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A Comprehensive Analysis of Augmented Reality Applications for Geometry Education: A Systematic Literature Review and Bibliometric Analysis

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Abstract

This research represents a significant step in exploring the potential of Augmented Reality (AR) in the context of geometry learning. By utilizing the Scopus database, this research explores AR-related trends and content in geometry learning. The literature review method was used, with a bibliometric analysis approach and systematic literature review, which included four stages: identification, screening, eligibility, and inclusion, resulting in 31 final data. This is not just a description of the data but rather an attempt to present a deeper understanding of the role and potential of AR in enhancing geometry learning. In the ever-evolving world of education, a better understanding of the role of technology such as AR can open the door to more innovative and effective learning approaches. Research shows that AR technology can improve students' understanding of geometry concepts, increase learning motivation, and improve teachers' teaching skills. With AR applications, learning geometry becomes more interactive, visual, and engaging for students at various levels of education. In addition, the use of AR technology can also help create a more in-depth learning experience and motivate students to be more active in the learning process.

Keywords

Augmented Reality; Geometry; Systematic Literature Review; Educational Technology

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1. INTRODUCTION

Technology that has recently emerged and has had a significant impact on human life is Augmented Reality (Chandrakar & Bhagat, 2020; Ventes et al., 2023), especially in the world of education., especially in the world of education (Monfared et al., 2022). Recent technological innovations, including the rapid adoption of smartphones by the public, have facilitated access to virtual reality and augmented reality for anyone (Martín-Gutiérrez et al., 2017). According to (Volioti et al., 2022), Augmented Reality (AR) is a new educational technology that can provide creative teaching strategies and create an engaging learning environment. AR-based applications make a significant difference in students' academic achievement, which can be stated as one of the most critical dimensions

(Çetin & Türkan, 2022). Augmented reality (AR) is also a powerful means of increasing student engagement (Walker et al., 2017). So, Augmented Reality is one of the technologies in education that can help teachers and students in the learning process.

Augmented reality connects teachers and students in ways that were unimaginable before (Jumani et al., 2022). Augmented reality is a three-dimensional medium that supports a tangible interface and enables seamless interaction between humans and information (Bokyung, 2009; Li et al., 2017). With AR, teachers can create simulations and three-dimensional objects that students can access through AR-enabled devices, such as tablets or smartphones (Bursztyn et al., 2017; Laine, 2018; Shirazi & Behzadan, 2015). This allows students to explore abstract or complex concepts more concretely and understandably (Candra Sari et al., 2022; Küçük et al., 2016; Yeh & Tseng, 2020).

Augmented reality technology can teach natural sciences and mathematics materials, such as mathematical geometry (Kaviyaraj & Uma, 2022). In addition to mathematical geometry lessons, this augmented reality application can be used in calculus material (Rahman et al., 2020) and algebra (Gao et al., 2023). Through AR applications, geometry concepts such as plane, line, and shape can be realized visually and tangibly, allowing students to interact with mathematical objects in their real space directly (Kudsiah et al., 2023; Manikam & Maat, 2023). AR in teaching geometry can also help students understand complex concepts more intuitively (Rifai & Harsanto, 2023; Sari et al., 2023). For example, students can use AR devices to visualize spatial figures on an accurate scale on their desks to directly see and manipulate mathematical objects. This not only increases the attractiveness of learning but also allows students to develop a deeper understanding of geometric relationships and fundamental mathematical concepts (Khadijah, 2023; Munir et al., 2023; Nevarini et al., 2023; Putra et al., 2023).

Augmented reality is a medium that has been widely used in education over the past few years (N. A. Ali et al., 2022; Kapetanaki et al., 2022). This is because augmented reality generates new opportunities for development in various fields of education (Sáez-López et al., 2019). Augmented Reality has been applied in all stages of education where most of it is done at the primary level (Fernández-Batanero et al., 2022). According to Goksu (2021), augmented reality research, higher education, and smartphone-oriented mobile learning are the most influential research.

