Journal for Re Attach Therapy and Developmental Diversities
eISSN: 2589-7799
2023 August; 6 (1): 450-467

Learning Mathematics Using Augmented Reality for Elementary School Students

Beti Istanti Suwandayani[1], Cholis Sa'dijah[2*], Punaji Setyosari[3], Suyono[4], Siti Salina Mustakim[5]

[1]Doctoral Program Graduate school, Universitas Negeri Malang, Malang, Indonesia, beti.istanti.2121039@students.um.ac.id

[2*]Mathematics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, Indonesia. Corresponding author: cholis.sadijah.fmipa@um.ac.id

[3]Faculty of Education, Universitas Negeri Malang, Malang, Indonesia

[4]Faculty of Letter, Universitas Negeri Malang, Malang, Indonesia,

[5]Faculty of Educational Studies, Universiti Putra Malaysia, Selangor, Malaysia

Received: 24- June -2023
Revised: 27- July -2023
Accepted: 21- August -2023

Abstract

Introduction: Studies on augmented reality (AR) are crucial for identifying its proper implementation in learning mathematics and finding the right solution to face the times.

Objectives: This study aimed to explore the definition, task characteristics, and implementation of augmented reality in mathematics.

Methods: A systematic literature review (SLR) was conducted on articles from 2013-2023 using the Scopus database. For the selection of the research papers, we used the terms "augmented reality and mathematics" in the disbursement menu in the Scopus database. The obtained data was stored in *RIS format and was synchronized to the Reference Manager (Mendeley). Further, VOS-viewer software was used to visualize the data, resulting in a more communicative, interesting, and clearer information presentation. The PRISMA flow diagram for the systematic literature review detailing the database searches, the number of abstracts screened, and the full texts retrieved. A number of 22 related studies were accessed for this study.

Results: The analysis was conducted focusing on the implementation of augmented reality in elementary mathematics, specifically on the (1) sample size and the target audience, (2) methodology, (3) author and keywords, and (4) learning outcomes. Research gaps and potential future studies in each theme were explored. It was found augmented reality (AR) can be a powerful tool to enhance mathematics learning for elementary school students. When integrated effectively into the curriculum, AR can lead to various learning outcomes that benefit students' understanding and engagement with mathematical concepts.

Conclusions: The integration of augmented reality into mathematics learning for elementary school students has the potential to enhance their understanding, engagement, and retention of mathematical concepts, ultimately preparing them for a more mathematically literate future.

Keywords: augmented reality; mathematics learning; elementary school student

1. Introduction

Tremendous scientific and technological advancements have been reported in various fields of life (Brynjolfsson & McAfee, 2014; Schindelin et al., 2015). In addition, the communication and information revolution led to the rapid development of human knowledge, especially science and technology. There have been tremendous leaps in the field of satellite, multimedia, and internet technology (Majeed & ALRikabi, 2022; Saad et al., 2019; Sulistiani et al., 2023). Previously, this huge leap in technology seemed only possible in cyberspace (Hayes, 2009; Maxwell, 1987). In the era of information technology and technological devices (Majid & Verma, 2021; Sandoval-Almazan & Gil-Garcia, 2014), the information technology education movement, also the expansion of

technological tools and devices, the technology education movement has witnessed tremendous development (Al'Abri, 2011; Alsunbul, 2002; Kuratko, 2005; Yaqoob et al., 2017). As the instruments have been widely spread and technology has multiplied, access to knowledge and digital representation collection, and storage are available everywhere and at any time (Cocchia, 2014; Deichmann et al., 2016; Gibbs, 20s18; Monino & Sedkaoui, 2016). Recently, individuals can easily purchase tablets and smartphones regardless of their age (Khanna & Tomar, 2016).

In general, following the technology advancement, current teaching and learning practices can be categorized as conventional (Anwar et al., 2023; Chachil et al., 2015; Wang et al., 2020; West, 2012), both in terms of educational access and infrastructure (Febrianto et al., 2020; Livingstone, 2012; Qureshi et al., 2012). Consequently, it triggers the development of immersive technological innovations in the world of education (Alam, 2021; Ausburn & Ausburn, 2004; Cabiria, 2012; P. Chen et al., 2017; Dieker et al., 2008; Lazou & Tsinakos, 2023). Virtual Reality (VR) and Augmented Reality (AR) technologies are innovative breakthroughs in educational technology (EdTech) that aim to enhance students' understanding, interest, and outcomes (Cevahir et al., 2022; De Pace et al., 2018; Farshid et al., 2018; Lu et al., 1999). In the last decade, the implementation of Augmented Reality (AR) has developed quite rapidly (Alamsyah & Fauziyah, 2021; Han et al., 2018; Höllerer & Feiner, 2004; Nee & Ong, 2013), as in line with the rapid development of cellular technology (Hosokawa & Katsura, 2018; Islam et al., 2010; Korucu & Alkan, 2011). AR is defined as a technology capable of incorporating two-dimensional or three-dimensional virtual objects into a real environment and then displaying or projecting them in real-time (Geng, 2013; Molnár & Benedek, 2015; Nevarini et al., 2023; Wainman et al., 2018). Therefore, "AR" extends real reality by adding layers of information.

The ability to understand materials is the main foundation of learning (Carrillo-Yañez et al., 2018; Tatto, 2013; Winter, 2022). Therefore, learning should facilitate students to understand each concept instead of just memorizing the material (Ayal et al., 2016; Dewi & Primayana, 2019; Syatriana & Sakkir, 2020; Wahyuni, 2019). In the long term, students are expected to use problem-solving strategies and knowledge related to the material, concepts, principles, and procedures for the presented problem (Barak, 2013; D. D. Utami et al., 2023; Yadav et al., 2014). Researchers must also be responsive to the challenges of technology-adaptive learning (Bagustari & Santoso, 2019; Durlach & Spain, 2014; Kleisch et al., 2017). Therefore, research on augmented reality according to the recent education needs, expectations, and demands is necessary. Studies on augmented reality (AR) are crucial for identifying its proper implementation in learning mathematics and finding the right solution to face the times (Hanggara et al., 2023; Kazanidis & Pellas, 2019; Safar et al., 2016).

Analysis of research published in the Scopus database (a database representing the largest reputable journal in the world) conducted in July 2023 signified that there were 536 publications on augmented reality (for the 2013-2023 category). These publications require deep analysis to identify the Augmented Reality (AR) form or model for mathematic learning in elementary schools. For that purpose, one of the most recommended techniques is a Systematic Literature Review (SLR).

Therefore, this study adopted the SLR technique to investigate, review, and compare various studies related to the use of augmented reality in mathematics learning in elementary schools. This SLR is expected to contribute to the development of elementary school mathematics learning that uses augmented reality technology. It can also be a reference for researchers and readers on this topic. Specifically, we focus mainly on the research articles analyzing elementary school mathematics learning using augmented reality technology and its implications. The available research has not highlighted and provided a research baseline on this topic. For the purpose of the review, we have exclusively incorporated research or original articles in order to offer a comprehensive insight and consensus among researchers on this subject. We formulate a form or model of mathematics learning that uses augmented reality technology. In the long term, this model is foreseen to become a reference for policymakers, stakeholders in mathematics education, and the general public in responding to the recent technological advancement. As a result, this systematic review serves as a reference point for further research regarding Augmented Reality in Primary School Students' Mathematics Learning, with the following two research questions.

RQ1: How is the publication trend related to the theme of "augmented reality for mathematics learning" in Scopus-indexed journals?

RQ2: How is the implementation of augmented reality in mathematics learning?

2. Methods

This study used a systematic literature review. A Systematic Literature Review (SLR) is a technique of identifying, evaluating, and analysing various existing and relevant information in the literature or references to answer research questions through deeper analysis (Snyder, 2019; Xiao & Watson, 2019). SLR has been proven to be helpful in summarizing the latest knowledge on a particular topic with a systematic and transparent method for answering research questions (Kurniati et al., 2022).

