaining practical experience, easy understanding of complex concepts, increasing teacher motivation, and providing teachers with practical experience in technology integration into education. Bosman et al. (2024) mainly examine the effects of AR and VR in higher education. The study reveals that AR and VR

technologies motivate experiential learning and affect student motivation. The study particularly states that among the effects of AR applications is the concretisation of abstract concepts. In addition, the findings obtained in the study also include the positive and negative effects of AR. Strengthening experiential learning, increasing student participation, concretising abstract concepts, contributing to interactive learning environments, facilitating learning in STEM fields, increasing student motivation in the course, and supporting visual and auditory learning are among the advantages of AR in the study. Another study that supports scientific research is the study conducted by Yıldırım and Kececi (2024) in the field of Mobile Augmented Reality (MAR). The study includes students discovering the lives and experiments of scientists using the MAR application. For example, students were able to observe Isaac Newton's apple falling experiment in a virtual environment with this application during or after the course. In addition, they were able to examine Marie Curie's radioactivity studies interactively. Based on this, it allows students to better understand scientific concepts and increase their interest in the history of science. This study also shows that the benefits of AR technology are effective not only in the STEM field but also in many areas.

1.1. Purpose of the Study

In this study, the aim is to examine academic studies conducted in the Google Sholar database to reveal the importance of AR in STEM education and to reveal the conveniences it provides to education. Based on this, the study aims to enrich the learning experiences of students by enabling them to better understand abstract concepts in STEM education and to increase their interest in STEM fields. In this way, to ensure that students are better prepared for the technological world of the future.

1.2. Aim of the Study

The following sub-objectives have been determined to help achieve the general purpose of the study:

1. What is the distribution map of studies on AR technologies in STEM Education by publication type?
2. What is the distribution of studies on AR technologies in STEM Education by journal names?
3. What is the distribution map of studies on AR technologies in STEM Education by publication year?
4. In which research topics are publications on AR technologies in STEM Education used?
5. What is the distribution of studies on AR technologies in STEM Education by countries of interest?

2. Method

In this study, content analysis, one of the qualitative research methods, was used to systematically examine the academic literature in the field of AR technology in STEM Education. Content analysis is a method that allows text-based data to be analysed objectively and systematically and classified under certain themes and categories (İçten & Bal, 2017). In this study, AR studies in STEM education in national and international literature are examined and suggestions for the current status and future research in this field are presented.

2.1. Scanning Criteria

In this study, certain screening and selection criteria were determined to achieve the desired result. After determining the points needed for the study, the terms were searched in the database (Scholar) with the title "AR in STEM Education" to find all publications published between 2020-2024. According to the search results, 22 journal publications were found in the field in question. As a result of scanning these articles, some criteria were determined and examined. The criteria in question were examined in terms of "Types of publications, years of publication, names

of journals published, number of authors, disciplines, distribution according to the countries where the study was conducted".

2.2. Samples

The study was searched as "AR in STEM Education" in the Google Scholar database between 2020-2024. To obtain results appropriate to the exact research content, the title was used in quotation marks while searching.

2.3. Data Collection and Analysis

The data of the study were evaluated using decisive statistical approaches such as percentage and frequency. In order to reach the answers to the study questions, the data rates were calculated according to separate frequencies for each question and supported by tables or graphs.

3. Findings and Comments

The content analysis method was used in the studies examined. The data obtained as a result of the research was analysed based on 5 research questions. In this section, the findings obtained as a result of the analysis are presented below, taking into account the percentage and frequency distributions.

3.1 Distribution of Articles by Publication Type

The study reveals that the majority of the publications in the study are journals containing academic studies with 96% and master's thesis with 4% (Table 1 and Figure 1).

Table 1. Distribution of studies on augmented reality technologies in STEM education by publication type
Source: Authors' own conception.