Research related to Augmented Reality in Education that uses systematic literature review in its papers has also been widely conducted, especially in the Scopus database in various subjects, namely 52 publications, where 11 are in learning mathematics (Ahmad & Junaini, 2020). Most of these studies used the Scopus database and set different inclusion criteria. From the previous studies above, both bibliometric and SLR analysis, no single study uses both approaches in 1 paper. Therefore researchers want to see research trends and content analysis related to Augmented reality in mathematics learning. This shows that although interest in using AR in mathematics learning is relatively high, researchers still have room to explore research trends and conduct more in-depth content analysis by integrating the two approaches. The potential to generate more comprehensive and in-depth insights on the use of AR in mathematics learning through this combined approach can be a valuable contribution to understanding the implementation and impact of this technology in the context of mathematics education.

In this digital era, integrating technology into education is no longer an option but a necessity. Augmented Reality is a technology that has transformational potential in the world of education, especially in geometry learning. This research aims to identify publication trends, the level of education that is often the focus of research, the research methods used, and the focus and novelty of AR research in geometry learning.

2. METHODS

In searching for data sources related to using Augmented Reality in learning geometry, researchers chose to use the Scopus database because of its broad interdisciplinary coverage. Researchers only use one database because the effective use of the VOSviewer application is only if the data comes from one source, as in this case. Combining different databases, such as Scopus and Web of Science, is not possible as it may result in data mismatches. In addition, the researcher did not have access to the Web of Science database. There are several steps in refining the collected data, as shown in Figure 1. The first is identification, screening, eligibility, and inclusion (Moher et al., 2009).

The first step is identifying relevant publications using a search string and removing identical or duplicates. The topic and scope is "Augmented Reality in Learning Geometry." to find the publications needed to be more effective, an advanced search is carried out by limiting or narrowing the keywords or the scope of the search based on the subject area. Search by limiting the scope to the field of mathematics "mathematics" because Augmented reality in learning geometry is a research domain in the field of mathematics. Only publications with these words are selected for further search processes. One hundred eleven publications have been identified and there are no duplicates obtained.

In the second step, screening is done in selecting publications in the required language and type of documents. The language that must match the needs of researchers is English because it is the most widely used international language in communication in scientific works. The type of document needed in this research is only research articles (not reviews). After the screening process, 70 publications were eliminated or removed from the data because they did not meet the criteria, so only 41 publications remained.

Data collection process

In the third step, 41 publications will be assessed for eligibility. The researcher will manually assess the titles and abstracts to identify which publications fit the inclusion criteria, i.e., research incorporating Augmented Reality in Geometry learning. This means that only publications that fit the criteria were included in the analysis related to the research discussion. At the end of this stage, 10 publications were deleted because they did not involve augmented reality in geometry learning. At the end of this third stage, 31 publications remained. All 31 publications were included to ensure the objectivity of the interpretation results. This data was collected during the inclusion stage on December 2, 2023.

Data Analysis Method

The publication trend related to Augmented Reality in geometry learning is done by descriptive analysis from the Scopus database with bibliometric. The number of publications and the linear trend each year in the last decade will be displayed in a graph using Microsoft Excel software. The trend of publication citations related to Augmented reality in learning geometry is seen from the number of citations per document. Researchers use Microsoft Excel software to display journal rankings based on quartile values to display journal ranking diagrams.

3. FINDINGS AND DISCUSSIONS

Findings

Bibliometric Analysis

In this section, researchers will discuss publication trends, citation trends, journal distribution, country cooperation, research focus, and research novelty.