Prisma

This systematic review was adapted according to the guidelines of the PRISMA statement (Santos et al., 2018). PRISMA or Preferred Items for Systematic Reviews and Meta-Analyses, has been published as a standard to help conduct a systematic literature review. Using PRISMA can reduce the risk of misreporting and improve the clarity and transparency of reviews (McInnes et al., 2018; Page et al., 2021). PRISMA is suitable for systematic literature reviews in the social sciences because it helps 1) define clear research questions that enable systematic research, 2) identify inclusion and exclusion criteria, and 3) attempt to search a large database of scientific literature over a period of time. This improves search results for exact terms related to augmented reality in mathematics learning for elementary school students.

The Systematic Review Process for Selecting the Articles

For the selection of the research papers, we used the terms “augmented reality and mathematics” in the disbursement menu in the Scopus database. The obtained data was stored in *RIS format and was synchronized to the Reference Manager (Mendeley). Further, VOS-viewer software was used to visualize the data, resulting in a more communicative, interesting, and clearer information presentation. The search history on Scopus was carried out through (TITLE-ABS-KEY (“augmented reality” +mathematics) AND PUBYEAR > 2012 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SUBJAREA, “SOCI”) OR LIMIT-TO (SUBJAREA, “MATH”)) AND (LIMIT-TO (OA, “all”))).

With these search terms and patterns, 536 articles were found. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) were used for the inclusion and exclusion model, as previously implemented in a study (Patrignani et al., 2016). Several important elements for the basis of inclusion criteria for SLR analysis include (1) articles published in January 2013 to July 2023, (2) open access articles, (3) publications in the form of research or original articles, (4) article in social sciences field; and (5) articles published in English and only related to “science learning” research. The order of inclusion and exclusion criteria is illustrated in Figure 1.

Data Analysis

The papers that met the inclusion criteria were thoroughly reviewed for the purpose of data analysis and subsequently categorized to extract systematic information in accordance with the criteria established for this research. The analysis was conducted focusing on the implementation of augmented reality in elementary mathematics, specifically on the (1) sample size and the target audience, (2) methodology, (3) author and keywords, and (4) learning outcomes.

3. Results

This section, divided into presents the findings of this study in detail. First, we describe the findings of the document analysis, and then we present the findings in a visual format to illustrate the findings. Following four phases of selecting eligible articles, a total of 22 were selected for inclusion in this systematic review. All the selected articles were exported to data organization and management software. Only English-language articles were used for this analysis. Since the outbreak, researches have continued to publish.

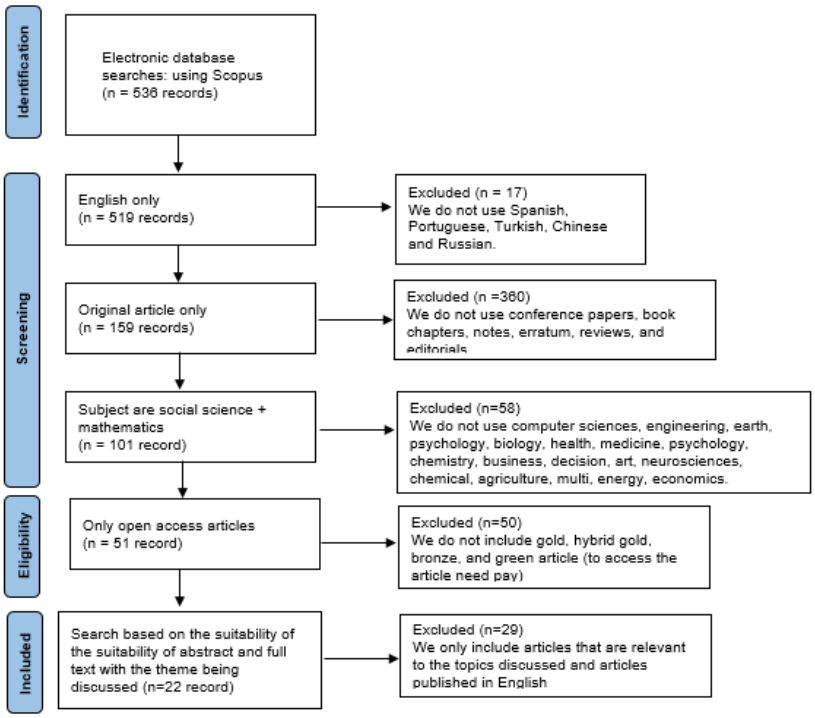

Figure 1. Systematic review flow diagram. Caption: The PRISMA flow diagram for the systematic literature review detailing the database searches, the number of abstracts screened, and the full texts retrieved.

Table 1. The main articles' summary, sorted by author name

No	Title	Author (s)	Aim	Main Result
1	Effect of Augmented Reality and Simulation on the Achievement of Mathematics and Visual Thinking Among Students	(Aldalalah et al., 2019)	To investigate the effect of augmented reality and simulation on students' mathematics achievement and visual thinking	Students using augmented reality performed significantly better than those in the simulation mode, specifically in achievements and visual thinking.
2	The effect of augmented reality mobile learning in microeconomic course	(Ali et al., 2023)	Investigate the effectiveness of augmented reality, namely Augmented Reality Mobile Learning in Microeconomic courses (ARMLAAPPS).	ARMLAAPPS can assist in highlighting student- centered learning, stimulating student interest and curiosity, increasing student cognitive, affective, and psychomotor processes, and increasing student involvement in the information-seeking process
3	Augmented reality technology in enhancing learning retention and critical thinking according to TEAM program	(Alkhabra et al., 2023)	To advocate e-content based on augmented reality (AR) technology, enhance retention learning (LR), and	Implementing AR in educational realms impacted students' LR. Furthermore, statistically significant differences were exhibited in overall CT skills between those with high and low

No	Title	Author (s)	Aim	Main Result
			reinforce critical thinking in the intermediate stage.	mental capacity (MC), favoring those with high MC. Even more interestingly, according to the STEAM program, male students' outcomes in science learning were more reinforced by AR than females.
4	Augmented Reality: The Improvement of Computational Thinking Based on Students' Initial Mathematical Ability	(Angraini et al., 2023)	This study focuses on assessing the fundamental level of mathematical skills that determine a student's readiness to learn under the guidance of a teacher.	The enhancement in students' mathematical computational thinking skills is more significant when they learn using augmented reality media compared to conventional learning, considering their initial mathematical abilities.
5	The usability analysis of using augmented reality for linus students	(Awang et al., 2019)	To evaluate the usability of Augmented Reality in a mobile application among LINUS students in primary schools	The students showed a significant interest in learning numbers by actively participating in the LINUS sessions.
6	Heuristic Evaluation on Affective 4-Dimensional Augmented Reality Mathematics for Children with Low Vision	(Aziz et al., 2023)	To investigate high school students' perceptions of AR and their STEM interest after they experienced two AR lessons that incorporated authentic inquiry activities for an exploration of medical surgery	The students had positive perceptions of the AR lessons and simulators (overall mean = 4.1) after completing the two lessons.
7	A STEAM Practice Approach to Integrate Architecture, Culture, and History to Facilitate Mathematical Problem-Solving	(Bedewy et al., 2022)	Investigate how different phases of this approach (such as motivation, modelling, and printing process) reflect opportunities of learning in STEAM education, with a particular lens on mathematical development from open tasks.	The introduced practices attempt to promote problem-solving strategies of architectural modelling in order to solve the problem.
8	Learning mathematical modelling with augmented reality mobile math trails	(Cahyono et al., 2020)	To investigate how an augmented reality mobile math trails program can provide opportunities for students to engage in	An educational program was successfully designed, which offered students a meaningful mathematical experience.