Document Types of Publications	Number of Articels	%
Journal Articles	22	96%
Master Thesis	1	4%
Total	**23**	**100%**

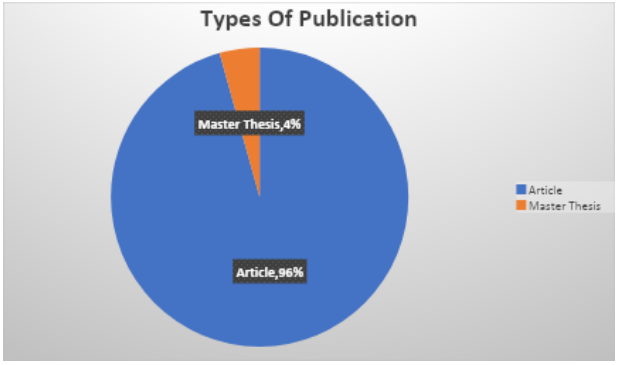

Figure 1. Types of publication.

3.2. Distribution of articles according to journal names in which they were published

Of the studies on AR technologies in STEM education, 22 of them are journal publications, 1 of which is a Master's thesis that is included in the Google Scholar database but not published in any journal, and when the distribution is examined according to the journal names published, MDPI journal has the most publications in this field with 23%, followed by Taylor&Francis journal with the most publications with 9.5%. 15 different journals (4.5%) have been published in the field of AR in STEM education.

Table 2. Distribution of studies on augmented reality technologies in STEM education according to the journal names in which they are published.
Source: Authors own conception

Journal Names	Number of Articels	%
Contemporary Educational Technology	1	4.5%
MDPI	5	23%
Estudios Economia Aplicada	1	4.5%
European Journal of Physics	1	4.5%
Frontiers	1	4.5%
IEEE Access	1	4.5%
The International Journal of Special Education (IJSE)	1	4.5%
International Journal of Curriculum and Instruction (IJCI)	1	4.5%
Taylor&Francis	2	9.5%
Routledge	1	4.5%
Iraqi Journal for Computer Science and Mathematics -esj	1	4.5%
Springer	1	4.5%
Wiley/Hindawi online libraray	1	4.5%
Journal of interactive learning Research	1	4.5%
The Eurasia Proceedings of Educational & Social Sciences (EPESS)	1	4.5%
Participatory Educational Research (PER)	1	4.5%
Revista Debates em Ensino de Quimica	1	4.5%
Total	**22**	**100%**