Publication Trends

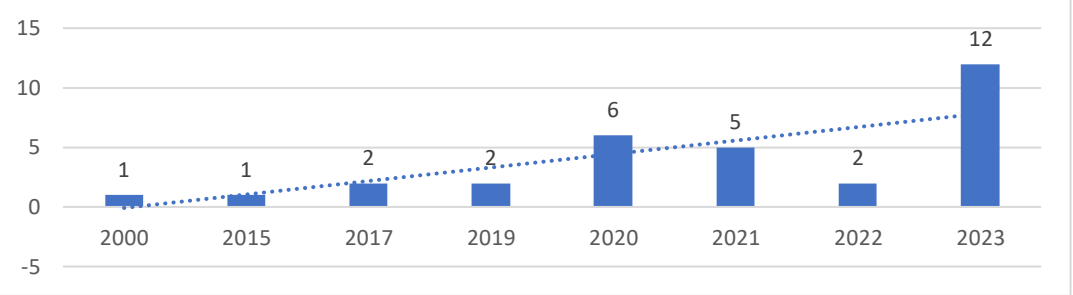

Figure 1. Publication Trends

Based on Figure 1, research on using augmented reality in learning mathematics has been carried out for some time, with articles published since 2000. This follows research conducted by (Maulana et al., 2021) with articles published since 2001 and (Karakus et al., 2019) with articles published since 1999 related to Augmented Reality in Education. This shows that augmented reality in the context of general education and mathematics learning is not a new concept but has been the subject of research for several years. Augmented reality has become an exciting topic for mathematics researchers to explore and study in the context of learning. In 2023, research on using augmented reality in mathematics learning peaked in many publications. This shows researchers' increased interest and focus in exploring the potential of augmented reality as a mathematics learning tool. The high number of publications in 2023 may also signal significant progress in understanding and applying this technology in the context of mathematics education.

Research Focus

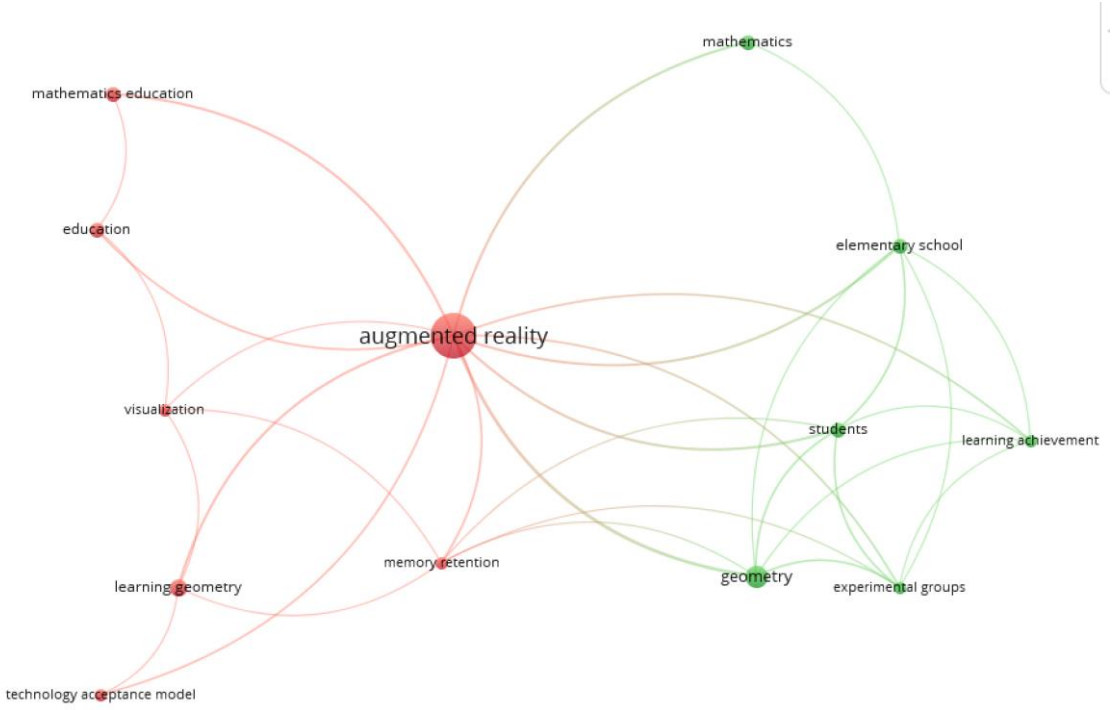

Figure 2. Network Visualization

Based on Figure 2, 2 colors indicate the existence of 2 research focuses related to augmented reality research in mathematics learning, especially in geometry material from 31 previously obtained data. The first research focus has 7 keywords: Augmented reality, memory retention, mathematics education, education, visualization, learning geometry, and technology acceptance model. The second research

focus has 6 keywords: geometry, students' elementary school, experimental groups, learning achievement, and mathematics. This shows that in the research of augmented reality in learning mathematics, there are two main focuses of attention: first, the effect of augmented reality on memory retention and geometry learning effectiveness; second, its effect on learning achievement and technology acceptance among elementary school students. As such, this research explores the technical aspects of the application of the technology but also its pedagogical and psychological implications in the context of mathematics learning.