No	Title	Author (s)	Aim	Main Result
	program: how can it work?		meaningful mathematical modelling activities	
9	Application in Augmented Reality for Learning Mathematical Functions: A Study for the Development of Spatial Intelligence in Secondary Education Students	(Del Cerro Velázquez & Méndez, 2021)	The aim of this study is to find out whether the integration of the Geo Gebra AR (Augmented Reality).	Given the scope and potential of the models learned in an interconnected and ubiquitous environment not yet established, the conclusions drawn from this work should be taken with prudence.
10	Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education	(Demitriadou et al., 2020)	Investigate the potential of using virtual and augmented reality technologies for teaching the lesson of geometric solids to primary school children.	The implementation of new technologies in education, such as virtual and augmented reality, improves interactivity and student interest in mathematics education, contributing to more efficient learning and understanding of mathematical concepts when compared to traditional teaching methods.
11	Effectiveness of the Augmented Reality on Improving the Visual Thinking in Mathematics and Academic Motivation for Middle School Students	(Elsayed & Al-Najrani, 2021)	To identify the effectiveness of augmented reality technology for improving visual thinking in mathematics and academic motivation among middle school learners in Saudi Arabia.	The experimental group surpassed the control group in visual thinking and academic motivation. Based on the results, researchers recommended the involvement of augmented reality technology in mathematics instruction at different levels of education.
12	On Augmented Reality for the Learning of 3D-Geometric Contents: A Preliminary Exploratory Study with 6-Grade Primary Students	(Flores-Bascuñana et al., 2020)	To explore the potential of AR-based activities through a short classroom intervention in a 6th-grade Primary class	Obtained data allow us to envisage that AR-based proposals slightly improve the classical didactic methods.
13	Examining Students' Intention to Use Augmented Reality in a Project Based Geometry Learning Environment	(Mailizar & Johar, 2021)	To examine factors that affect secondary students' behaviour intention to use Geo Gebra Augmented Reality to support a project-based geometry learning environment	Geo Gebra Augmented Reality was properly accepted by secondary school students. It was found that perceived usefulness (PU) is the most substantial factor in students' behaviour intention (BI)

No	Title	Author (s)	Aim	Main Result
14	Effect of Augmented Reality Technology on Spatial Intelligence among High School Students	(Majeed & ALRikabi, 2022)	To investigate the impact of AR technology in developing spatial intelligence for secondary school students, Baghdad	AR technology has a positive on spatial intelligence in mathematics and concluded with a set of recommendations and proposals.
15	An Augmented Reality Learning Toolkit for Fostering Spatial Ability in Mathematics Lesson: Design and Development	(Ozcakir & Cakiroglu, 2021)	To design and develop an augmented reality learning toolkit to foster spatial ability in middle school students using mobile devices	The study showed that augmented reality seemed helpful in enhancing the usage of mobile devices, not just for the reading of books, communication, or playing games, but also as a support mechanism for the learning of mathematics.
16	Enhancing mathematical literacy ability through guided inquiry learning with augmented reality	(Pujiastuti & Haryadi, 2023)	To determine the effectiveness of Guided Inquiry Learning-Augmented Reality (GILAR) on mathematical literacy ability	The experimental class produced 58.88%, while the control class was 45.77%. Based on these results, learning by using GILAR can improve mathematical literacy skills in junior high school students.
17	The Effects of Mobile Technology on Learning Performance and Motivation in Mathematics Education	(Poçan et al., 2023)	To assess mobile-assisted seamless learning environments' effects on students' success and motivation in the secondary school 7th-grade mathematics class algebra unit and student opinions about the application.	There were statistically significant differences in favor of the experiment group in AAT and MMS scores
18	Effectiveness of flipped learning and augmented reality in the new educational normality of the Covid-19 era	(Pozo-Sánchez et al., 2021)	Analyse the effectiveness of flipped learning and augmented reality in various dimensions related to the learning process	There is a high appreciation from students in both educational experiences, although differences in various dimensions are present. Those who have received teaching based on flipped learning show significance in the teacher-student autonomy, deepening, and class time dimension.
19	Active Learning Augmented Reality for STEAM Education—A Case Study	(Rhea & Bauml, 2020)	To investigate the method of Active Learning for the teaching of STEAM subjects, using a format where students are tasked with building an AR	Students can develop a final project and gain a qualification as skills evidence for the university application process. This approach possibly changes the learning results from mere

No	Title	Author (s)	Aim	Main Result
			application as part of their learning.	remembering to facilitating analyzing and understanding of concepts.
20	Students' Attitudes Toward The Application of Mobile Augmented Reality In Higher Education	(Stojšić et al., 2020)	to determine students' attitudes toward the application of MAR in HE institutions in the Republic of Serbia	The students have a mostly positive attitude, and there was no statistically significant difference between the STEM (science, technology, engineering, and mathematics) and non-STEM students' opinions regarding this topic
21	Development of augmented reality-based learning models for students with specific learning disabilities	(Wiliyanto et al., 2022)	To develop a learning model based on augmented reality applications to overcome barriers in learning mathematics for Students with Specific Learning Disabilities (SLD) in Inclusive Schools	There is still hope and excellence in achieving the learning process desired by STC, where the learning process is still in the sufficient category level and necessary as a learning medium in the inclusive class.
22	The Potential Of Mobile Augmented Reality As A Didactic And Pedagogical Source In Learning Geometry 3D	(Yaniawati et al., 2023)	Provides a learning alternative by exploring the potential of augmented reality as a didactic and pedagogical source in learning geometry	The use of augmented reality is worthy of being an alternative didactic and pedagogical source and has the potential to be applied to other subjects both during the COVID-19 pandemic and after the COVID-19 pandemic.

Research Paper Identified by Search Terms

Figure 1 shows the results of an initial search via Scopus, concentrating on their "article, abstract, keywords" found 536 articles. From those articles, we identified 519 articles that used English, while the remaining 17 articles were excluded, as they were written in Spanish, Portuguese, Turkish, Chinese, and Russian. Besides, we also used the only "article" document type, resulting in 159 articles. There were 360 articles being excluded since they were conference papers, conference reviews, book chapters, books, erratum, reviews, and editorials. Furthermore, the inclusion criteria necessitated the research to be in the field of "social sciences" and "mathematics," so there were 101 articles. This screening excluded 58 articles consisting of articles in the fields of computer sciences, social sciences, engineering, mathematics, physics and astronomy, decision sciences, psychology, arts and humanities, earth and planetary sciences, medicine, health professionals, business, management and accounting, materials science, biochemistry, genetics and molecular biology, energy, chemistry, neuroscience, environmental science, chemical engineering, economics, econometrics and finance, agricultural and biological sciences, multidisciplinary. Further, we also involved only the open-access article. From this criteria, we obtained 51 articles that met the criteria, indicating that 50 articles were excluded as they were in gold, green, bronze, and hybrid gold access. In the last phase, the review of existing articles was carried out, ensuring articles were in accordance with the research themes, accessible, and written in English. From this final stage, we obtained 22 research papers. The distribution of the 22 articles published in the last 5 (2019-2023) years on Scopus is illustrated in Figure 2.