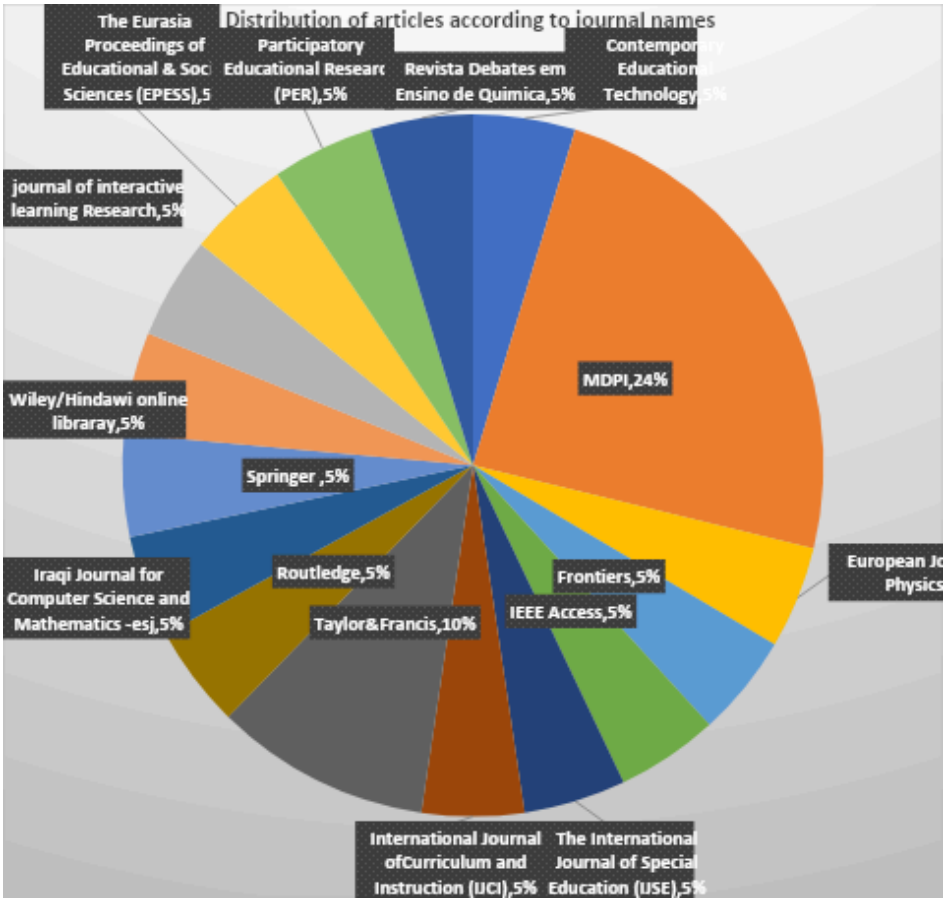

Figure 2. Distribution of articles according to journal names.

3.3. Distribution of articles according to the country of publication

When the distribution of studies on AR technologies in STEM education between 2020-2024 is examined according to the countries of interest, Malaysia (23%) comes first with 5 studies. Then Turkey (19%), which contributed to the world of science with 4 studies, and the USA (14%) with 3 studies in the relevant field. The other countries listed in the table also contributed to the world of science with 1 study each.

Table 3. Distribution of studies on augmented reality technologies in STEM education by countries of interest. Source: Authors' own conception

Publications by Country	Number of Articles	%
USA	3	14
Germany	1	4
Bosnia and Herzegovina	1	4
Brazil	1	4
Chinese	1	4
Indonesia	1	4
Estonia	1	4
India	1	4
Italy	1	4
Switzerland	1	4
Spain	1	4
Canada	1	4
Malaysia	5	23
Turkey	4	19
Total	23	100

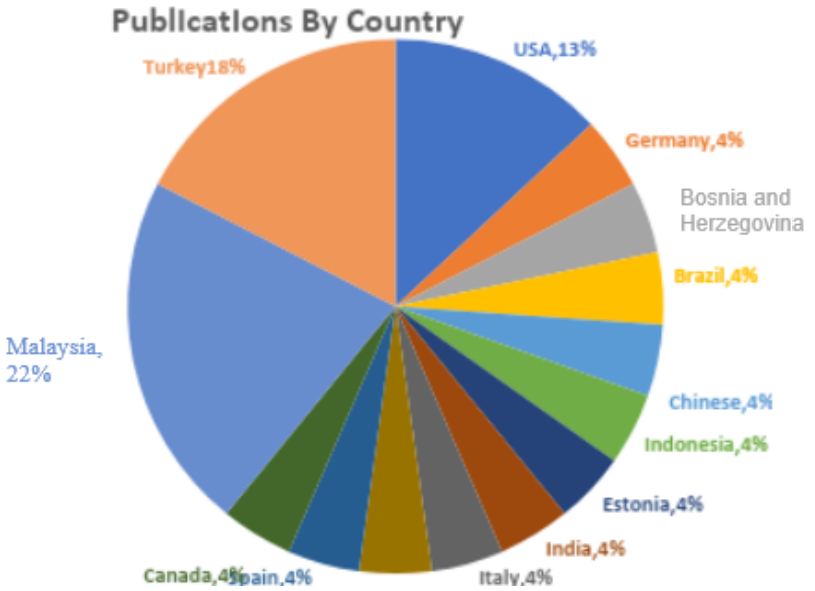

Figure 3. Publication by country.