Research Novelty

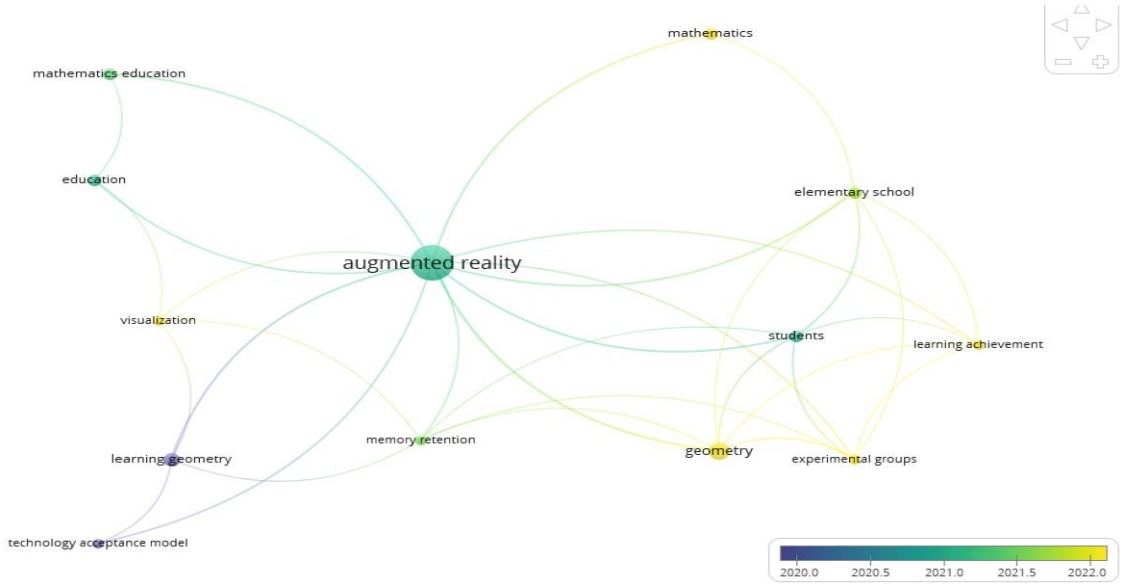

Figure 3. Overlay Visualization

Literature Review

The use of technology in mathematics education, particularly augmented reality (AR), has become a topic of increasing interest to improve mathematics learning. Various studies have highlighted the potential of AR technology in helping students understand math concepts more visually and interactively. In the context of geometry learning, AR technology offers the possibility to visualize geometry objects and concepts in real-time, which can improve students' understanding of the material being taught. Recent research results show that the use of AR technology in geometry learning positively impacts student performance.

Mathematics teachers experience benefits in teaching complex mathematical concepts, especially to students with learning difficulties. In addition, students' perceptions of AR technology in geometry learning also tend to be positive, indicating a good acceptance of such technology. Recommendations from various studies also highlight the importance of further development in the integration of AR technology in mathematics learning. Mathematics teachers are expected to continue to pay attention to the usefulness of AR technology in increasing students' motivation and understanding of mathematics. In addition, the need for research-based guidelines to design practical AR tools that can be applied in school learning is essential to note.

In developing AR applications for geometry learning, research also highlights the need for a structured pedagogical approach to make it easier for students to relate content to their textbooks and retain information. Thus, a deep understanding of the research results and recommendations for using AR technology in geometry learning is vital in improving the quality of mathematics learning in this digital era. Here, we present 5 recommendations to provide comprehensive and applicable insights and strengthen the relevance and significance of the research conducted. The following 5 recommendations

provide comprehensive insights and strengthen the relevance and significance of the 31 studies that have been conducted:

a. Mathematics teachers need to pay attention to their needs and perspectives in developing the integration of state-of-the-art reality technology in mathematics learning in primary schools. They are expected to provide easy access to instructional resources, systematic structures to facilitate exploration and tasks that assist students in learning.

b. Integrating augmented reality (AR) technology in the elementary school curriculum can help clarify progress in geometry learning and improve student learning achievement, especially in concept visualization, long-term memory reinforcement, and conceptual understanding.

c. Using modules with augmented reality (AR) in learning geometry is expected to improve students' problem-solving skills, especially in visually understanding geometry concepts and utilizing computational thinking.

d. The development of Augmented Reality (AR)-based applications and textbooks can help teach math concepts, such as polyhedra, in a more interactive and immersive way.

e. AR-based Global Learning Application (GLA) can provide an interactive and immersive learning experience for students in learning the concept of 3D vectors and directional ratios.