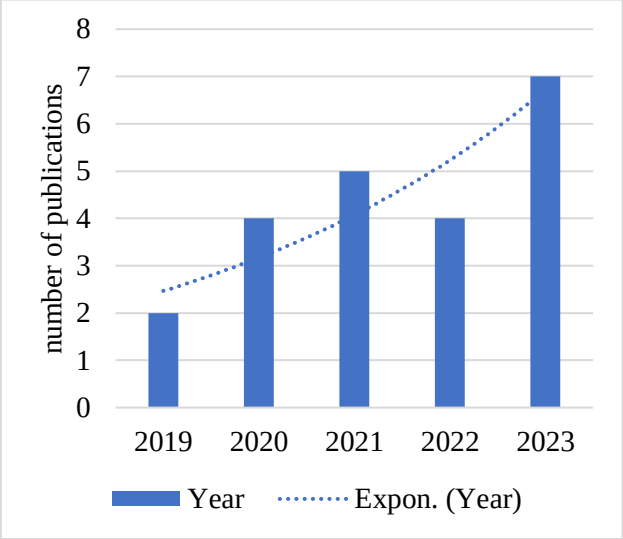

Figure 2. Distribution of 22 published articles over the last 5 (2019 - 2023) years on Scopus

Sample size and the target audience

In terms of sample size, there was considerable variation observed across studies, with some involving as few as fifteen students and others including as many as 120 students. Among those studies, a development study does not account for sample size and is characterized by its qualitative nature, which focuses on the context and narratives of the individuals involved in development. Additionally, the target audience in these studies also varied, ranging from elementary school students to the tertiary level. Among these studies, a study involves general subjects. There are four studies using the target audience at the elementary school level (18%), while fourteen studies target secondary school students as the target audience (64%). Besides, 5 and 9 % of research target the senior high school level and tertiary level as the target audience. In the end, one research mentions no specific target audience (5%).

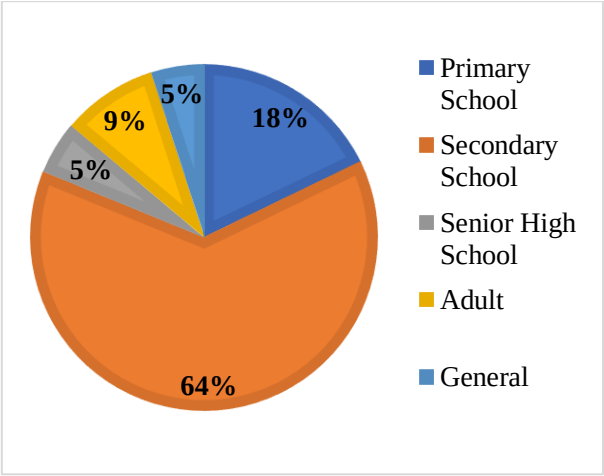

Figure 3. Distribution of papers analysing the use of augmented reality in mathematics learning published in Scopus

Methodology Used

The trend in research related to augmented reality in mathematics is depicted in Table 1. Most of the research conducted in the field of science learning has employed a quantitative approach, accounting for 14 articles or 64% of the total. Additionally, there are a notable number of qualitative studies, total of four articles (18%), while mixed-method research accounts for four articles as well (18%). These findings indicate that the investigation of augmented reality in mathematics can be addressed using a combination of quantitative, qualitative, and mixed-

method research approaches. Furthermore, Table 1 presents the distribution of research methods adopted in the sample articles.

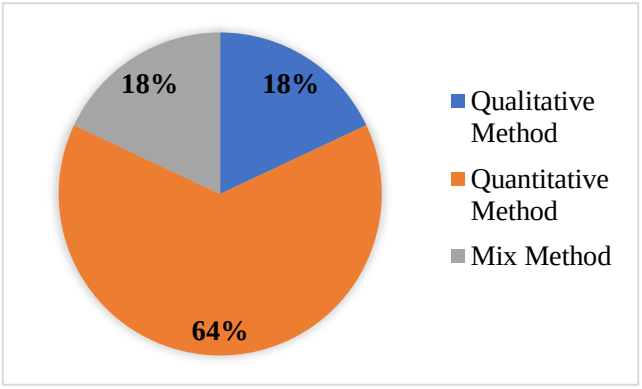

Figure 4. Distribution of Research Methods Adopted in Augmented Reality Research

Table 2. Types of research on augmented reality in mathematics

No	Type of Research	Total	References
1	Quantitative	14	(Aldalalah et al., 2019; Ali et al., 2023; Alkhabra et al., 2023; Angraini et al., 2023; Awang et al., 2019; Aziz et al., 2023; Del Cerro Velázquez & Méndez, 2021; Demitriadou et al., 2020; Elsayed & Al-Najrani, 2021; Flores-Bascuñana et al., 2020; Mailizar & Johar, 2021; Majeed & ALRikabi, 2022; Pozo-Sánchez et al., 2021; Pujiastuti & Haryadi, 2023)
2	Qualitative	4	(Cahyono et al., 2020; Rhea & Bauml, 2020; Stojšić et al., 2020; Yaniawati et al., 2023)
3	Mix-method	4	(Bedewy et al., 2022; Ozcakir & Cakiroglu, 2021; Poçan et al., 2023; Wiliyanto et al., 2022)

Author and Keywords

Figure 4 summarizes the author's nationality and continental from the research in augmented reality on mathematics learning.

Figure 5. Author's nationality and continental from research on augmented reality in mathematics learning

In addition, Figure 5 illustrates the two most dominant keywords, namely augmented reality and mathematics education. These keywords appear most frequently and are interconnected. Further, the other keywords related to

Augmented reality include STEM, mathematics, spatial abilities, and learning STEMS. Interestingly, the correlation between the themes of augmented reality and mathematics spans from elementary school to university levels. Additionally, it is noteworthy that these themes in augmented reality and mathematics intersect with thematic learning, allowing for the integration of diverse subject matter expertise.

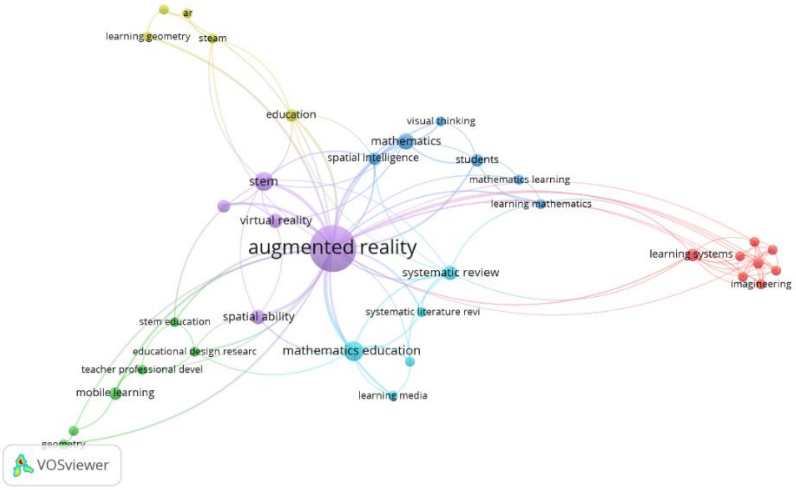

Figure 6. VOS-viewer display for co-occurrence + keywords analysis.

A frame represented each word in the cluster, and frames were connected by an edge/link. The bigger word frames represent the more often they appeared within the articles, and the closer distances between one frame to another frame indicate their greater correlation (van Eck & Waltman, 2022).

4. Discussion

This study attempted to analyze the existing studied publish between 2019 – 2023 on augmented reality in mathematics learning for elementary school students. According to the selected articles, there are several implementation of augmented reality in mathematics learning for elementary school students. Two criteria were considered for the discussion of learning results, namely, the technical and fixation of content. The technical analysis refers to the results related to the degree of correctness, while the fixation of content includes the research participants' knowledge skills and behaviour outcomes, as well as their motivation and engagement. Table 1 summarizes the main information, including the aim, level, method, and main results of the research. The main results are briefly described in the last column. The results from these studies indicate the need for special workshops and training for mathematics teachers on the use of AR technology and AR applications in the learning process. From its characteristics, AR also presents the potential for further research on other mathematical learning content (Rahmawati et al., 2022; Sommerauer & Müller, 2014). The models' presentation from the augmented reality applications, especially in representing the abstract concepts, is of significant importance, particularly for middle school students. Augmented reality (AR) stands as a novel technology with substantial potential for educational applications. The inquiries pertaining to the actual impact of this technology warrant further investigation in future research (Limperos et al., 2015).