3.4. Distribution of Articles by Publication Year

The review recorded 23 articles related to research questions published from 2020 to October 2024. Three studies (13%) were published in 2020, two studies (9%) were published in 2021, two studies (9%) were published in 2022, seven studies (30%) were published in 2023, and

nine studies (39%) were published in 2024. The distribution map of studies on the use of AR Technologies in STEM Education reveals that the highest number of studies was in 2024, with 9 studies (39%).

Table 4. Distribution of studies on augmented reality technologies in STEM education according to publication years
Source: Authors' own conception

Publishing Years of Studies	Number of Articles	%
2020	3	13%
2021	2	9%
2022	2	9%
2023	7	30%
2024	9	39%
Total	23	100%

Figure 4. Publishing years of studies.

3.5. Research Topics Where Articles Are Used

The research topics where studies on the use of AR in STEM education are used are listed below. In the study, there are a total of 9 different disciplines in the field of education. STEM Education has the highest rate of 44% with the most studies in these disciplines. This is followed by AR in Education with 18%. Physics education and Mathematics education are in third place with 9%. The remaining fields of PPS Education, Biology, Electrical Engineering, Chemistry, and PE education are seen to have used AR and have a rate of 4% with only one study in these fields.

Table 5. Fields used in publications of studies on Augmented Reality Technologies in STEM Education
Source: Authors' own conception

Research Topics	Research Number	%
AR in STEM	10	44
AR in PPS Education	1	4
AR in Biology	1	4
Ar in Electrical Engineering Education	1	4
AR in Physics Education	2	9
AR in Chemistry Education	1	4
Ar in Mathematics Education	2	9
Ar in PE Education	1	4
AR Education	4	18
Total	**23**	**100**

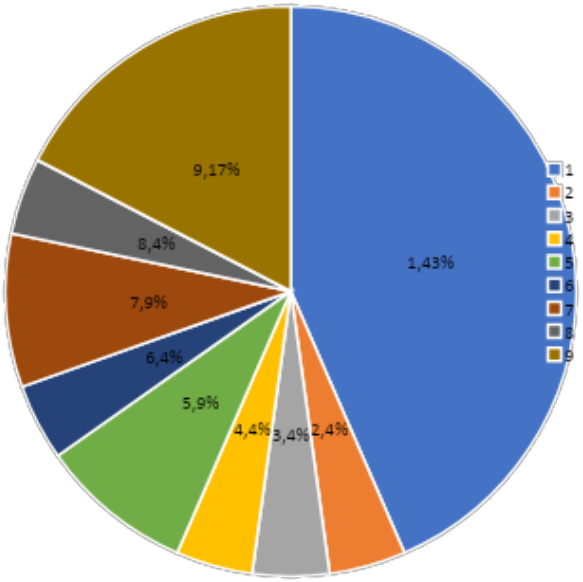

Figure 5. Publications by research topics.