Level of education, type of research, topic, number of subjects, country.

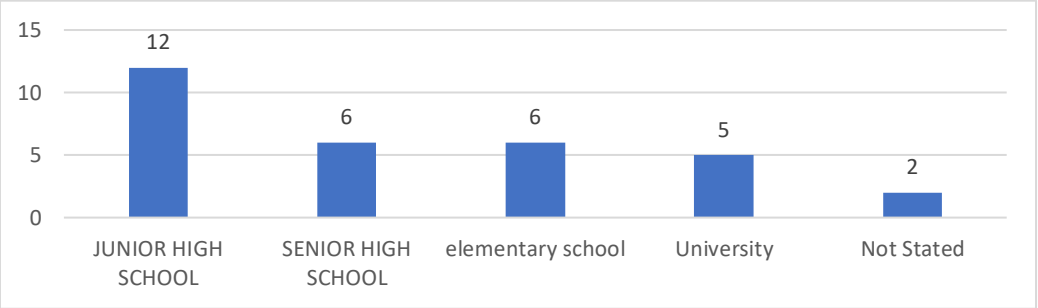

Figure 4. Education Level

Based on the data presented in Figure 4, there is a distribution of the use of Augmented Reality for geometry learning at various levels of education. Specifically, many studies are conducted at various levels of education, ranging from elementary school, junior high school, and high school to university. This shows that the use of Augmented Reality technology in the context of geometry learning has received wide attention and is not limited to one level of education but has been explored and applied at various levels of education. The number of studies conducted on using Augmented Reality for geometry learning is most prevalent at the junior high school level.

The importance of using Augmented Reality in learning geometry at various levels of education shows the potential of this technology in improving student understanding and engagement in geometry materials. With Augmented Reality applications, learning geometry can become more interactive, visual, and engaging for students at various levels of education. Advanced technology, such as Augmented Reality, can also help create a more immersive learning experience and motivate students to be more active in learning. Therefore, research and implementation of Augmented Reality in geometry learning needs to be continuously developed and adapted to the needs and characteristics of each level of education to achieve optimal learning outcomes.

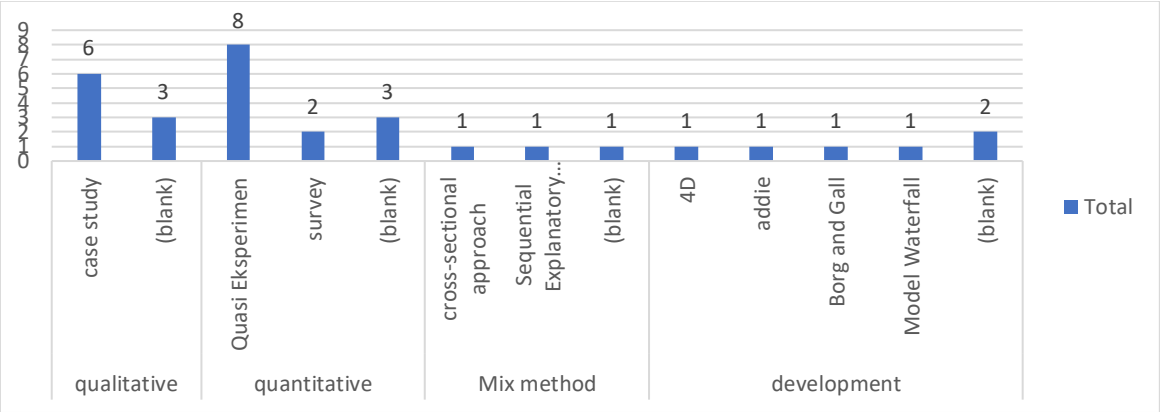

Figure 5. Type of Research

Based on the data presented in Figure 5, there is information about the type of research conducted in the context of using Augmented Reality for geometry learning. The types of research include several categories, such as case studies, quasi-experiments, surveys, cross-sectional approaches, Sequential Explanatory Design, and others. The figure shows that the most common type of research is case studies, followed by quasi-experiments and surveys. This shows the variation in research approaches used to examine the use of Augmented Reality in learning geometry.