Recently, the paradigm of education has been changing, emphasizing the development of human resources with excellent creative problem-solving skills in order to full fill the demands of the contemporary digital era following dynamic technological innovations (Marsitin et al., 2022; Sa'dijah et al., 2023; Setyosari et al., 2023; Wuryaningrum et al., 2017). The mobile application, equipped with augmented reality (AR) features, played a crucial role in assisting students in bridging the gap between real-world scenarios and mathematical concepts during problem-solving while adhering to the mathematical modelling cycle (N. A. Utami et al., 2023). Through AR development, augmented reality usage increases student's achievement and visual thinking. These findings from the available studies also signify the potential of AR-based activities in promoting students' acquisition of geometric and spatial abilities. Besides, augmented reality in the mathematics curriculum also aims to address the

students' mathematical literacy. The findings from 76.25% of those studies also highlight the need to develop an Augmented reality (AR) based on learning model for students in inclusive schools. The adoption of technology-based learning media is crucial to overcoming mathematic learning obstacles for SLD students during the COVID-19 period. Further, augmented reality is reported as an efficient solution for its users due to its capacity to create 3D visual displays (Limperos et al., 2015; Molnár & Benedek, 2015).

Augmented Reality (AR) can be a powerful tool to enhance mathematics learning for elementary school students(Chao & Chang, 2018; Y. Chen, 2019; Kramarenko et al., 2019). When integrated effectively into the curriculum, AR can lead to various learning outcomes that benefit students' understanding and engagement with mathematical concepts (S. Chen et al., 2016). Some potential learning outcomes from implementing using augmented reality in mathematics education for elementary school students such as improved understanding of abstract concepts (Bujak et al., 2013; Marini et al., 2022; Wu et al., 2013). AR can provide visual and interactive representations of abstract mathematical concepts, making it easier for students to grasp concepts like fractions, geometry, and algebra. The immersive and interactive nature of AR can make mathematics learning more engaging and fun for students, motivating them to explore and solve mathematical problems (Dunleavy et al., 2009; Estapa & Nadolny, 2015; Rahayuningsih et al., 2022).

By utilizing Augmented Reality (AR) learning media developed in android-based mobile phone technology (Suryanto et al., 2018; Susilo et al., 2021). The method used in the development of this system is the waterfall method (Munir & Wanti, 2022). With the development of this learning media can look more real and can make these students become more interested in learning math subjects (Astuti et al., 2019). AR can link mathematical concepts to real-world applications, helping students see the relevance of math in everyday life (Blum, 2015; Blum & Niss, 1991; Boaler, 1993; Gainsburg, 2008; Sari, 2020). For example, students can use AR to measure objects or solve practical problems (Jiang et al., 2021). It also can support the development of spatial reasoning skills by allowing students to manipulate 3D objects and explore geometric shapes in a tangible way (Baki et al., 2011; Del Cerro Velázquez & Méndez, 2021; Maharani et al., 2020). AR applications can adapt to individual students' learning needs, providing tailored feedback and challenges based on their performance, promoting personalized learning. AR can facilitate collaborative learning experiences, where students work together to solve math problems or explore mathematical concepts, promoting communication and teamwork (Handoyo et al., 2021; Yu et al., 2022). The integration of augmented reality into mathematics learning for elementary school students has the potential to enhance their understanding, engagement, and retention of mathematical concepts, ultimately preparing them for a more mathematically literate future.

5. Conclusion

Tremendous scientific and technological advancements have been reported in various fields of life.In the era of information technology and technological devices. In general, following the technology advancement, current teaching and learning practices can be categorized as conventional. The ability to understand materials is the main foundation of learning. For the selection of the research papers, we used the terms "augmented reality and mathematics" in the disbursement menu in the Scopus database. This section, divided into, details the results of this study. First, we describe the results of the document analysis, then we present the results in a visual form to illustrate the results. After four stages of screening eligible articles, a total of 22 articles were selected for inclusion in this systematic review. In the last phase, the review of existing articles was carried out, ensuring articles were in accordance with the research themes, accessible, and written in English. From this final stage, we obtained 22 research papers.

There are four studies using the target audience at the elementary school level (18%), while fourteen studies target secondary school students as the target audience (64%). Besides, 5 and 9 % of research target the senior high school level and tertiary level as the target audience. In the end, one research mentions no specific target audience (5%). Most of the research conducted in the field of science learning has employed a quantitative approach, accounting for 14 articles or 64% of the total. Additionally, there are a notable number of qualitative studies, totaling four articles (18%), while mixed-method research accounts for four articles as well (18%). The integration of augmented reality into mathematics learning for elementary school students has the potential to enhance their

understanding, engagement, and retention of mathematical concepts, ultimately preparing them for a more mathematically literate future.

Acknowledgments

The researchers gratefully acknowledge Universitas Negeri Malang for funding this research with contract number 5.4.441/UN32.20.1/LT/2023.

References

1. Al'Abri, K. (2011). The impact of globalization on education policy of developing countries: Oman as an example. *Literacy Information and Computer Education Journal*, *2*(4), 491–502.
2. Alam, A. (2021). Notice of Retraction: Designing XR into Higher Education using Immersive Learning Environments (ILEs) and Hybrid Education for Innovation in HEIs to attract UN's Education for Sustainable Development (ESD) Initiative. *2021 International Conference on Advances in Computing, Communication, and Control (ICAC3)*, 1–9.
3. Alamsyah, N., & Fauziyah, D. (2021). Implementation of Augmented Reality Learning Media Technology at the Primary and Secondary Education Levels in Cimahi City, West Java. *International Journal of Management Science and Information Technology*, *1*(2), 25–30.
4. Aldalalah, O., Ababneh, Z. W. M., Bawaneh, A. K., & Alzubi, W. M. M. (2019). Effect of Augmented Reality and Simulation on the Achievement of Mathematics and Visual Thinking Among Students. *International Journal of Emerging Technologies in Learning*, *14*(18), 164–185. https://doi.org/10.3991/ijet.v14i18.10748
5. Ali, D. F., Johari, N., & Ahmad, A. R. (2023). The effect of augmented reality mobile learning in microeconomic course. *International Journal of Evaluation and Research in Education*, *12*(2), 859–866. https://doi.org/10.11591/ijere.v12i2.24943
6. Alkhabra, Y. A., Ibrahem, U. M., & Alkhabra, S. A. (2023). Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program. *Humanities and Social Sciences Communications*, *10*(1), 1–10. https://doi.org/10.1057/s41599-023-01650-w
7. Alsunbul, A. (2002). Issues relating to distance education in the Arab world. *Convergence*, *35*(1), 59.
8. Angraini, L. M., Alzaber, Debby Permata Sari, & Ilham Muhammad. (2023). Augmented Reality: Improvement of Critical Thinking Based on Students' Initial Mathematical Ability. *Indonesian Journal of Teaching and Learning (INTEL)*, *2*(1), 137–152. https://doi.org/10.56855/intel.v2i1.176
9. Anwar, L., Sa'dijah, C., & Arnawa, I. M. (2023). Teachers' Perception of Teaching and Learning During to Post Covid-19 Pandemic Era: A Case of Indonesian Mathematics Teachers. *Journal of Higher Education Theory and Practice*, *23*(8), 18–29.
10. Astuti, D. P., Bhakti, Y. B., & Astuti, I. A. D. (2019). Developing Adobe Flash-based mathematics learning media for 7th-grade students of junior high school. *Journal of Physics: Conference Series*, *1188*(1), 12098.
11. Ausburn, L. J., & Ausburn, F. B. (2004). Desktop virtual reality: A powerful new technology for teaching and research in industrial teacher education. *Journal of Industrial Teacher Education*, *41*(4), 1–16.
12. Awang, K., Shamsuddin, S. N. W., Ismail, I., Rawi, N. A., & Amin, M. M. (2019). The usability analysis of using augmented reality for linus students. *Indonesian Journal of Electrical Engineering and Computer Science*, *13*(1), 58–64. https://doi.org/10.11591/ijeecs.v13.i1.pp58-64
13. Ayal, C. S., Kusuma, Y. S., Sabandar, J., & Dahlan, J. A. (2016). The Enhancement of Mathematical Reasoning Ability of Junior High School Students by Applying Mind Mapping Strategy. *Journal of Education and Practice*, *7*(25), 50–58.
14. Aziz, N., Ahmad, S. Z., Binsaleh, S., & Rahman, W. W. R. Z. W. A. (2023). Heuristic Evaluation on Affective 4-Dimensional Augmented Reality Mathematics for Children with Low Vision. *International Journal of Information and Education Technology*, *13*(2), 313–319. https://doi.org/10.18178/ijiet.2023.13.2.1809
15. Bagustari, B. A., & Santoso, H. B. (2019). Adaptive user interface of learning management systems for education 4.0: a research perspective. *Journal of Physics: Conference Series*, *1235*(1), 12033.
16. Baki, A., Kosa, T., & Guven, B. (2011). A comparative study of the effects of using dynamic geometry software and physical manipulatives on the spatial visualisation skills of pre-service mathematics teachers. *British Journal of Educational Technology*, *42*(2), 291–310.
17. Barak, M. (2013). Impacts of learning inventive problem-solving principles: Students' transition from systematic searching to heuristic problem solving. *Instructional Science*, *41*, 657–679.
18. Bedewy, S. El, Lavicza, Z., Haas, B., & Lieban, D. (2022). A STEAM Practice Approach to Integrate Architecture, Culture and History to Facilitate Mathematical Problem-Solving. *Education Sciences*, *12*(1). https://doi.org/10.3390/educsci12010009