4. Results and Discussion

In this study, 23 national and international academic studies using AR technology in STEM education were examined according to the type of publication, publication years, publication locations, number of authors of the publications, disciplines used, and countries interested in and working in this field. In the study, it was observed that the least studies were conducted in 2021 and 2022 (9%) among the specified years and that the number of studies conducted in the previous year, 2020, was higher than in the following two years, although the values were close (13%). At this stage, it was observed that studies on the use of AR in STEM education decreased, although there should have been an increase. In 2023, the studies conducted suddenly increased with a significant difference (30%), and the number of studies conducted until October 2024 increased noticeably compared to the previous year (39%) (Avila-Garzon et al., 2021). The analysis results obtained in the bibliometric study showed that the publications on AR in the field of education increased by an average of 21% annually. This finding supports the increasing importance of AR in education and the intensification of research activities in this field. A similar increasing trend was determined in the previous studies conducted by Akçayır and Akçayır (2017), Herpich et al. (2019), and López et al. (2019). It can be said that the rapid development in the device technology that forms the basis of AR environments, and the ease of access to information, increased the interest of researchers in this field and as a result, led to the expansion of the application areas of AR technologies. To reveal the reasons for this increase and changes more precisely, it was concluded that long-term studies should be conducted on a larger number of examples. In the study, it was seen that 23 studies examined were published in 17 different sources. It has been revealed in the examinations that most studies were published in MDPI (23%) between 2020-2024 and that one study was published in the journal in question every year. It was determined that Taylor&Francis (9.5%) followed, and 10 other journals and 1 master's thesis were published. It is thought that the fact that the number of studies published in MDPI (MDPI: Multidisciplinary Digital Publishing Institute) is considerably higher than the number of other journals and master's thesis publications is because this journal is the world's largest professional organisation publication established for the advancement of technology. In addition, this number of publications can be explained by the fact that MDPI is among the best publishers in the world and is the largest among open-access journals. ("Guest Post – MDPI's Remarkable Growth". The Scholarly Kitchen. August 10, 2020. Retrieved March 1, 2021.)

When the geographical distribution of studies conducted on AR technologies in STEM education between 2020-2024 is examined, it is seen that Malaysia ranks first, Turkey ranks second, and the USA ranks third. In the examination, Malaysia reveals its interest in this field with five studies. Turkey is one of the countries that are interested in and contribute to this field after Malaysia with four studies. The USA ranks third on the list with three studies in this field. Other countries are seen to have contributed to the literature with one study each. According to Azzahra et al. (2024), in the age of technology we are in, it is important to understand the extent to which AR research is widespread in various countries. The reason for this is to provide a deep understanding of each country's contribution to technological advancement in the world. Examining the studies of various countries on AR supports cooperation between countries. Therefore, it can enable information sharing, collaborative projects, and more efficient use of resources. Due to differences in cultural, economic, and technological frameworks from country to country in AR research, different approaches and solutions emerge. This provides innovations in the perspective of technology. If AR technology is given more importance in some countries, it means that more research is being done in this field and new applications are being developed. Thus, following AR research in different countries can help us shape the future of this technology. And thus, we can benefit from the opportunities that AR technology will offer us.

When we examine the distribution of studies according to the number of authors, it is seen that there are different numbers of authors. The lowest number of authors was determined as one, and the highest number of authors was determined as eight. Most of the studies were conducted between two and five authors. In addition, it is seen in the examination that studies with two and three authors are frequently preferred. The number of studies with six or more authors is lower. The diversity of authors in these studies shows that the studies in question cover different branches of science and different dimensions. While studies with two or three authors generally indicate research in smaller areas, studies with multiple authors usually represent large-scale and multi-disciplinary projects. This distribution in the number of authors provides important information about the level of cooperation and expertise in the research in question. In addition, the importance of researchers from different fields coming together to conduct joint studies is emphasised. In their study, Avila-Garzon et al. (2021) revealed that there is an increase in the number of scientists interested in the use of AR technology in education. The reason for this is the benefits that AR technology provides to education and the developments made for schools to have easier access to AR technology compared to other technologies. In short, scientists are doing more research every day on what AR can do in the field of education. It is expected that these studies will continue to guide the future. In the process we are in, more research will be done on AR and it is estimated that AR technology will be used more widely in education. Thus, education can become more fun and effective. It is seen that the studies on the use of AR technology in STEM education have an interdisciplinary structure. It was observed that most of the studies examined were in the field of STEM education, and the title generalised as AR in education was 18%. Physics and Mathematics education ranked third with a share of 9%. In other fields such as PPS Education, Biology, Electrical Engineering, Chemistry, and PE education, the use of AR has been more limited compared to other disciplines, and it has been determined that only one study has been conducted in each field. The findings obtained in the study show that AR technology has attracted great interest, especially in the field of STEM education. STEM education brings together different fields such as science, technology, engineering, and mathematics. AR provides a better understanding of the information in these different fields. Especially in fields such as physics and mathematics, students can see abstract concepts more concretely with AR technology. However, the use of AR in other fields such as biology and electrical engineering is not yet that widespread. This may be due to the fact that teachers in these fields do not know exactly how to use AR or that there are not enough suitable AR applications for these fields. In the review conducted by Bicen & Demir, (2020) it is revealed that an interdisciplinary approach is adopted in studies on the use of AR technology in education. It is observed that AR-related studies are particularly concentrated in the fields of