The importance of various research types in using Augmented Reality for geometry learning shows the complexity and depth of research conducted in this field. Case studies can provide deep insights into implementing AR technology in the context of geometry learning in natural environments. Meanwhile, quasi-experiments can provide an understanding of the impact of using AR on student learning outcomes in a more controlled manner. Surveys can help collect perception data and responses from various stakeholders related to the use of AR in geometry learning. Thus, combining these different types of research can provide a comprehensive and in-depth understanding of the effectiveness, challenges, and potential use of Augmented Reality in geometry learning.

Topics covered

Various variables are often used in Augmented Reality research for Geometry learning. These variables include teacher learning difficulty, student motivation, teacher gender, education level, teaching experience, math achievement, spatial perception, concept understanding, visual thinking, academic motivation, spatial ability, math literacy ability, mathematical creative thinking ability, memory retention, and spatial ability. These variables provide a comprehensive picture of the factors that can influence the effectiveness of learning Geometry through Augmented Reality.

The importance of these variables in Augmented Reality research for Geometry learning indicates the complexity and depth of aspects that must be considered in designing and implementing effective learning programs. For example, student motivation can be a crucial factor in determining the extent to which students engage in learning Geometry through Augmented Reality technology. In addition, variables such as concept understanding, spatial ability, and mathematical creative thinking ability also play an essential role in improving students' understanding and mastery of Geometry materials. By paying attention to these variables, educational researchers and practitioners can design learning strategies that are more effective and appropriate to the needs of students. In addition, the use of Augmented Reality technology in Geometry learning can provide a more exciting and interactive learning experience for students, improving their learning motivation and learning outcomes.

Research subject

The research subjects involved in Augmented Reality research for Geometry learning include teachers and students. These research subjects include various aspects, such as teacher learning

difficulties, student motivation, teacher gender, education level, teaching experience, mathematics achievement, spatial perception, concept understanding, visual thinking, academic motivation, spatial ability, mathematical literacy ability, mathematical creative thinking ability, and memory retention. The involvement of these diverse research subjects provides a comprehensive picture of the various factors that can influence the effectiveness of learning Geometry through Augmented Reality technology.

The involvement of diverse research subjects in terms of teachers and students shows the importance of paying attention to various aspects in designing and implementing effective learning programs. Teachers have an essential role in implementing Augmented Reality technology in Geometry learning, so understanding factors such as learning difficulties, gender, education level, and teaching experience is relevant. On the other hand, students are also important research subjects, with motivation, concept understanding, spatial ability, and academic motivation playing a pivotal role in determining their learning outcomes. By considering these diverse research subjects, educational researchers and practitioners can develop more holistic learning approaches that suit individual needs and characteristics in the context of learning Geometry through Augmented Reality technology.

Discussion

This publication trend aligns with the research results (Zhao et al., 2023). Although the study used the Web of Science database in its data collection, the interest in augmented reality in education has increased from 2018 to 2022. At the same time, augmented reality research at the higher education level has also increased in recent years (Utami et al., 2023). The parallel research trends between the use of augmented reality in mathematics learning and education in general and at various levels show that this technology has comprehensive and relevant applications in various learning contexts. This illustrates the importance of collaboration between technology, education and mathematics research to optimize the use of augmented reality in improving students' understanding and learning achievement.

The results show variations in the distribution of publications related to augmented reality (AR) education research, depending on the data sources used by researchers. While the results of (Karakus et al., 2019) highlighted the dominance of Spain in publications related to AR in education in general, other studies, such as (Hincapie et al., 2021), show that the United States is the country with the most publications in the context of technical education. In addition, findings from (Ahmad and Junaini, 2020) confirmed that Indonesia is also active in publishing articles related to AR in mathematics learning through systematic analysis. This indicates that researchers from Indonesia strongly focus on the development and application of AR in the context of mathematics learning. Although Indonesia did not emerge as a leader in all studies, the presence of publications from this country significantly contributes to enriching the academic literature on the use of AR in mathematics education. The importance of Indonesian researchers' role in this field reflects a commitment to improving the quality of mathematics education locally and globally. By continuing to participate in research and sharing their findings, Indonesian researchers can become significant agents of change in the future development of technology-based education.