19. Blum, W. (2015). Quality teaching of mathematical modelling: What do we know, what can we do? *The Proceedings of the 12th International Congress on Mathematical Education: Intellectual and Attitudinal Challenges*, 73–96.
20. Blum, W., & Niss, M. (1991). Applied mathematical problem solving, modelling, applications, and links to other subjects—State, trends and issues in mathematics instruction. *Educational Studies in Mathematics*, *22*(1), 37–68.
21. Boaler, J. (1993). The Role of Contexts in the Mathematics Classroom: Do they Make Mathematics More" Real"? *For the Learning of Mathematics*, *13*(2), 12–17.
22. Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. WW Norton & Company.
23. Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education*, *68*, 536–544.
24. Cabiria, J. (2012). Augmenting engagement: Augmented reality in education. In *Increasing student engagement and retention using immersive interfaces: Virtual worlds, gaming, and simulation* (pp. 225–251). Emerald Group Publishing Limited.
25. Cahyono, A. N., Sukestiyarno, Y. L., Asikin, M., Miftahudin, Ahsan, M. G. K., & Ludwig, M. (2020). Learning mathematical modelling with augmented reality mobile math trails program: How can it work? *Journal on Mathematics Education*, *11*(2), 181–192. https://doi.org/10.22342/jme.11.2.10729.181-192
26. Carrillo-Yañez, J., Climent, N., Montes, M., Contreras, L. C., Flores-Medrano, E., Escudero-Ávila, D., Vasco, D., Rojas, N., Flores, P., & Aguilar-González, Á. (2018). The mathematics teacher's specialised knowledge (MTSK) model. *Research in Mathematics Education*, *20*(3), 236–253.
27. Cevahir, H., Özdemir, M., & Baturay, M. H. (2022). The Effect of Animation-Based Worked Examples Supported with Augmented Reality on the Academic Achievement, Attitude and Motivation of Students towards Learning Programming. In *Participatory Educational Research* (Vol. 9, Issue 3, pp. 226–247). https://doi.org/10.17275/per.22.63.9.3
28. Chachil, K., Engkamat, A., Sarkawi, A., & Shuib, A. R. A. (2015). Interactive multimedia-based mobile application for learning Iban language (I-MMAPS for learning Iban language). *Procedia-Social and Behavioral Sciences*, *167*, 267–273.
29. Chao, W.-H., & Chang, R.-C. (2018). Using augmented reality to enhance and engage students in learning mathematics. *Advances in Social Sciences Research Journal*, *5*(12), 455–464.
30. Chen, P., Liu, X., Cheng, W., & Huang, R. (2017). A review of using Augmented Reality in Education from 2011 to 2016. *Innovations in Smart Learning*, 13–18.
31. Chen, S., Yang, S. J. H., & Hsiao, C. (2016). Exploring student perceptions, learning outcome and gender differences in a flipped mathematics course. *British Journal of Educational Technology*, *47*(6), 1096–1112.
32. Chen, Y. (2019). Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course. *Journal of Educational Computing Research*, *57*(7), 1695–1722.
33. Cocchia, A. (2014). Smart and digital city: A systematic literature review. *Smart City: How to Create Public and Economic Value with High Technology in Urban Space*, 13–43.
34. De Pace, F., Manuri, F., & Sanna, A. (2018). Augmented reality in industry 4.0. *Am. J. Comput. Sci. Inf. Technol*, *6*(1), 17.
35. Deichmann, U., Goyal, A., & Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *Agricultural Economics*, *47*(S1), 21–33.
36. Del Cerro Velázquez, F., & Méndez, G. M. (2021). Application in augmented reality for learning mathematical functions: A study for the development of spatial intelligence in secondary education students. *Mathematics*, *9*(4), 1–19. https://doi.org/10.3390/math9040369
37. Demitriadou, E., Stavroulia, K. E., & Lanitis, A. (2020). Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education. *Education and Information Technologies*, *25*(1), 381–401. https://doi.org/10.1007/s10639-019-09973-5
38. Dewi, P. Y. A., & Primayana, K. H. (2019). Effect of learning module with setting contextual teaching and learning to increase the understanding of concepts. *International Journal of Education and Learning*, *1*(1), 19–26.
39. Dieker, L., Hynes, M., Hughes, C., & Smith, E. (2008). Implications of mixed reality and simulation technologies on special education and teacher preparation. *Focus on Exceptional Children*, *40*(6), 1.
40. Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*, 7–22.
41. Durlach, P. J., & Spain, R. D. (2014). Framework for instructional technology: methods of implementing adaptive training and education. *Defense Technical Information Center*.
42. Elsayed, S. A., & Al-Najrani, H. I. (2021). Effectiveness of the Augmented Reality on Improving the Visual