Information Technologies, Mathematics, and Educational Sciences. These results are also supported by the findings of previous studies. In the study, Altınpulluk (2018) stated that theses on AR in Turkey are generally carried out in the fields of Engineering and Education, and when the data is analysed, theses in the fields of Computer Engineering, Education, and Information Technologies are more prominent. Tekdal & Saygıner (2012) determined that AR applications are used at the highest rate in the fields of Physics and Engineering education. As a result of the research, STEM education is at the center of the education policies of many countries today. AR technology is seen as an important tool in the field of education to increase the effectiveness of STEM education and to develop students' interests and abilities in this field. The development of AR applications requires researchers from different fields to come together. Therefore, interdisciplinary collaboration should be encouraged for more effective use of AR technologies in education. The limited use of AR in some areas indicates that more research is needed in these areas. In particular, more studies are needed on how AR can be used in accordance with different learning styles and student characteristics. There are some technical and cost difficulties in developing and disseminating AR applications. To overcome these difficulties, support and infrastructure investments should be provided for educators and researchers. Although AR technology has the potential to create a major transformation in education, especially in the STEM field, more research and application are needed for this potential to be fully realised.

5. Conclusion

This research includes a comprehensive literature review on the use of AR technologies in STEM education. The study examined studies conducted between 2020-2024, and it was shown that AR technologies are being used more and more in STEM education. In the review, it was observed that most of the studies were published in academic journals, and MDPI and Taylor & Francis journals were prominent in this field. Geographically, Malaysia, Turkey, and the USA are among the countries where the most research has been conducted in AR-based STEM education research. When we examine the change over time, it is seen that there has been a significant increase in the number of publications in this field, especially in the last two years. When we look at the research, the most frequently used discipline is STEM education. This was followed by AR in education, physics education, and mathematics education. While most of the studies had 2-3 authors, some studies had up to 8 authors. As a result, the use of AR technologies in STEM education is increasingly gaining importance due to its potential to make learning processes more effective. However, more research is needed in this field. It is recommended that interdisciplinary studies be conducted, especially by researchers from different disciplines collaborating, that studies be conducted on the use of AR technologies at different levels of education and in different learning areas, and that the effectiveness of AR-based educational applications be evaluated in the long term. The importance of this study is that it compiles the existing literature on the use of AR in STEM education and guides researchers and educators in this field. It also provides important clues on what needs to be done to use AR technologies more effectively in education.

The importance of this study is that it compiles the existing literature on the use of AR in STEM education and guides researchers and educators in this field. Another important point that emerged from the literature review is that the disadvantages of AR in education have not been addressed in detail. Among the leading clues about what needs to be done for more effective use of AR technologies in education, prioritizing the possible disadvantages in education in detail as well as addressing the advantages of AR in education in future research will allow future research to address these challenges and develop strategies for more effective use of AR in education.

6. Limitations

This study is of great importance in terms of the place and importance of AR in education. The number of studies conducted in this field may increase in recent years. In this study, the “Google Scholar” database, which has important data content, was selected. The study was limited to the Google Scholar database. It is recommended that this method be examined in other databases,

such as Scopus and Web of Science. According to Vitouladiti (2014), in future studies, combining quantitative and qualitative data with content analysis will allow us to understand the findings better.

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