New themes related to augmented reality in geometry learning are visualization, geometry, experimental groups, learning achievement, and mathematics. This means that the new theme related to augmented reality in geometry learning leads to combining the concepts of visualization, geometry, experimental groups, learning achievement, and mathematics as a basis for developing innovative learning approaches. By emphasizing direct interaction between students and geometric concepts in a natural environment through AR technology, the main goal is to enrich the learning experience and improve understanding of mathematical concepts. Through this approach, students can see and understand geometric concepts more visually and test their understanding through experiments integrated into the AR environment. Thus, this theme highlights a shift towards learning that is more interactive, experimental, and oriented towards better learning outcomes in the context of geometry.

Augmented Reality technology in geometry learning can increase student engagement and

improve their understanding of geometry concepts, especially at the JHS level (Bulut & Ferri, 2023). JHS is the level of education with the most significant number of studies conducted, which aligns with the results (Pahmi et al., 2023). Out of 23 publications related to AR research 10 of them were conducted at the JHS Education Level. Students who use Augmented Reality technology to learn geometry have better spatial abilities and better visually understand geometry concepts. Augmented Reality technology in learning geometry can also increase student motivation to learn. Students who use Augmented Reality technology in learning geometry are more motivated to learn and more interested in the subject matter. Teachers who use Augmented Reality technology in learning geometry have a better ability to teach and are more able to motivate students to learn. This shows that using Augmented Reality technology in learning geometry has excellent potential to improve the quality of learning and student learning outcomes. Therefore, the use of Augmented Reality technology in learning geometry should continue to be explored and developed to improve learning effectiveness in the future.

The positive impact of using augmented reality (AR) technology in geometry learning, both in student performance and ease of teaching for teachers, is directly related to learning achievement, which is the yellow keyword in Figure 4. With improved student performance in estimation and understanding of mathematical concepts, AR has improved student learning achievement in geometry. The recommendation to continue developing the integration of AR technology in mathematics learning can also be linked to learning achievement, as the development of more effective technologies and research-based guidance can help improve the quality of learning and ultimately achieve better learning achievement. Thus, the results and recommendations are directly related to efforts to improve student learning achievement by applying AR technology in geometry learning.

Augmented Reality technology in geometry learning has great potential to improve the quality of learning and student learning outcomes. By utilizing Augmented Reality technology, learning geometry can be more interactive, visual, and engaging for students at various levels of education. In addition, using advanced technology such as Augmented Reality can also help create a more immersive learning experience and motivate students to be more active in the learning process. Another implication is that using Augmented Reality technology in learning geometry can also improve teachers' skills in teaching. With the Augmented Reality application, teachers can have better teaching abilities and can motivate students to learn. Thus, this study shows that the use of Augmented Reality technology in learning geometry positively impacts both students and teachers. Therefore, the development and implementation of Augmented Reality in geometry learning needs to be continuously developed and adapted to the needs and characteristics of each level of education to achieve optimal learning outcomes.

4. CONCLUSION

From the results of this research, it can be concluded that the use of Augmented Reality (AR) technology in geometry learning has a positive impact on students' understanding of concepts and learning achievement, as well as making the teaching process more accessible for teachers. Research shows that interest in using AR in mathematics learning, especially geometry, has increased in recent years. With a variety of research focuses, including the effects of AR on memory retention, the effectiveness of learning geometry, and the acceptance of technology among elementary school students, this research explores not only the technical aspects of implementing the technology but also its pedagogical and psychological implications in the context of mathematics learning.

Recommendations from this research highlight the importance of developing AR in the elementary school curriculum to improve student understanding of concepts, learning achievement and motivation. In addition, using modules with AR technology is expected to improve students' problem-solving skills, especially in visually understanding geometric concepts and using computational thinking. Research also emphasizes the importance of a structured pedagogical approach in developing AR applications to make it easier for students to relate content to their textbooks and retain information.

In the context of publications, the results of this study note variations in the distribution of publications related to AR research in education, depending on the data sources used by researchers. However, the findings show that collaboration between research in the fields of technology, education, and mathematics is essential to optimize the use of AR in improving students' understanding and learning achievement. The development and implementation of AR technology in geometry learning have great potential to improve the quality of learning and student achievement. By continuing to develop and adapt AR technology to the needs and characteristics of each level of education, optimal learning outcomes are hoped to be achieved.

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