Thinking in Mathematics and Academic Motivation for Middle School Students. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(8), 1–16. https://doi.org/10.29333/ejmste/11069
43. Estapa, A., & Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. *Journal of STEM Education*, *16*(3).
44. Farshid, M., Paschen, J., Eriksson, T., & Kietzmann, J. (2018). Go boldly!: Explore augmented reality (AR), virtual reality (VR), and mixed reality (MR) for business. *Business Horizons*, *61*(5), 657–663.
45. Febrianto, P. T., Mas'udah, S., & Megasari, L. A. (2020). Implementation of online learning during the covid-19 pandemic on Madura Island, Indonesia. *International Journal of Learning, Teaching and Educational Research*, *19*(8), 233–254.
46. Flores-Bascuñana, M., Diago, P. D., Villena-Taranilla, R., & Yáñez, D. F. (2020). On augmented reality for the learning of 3D-geometric contents: A preliminary exploratory study with 6-grade primary students. *Education Sciences*, *10*(1). https://doi.org/10.3390/educsci10010004
47. Gainsburg, J. (2008). Real-world connections in secondary mathematics teaching. *Journal of Mathematics Teacher Education*, *11*, 199–219.
48. Geng, J. (2013). Three-dimensional display technologies. *Advances in Optics and Photonics*, *5*(4), 456–535.
49. Gibbs, G. R. (2018). *Analyzing qualitative data* (Vol. 6). Sage.
50. Han, D.-I., tom Dieck, M. C., & Jung, T. (2018). User experience model for augmented reality applications in urban heritage tourism. *Journal of Heritage Tourism*, *13*(1), 46–61.
51. Handoyo, B., Astina, I. K., & Mkumbachi, R. L. (2021). Students' environmental awareness and pro-environmental behaviour: preliminary study of geography students at state university of malang. *IOP Conference Series: Earth and Environmental Science*, *683*(1), 12049.
52. Hanggara, Y., Sa'dijah, C., & Qohar, A. (2023). Theory and practice of constructive approaches in mathematics learning. *JCP (Jurnal Cahaya Pendidikan) Fakultas Keguruan Dan Ilmu Pendidikan*, *9*(1), 27–34.
53. Hayes, D. J. (2009). An examination of biorefining processes, catalysts and challenges. *Catalysis Today*, *145*(1–2), 138–151.
54. Höllerer, T., & Feiner, S. (2004). Mobile augmented reality. *Telegeoinformatics: Location-Based Computing and Services*, *21*, 221–260.
55. Hosokawa, R., & Katsura, T. (2018). Association between mobile technology use and child adjustment in early elementary school age. *PloS One*, *13*(7), e0199959.
56. Islam, R., Islam, R., & Mazumder, T. (2010). Mobile application and its global impact. *International Journal of Engineering & Technology*, *10*(6), 72–78.
57. Jiang, Y., Gong, T., Saldivia, L. E., Cayton-Hodges, G., & Agard, C. (2021). Using process data to understand problem-solving strategies and processes for drag-and-drop items in a large-scale mathematics assessment. *Large-Scale Assessments in Education*, *9*, 1–31.
58. Kazanidis, I., & Pellas, N. (2019). Developing and Assessing Augmented Reality Applications for Mathematics with Trainee Instructional Media Designers: An Exploratory Study on User Experience. *J. Univers. Comput. Sci.*, *25*(5), 489–514.
59. Khanna, A., & Tomar, R. (2016). IoT based interactive shopping ecosystem. *2016 2nd International Conference on next Generation Computing Technologies (NGCT)*, 40–45.
60. Kleisch, E., Sloan, A., & Melvin, E. (2017). Using a Faculty Training and Development Model to Prepare Faculty to Facilitate an Adaptive Learning Online Classroom Designed for Adult Learners. *Journal of Higher Education Theory & Practice*, *17*(7).
61. Korucu, A. T., & Alkan, A. (2011). Differences between m-learning (mobile learning) and e-learning, basic terminology and usage of m-learning in education. *Procedia-Social and Behavioral Sciences*, *15*, 1925–1930.
62. Kramarenko, T. H., Pylypenko, O. S., & Zaselskyi, V. (2019). *Prospects of using the augmented reality application in STEM-based Mathematics teaching*.
63. Kuratko, D. F. (2005). The emergence of entrepreneurship education: Development, trends, and challenges. *Entrepreneurship Theory and Practice*, *29*(5), 577–597.
64. Kurniati, E., Ibrohim, I., Suryadi, A., & Saefi, M. (2022). International scientific collaboration and research Topics on STEM education: A systematic review. *EURASIA Journal of Mathematics, Science and Technology Education*, *18*(4), em2095. https://doi.org/10.29333/ejmste/11903
65. Lazou, C., & Tsinakos, A. (2023). Critical Immersive-Triggered Literacy as a Key Component for Inclusive Digital Education. *Education Sciences*, *13*(7), 696.
66. Limperos, A. M., Buckner, M. M., Kaufmann, R., & Frisby, B. N. (2015). Online teaching and technological affordances: An experimental investigation into the impact of modality and clarity on perceived and actual learning. *Computers & Education*, *83*, 1–9.
67. Livingstone, S. (2012). Critical reflections on the benefits of ICT in education. *Oxford Review of Education*,

38(1), 9–24.
68. Lu, S.-Y., Shpitalni, M., & Gadh, R. (1999). Virtual and augmented reality technologies for product realization. *CIRP Annals*, *48*(2), 471–495.
69. Maharani, R., Marsigit, M., & Wijaya, A. (2020). Collaborative learning with scientific approach and multiple intelligence: Its impact toward math learning achievement. *The Journal of Educational Research*, *113*(4), 303–316.
70. Mailizar, & Johar, R. (2021). Examining students' intention to use augmented reality in a project-based geometry learning environment. *International Journal of Instruction*, *14*(2), 773–790. https://doi.org/10.29333/iji.2021.14243a
71. Majeed, B. H., & ALRikabi, H. T. S. (2022). Effect of Augmented Reality Technology on Spatial Intelligence among High School Students. *International Journal of Emerging Technologies in Learning*, *17*(24), 131–143. https://doi.org/10.3991/ijet.v17i24.35977
72. Majid, I., & Verma, S. (2021). Web 2.0 technological tools in teaching and learning. *Majid, I., & Verma, S.(2018). Web*, *2*, 55–60.
73. Marini, A., Nafisah, S., Sekaringtyas, T., Safitri, D., Lestari, I., Suntari, Y., Sudrajat, A., & Iskandar, R. (2022). Mobile augmented reality learning media with Metaverse to improve student learning outcomes in science class. *International Journal of Interactive Mobile Technologies*, *16*(7).
74. Marsitin, R., Sa'dijah, C., Susiswo, S., & Chandra, T. D. (2022). Creative Mathematical Reasoning Process of Climber Students in Solving Higher Order Thinking Skills Geometry Problems. *TEM Journal*, *11*(4).
75. Maxwell, I. E. (1987). Zeolite catalysis in hydroprocessing technology. *Catalysis Today*, *1*(4), 385–413.
76. McInnes, M. D. F., Moher, D., Thombs, B. D., McGrath, T. A., Bossuyt, P. M., Clifford, T., Cohen, J. F., Deeks, J. J., Gatsonis, C., & Hooft, L. (2018). Preferred reporting items for a systematic review and meta-analysis of diagnostic test accuracy studies: the PRISMA-DTA statement. *Jama*, *319*(4), 388–396.
77. Molnár, G., & Benedek, A. (2015). Three Dimensional Applications in Teaching and Learning Processes. *Procedia-Social and Behavioral Sciences*, *191*, 2667–2673.
78. Monino, J.-L., & Sedkaoui, S. (2016). *Big data, open data and data development* (Vol. 3). John Wiley & Sons.
79. Munir, F. S., & Wanti, P. (2022). Development of English Learning Media for Elementary School Students Assisted Augmented Reality Technology Based Android. *Edumaspul: Jurnal Pendidikan*, *6*(2), 1839–1849.
80. Nee, A. Y. C., & Ong, S.-K. (2013). Virtual and augmented reality applications in manufacturing. *IFAC Proceedings Volumes*, *46*(9), 15–26.
81. Nevarini, M., Agustiani, R., & Zahra, A. (2023). Application of Augmented Reality in Geometry Learning in Increasing Student Learning Motivation. *Journal of Curriculum and Pedagogic Studies (JCPS)*, *2*(1), 40–50.
82. Ozcakir, B., & Cakiroglu, E. (2021). An augmented reality learning toolkit for fostering spatial ability in mathematics lesson: Design and development. *European Journal of Science and Mathematics Education*, *9*(4), 145–167. https://doi.org/10.30935/SCIMATH/11204
83. Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *Bmj*, *372*.
84. Patrignani, C., Agashe, K., Aielli, G., Amsler, C., Antonelli, M., Asner, D. M., Baer, H., Banerjee, S., Barnett, R. M., & Basaglia, T. (2016). *Review of particle physics*.
85. Poçan, S., Altay, B., & Yaşaroğlu, C. (2023). The Effects of Mobile Technology on Learning Performance and Motivation in Mathematics Education. *Education and Information Technologies*, *28*(1), 683–712. https://doi.org/10.1007/s10639-022-11166-6
86. Pozo-Sánchez, S., Lopez-Belmonte, J., Moreno-Guerrero, A. J., & Fuentes-Cabrera, A. (2021). Effectiveness of flipped learning and augmented reality in the new educational normality of the Covid-19 era. *Texto Livre*, *14*(2), 1–17. https://doi.org/10.35699/1983-3652.2021.34260
87. Pujiastuti, H., & Haryadi, R. (2023). Enhancing mathematical literacy ability through guided inquiry learning with augmented reality. *Journal of Education and E-Learning Research*, *10*(1), 43–50. https://doi.org/10.20448/jeelr.v10i1.4338
88. Qureshi, I. A., Ilyas, K., Yasmin, R., & Whitty, M. (2012). Challenges of implementing e-learning in a Pakistani university. *Knowledge Management & E-Learning*, *4*(3), 310.
89. Rahayuningsih, S., Sa'dijah, C., Sukoriyanto, S., & Qohar, A. (2022). Exploring students' understanding layers in solving arithmagon problems. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan*, *41*(1), 170–185.
90. Rahmawati, A. N. L., Sa'dijah, C., & Anwar, L. (2022). High School Students' Ability with Translation Among Mathematical Representations in Solving the HOTS-Based Problems. *Jurnal Pendidikan MIPA*, *23*(4), 1887–1899.
91. Rhea & Bauml, 2018. (2020). *education sciences Active Learning Augmented Reality for STEAM Education*

— *A Case Study*. 1–15.
92. Sa'dijah, C., Purnomo, H., Abdullah, A. H., Permadi, H., Anwar, L., Cahyowati, E. T. D., & Sa'diyah, M. (2023). Students' numeracy skills in solving numeracy tasks: Analysis of students of junior high schools. *AIP Conference Proceedings*, *2569*(1).
93. Saad, W., Bennis, M., & Chen, M. (2019). A vision of 6G wireless systems: Applications, trends, technologies, and open research problems. *IEEE Network*, *34*(3), 134–142.
94. Safar, A. H., Al-Jafar, A. A., & Al-Yousefi, Z. H. (2016). The effectiveness of using augmented reality apps in teaching the English alphabet to kindergarten children: A case study in the State of Kuwait. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2), 417–440.
95. Sandoval-Almazan, R., & Gil-Garcia, J. R. (2014). Towards cyberactivism 2.0? Understanding the use of social media and other information technologies for political activism and social movements. *Government Information Quarterly*, *31*(3), 365–378.
96. Santos, W. M. dos, Secoli, S. R., & Püschel, V. A. de A. (2018). The Joanna Briggs Institute approach for systematic reviews. *Revista Latino-Americana de Enfermagem*, *26*, e3074.
97. Sari, E. P. (2020). CORE (Connecting, Organizing, Reflecting & Extending) learning model to improve the ability of mathematical connections. *Journal of Physics: Conference Series*, *1581*(1), 12028.
98. Schindelin, J., Rueden, C. T., Hiner, M. C., & Eliceiri, K. W. (2015). The ImageJ ecosystem: An open platform for biomedical image analysis. *Molecular Reproduction and Development*, *82*(7–8), 518–529.
99. Setyosari, P., Kuswandi, D., & Ulfa, S. (2023). Creative Problem Solving Process Instructional Design in the Context of Blended Learning in Higher Education. *Electronic Journal of E-Learning*, *21*(2), 80–97.
100. Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*(July), 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039
101. Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59–68.
102. Stojšić, I., Ivkov-Džigurski, A., Maričić, O., Stanisavljević, J., Milanković Jovanov, J., & Višnić, T. (2020). Students' attitudes toward the application of mobile augmented reality in higher education. *Drustvena Istrazivanja*, *29*(4), 535–554. https://doi.org/10.5559/di.29.4.02
103. Sulistiani, I. R., Setyosari, P., Sa'dijah, C., & Praherdhiono, H. (2023). Technology integration through acceptance of e-learning among preservice teachers. *Indonesian Journal of Electrical Engineering and Computer Science*, *31*(3), 1821–1828. https://doi.org/10.11591/ijeecs.v31.i3.pp1821-1828
104. Suryanto, A., Kusumawati, D. A., & Sanhoury, I. M. H. (2018). Development of augmented reality technology based learning media of lathe machines. *Jurnal Pendidikan Teknologi Dan Kejuruan*, *24*(1), 32–38.
105. Susilo, A., Hardyanto, W., Martuti, N. K. T., & Purwinarko, A. (2021). Mobile learning development using augmented reality as a biology learning media. *Journal of Physics: Conference Series*, *1918*(4), 42013.
106. Syatriana, E., & Sakkir, G. (2020). Implementing learning model based on interactive learning community for EFL students of Muhammadiyah University. *ELT Worldwide: Journal of English Language Teaching*, *7*(1), 24–30.
107. Tatto, M. T. (2013). *The Teacher Education and Development Study in Mathematics (TEDS-M): Policy, Practice, and Readiness to Teach Primary and Secondary Mathematics in 17 Countries. Technical Report.* ERIC.
108. Utami, D. D., Setyosari, P., Fajarianto, O., Kamdi, W., & Ulfa, S. (2023). The Correlation Between Metacognitive and Problem Solving Skills among Science Students. *EduLine: Journal of Education and Learning Innovation*, *3*(1), 138–143.
109. Utami, N. A., Sa'dijah, C., & Chandra, T. D. (2023). Students' Mathematical Representation in Solving Exponential Function. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, *12*(1), 450–458.
110. van Eck, N. J., & Waltman, L. (2022). *Crossref as a source of open bibliographic metadata*.
111. Wahyuni, P. (2019). The effect of cooperative learning type student teams achievement division (STAD) on understanding mathematical concepts in class VIII students of MTs N Pekanbaru. *International Journal of Trends in Mathematics Education Research*, *2*(4), 168–172.
112. Wainman, B., Wolak, L., Pukas, G., Zheng, E., & Norman, G. R. (2018). The superiority of three-dimensional physical models to two-dimensional computer presentations in anatomy learning. *Medical Education*, *52*(11), 1138–1146.
113. Wang, Y., Li, J., Zhao, X., Feng, G., & Luo, X. (2020). Using mobile phone data for emergency management: a systematic literature review. *Information Systems Frontiers*, *22*, 1539–1559.
114. West, D. (2012). How mobile devices are transforming healthcare. *Issues in Technology Innovation*, *18*(1), 1–11.
115. Wiliyanto, D. A., Gunarhadi, G., Anggarani, F. K., Yusuf, M., & Subagya, S. (2022). Development of augmented reality-based learning models for students with specific learning disabilities. *Cypriot Journal of*

Educational Sciences, *17*(8), 2915–2926. https://doi.org/10.18844/cjes.v17i8.7845
116. Winter, R. (2022). *I am a mathematician…*.
117. Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49.
118. Wuryaningrum, R., Suyitno, I., Suyono, S., & Sunaryo, S. (2017). *Efferent-Aesthetic Reading in Reading across Curricula (An Implementation at Living Environment Education in Islamic Elementary School As-Salam, Malang, Indonesia)*.
119. Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, *39*(1), 93–112. https://doi.org/10.1177/0739456X17723971
120. Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education (TOCE)*, *14*(1), 1–16.
121. Yaniawati, P., Sudirman, Mellawaty, Indrawan, R., & Mubarika, M. P. (2023). the Potential of Mobile Augmented Reality As a Didactic and Pedagogical Source in Learning Geometry 3D. *Journal of Technology and Science Education*, *13*(1), 4–22. https://doi.org/10.3926/jotse.1661
122. Yaqoob, I., Ahmed, E., Hashem, I. A. T., Ahmed, A. I. A., Gani, A., Imran, M., & Guizani, M. (2017). Internet of things architecture: Recent advances, taxonomy, requirements, and open challenges. *IEEE Wireless Communications*, *24*(3), 10–16.
123. Yu, M. V. B., Liu, Y., Hsieh, T., Lee, G., Simpkins, S. D., & Pantano, A. (2022). "Working together as a team really gets them fired up": Afterschool program mentoring strategies to promote collaborative learning among adolescent participants. *Applied Developmental Science*, *26*(2), 347–361.