UNP JOURNAL MANAGEMENT CENTER

math.ppj.unp.ac.id
p-ISSN 2716-0726
e–ISSN 2716-0734

Indexed

The Existence of Augmented Reality in Mathematics Learning: A Systematic Literature Review

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Article History
Vol 3, No. 2, 2024

Subject Areas:
Mathematics Education

Keywords:
Augmented Reality, Systematic Review, Mathematics Education

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Abstract- Augmented reality (A.R.) represents cutting-edge technology bridging digital information with the real world. In the context of learning, particularly concerning augmented reality, researchers, educators, and practitioners face the imperative of adapting to the challenges posed by this digital era. This systematic literature review aims to comprehensively explore and contrast multiple articles indexed in the Scopus Database, focusing on the intersection of mathematics education and Augmented Reality. The analysis underscores that A.R. presents a promising tool for heightening engagement and comprehension of mathematical concepts, particularly emphasized in elementary education and centered around matrices/geometry topics. The outcomes carry substantial implications for educators, advocating for the incorporation of A.R. as an innovative teaching method in mathematics and policymakers, signaling the necessity to foster the integration of A.R. technology in educational settings. Furthermore, this study's implications offer valuable direction for future research endeavors, suggesting the need for a more comprehensive exploration of specific facets of using A.R. in mathematics education.

1. Introduction

Augmented reality (A.R.) represents the latest technology that integrates digital information with the natural world (Castañeda et al., 2018; Hussein, 2022). According to (Hsiao & Chang, 2016), A.R. goes beyond merging the virtual and real worlds by adding virtual elements like images, videos, and three-dimensional objects into the physical environment. Additionally, (Dutta et al., 2022) define Augmented Reality as a tool facilitating interactive viewing of 3D virtual objects within the real world. A.R. has emerged as a significant trend among application developers, offering users enhanced insights into the physical environment (Alamäki et al., 2021; Borgohain et al., 2022; Chen et al., 2019; Sungkur et al., 2016).

Its increasing use in education is evident (Hanid et al., 2020; Hedenqvist et al., 2021; Medina & Ferrer,

RANGKIANG MATHEMATICS JOURNAL
Journal of Mathematics and Mathematics Education

2022). Research (Garrett et al., 2015; Li & Liu, 2022; Lorenzo et al., 2022) suggests that integrating Augmented Reality in learning environments enhances classroom teaching and mobile learning effectiveness.

Integrating A.R. into education offers numerous advantages (Almenara & Vila, 2019; Patzer et al., 2014). As highlighted by (Santos et al., 2016), the benefits encompass increased student attention and satisfaction with the learning experience. Moreover, studies (Hanid et al., 2022) indicate that Augmented Reality enhances students' computational thinking, visualization skills, and academic achievement. It also fosters collaborative discussions among students, encouraging them to engage and deliberate on conceptual topics together (Sarkar et al., 2020).

Researchers, educators, and practitioners, particularly those engaged in learning utilizing technologies like augmented reality, must remain responsive to the challenges posed by education in the digital era. The recent surge in research interest in Augmented Reality is primarily attributed to the increased accessibility provided by mobile devices, making Augmented Reality more accessible, cost-effective, and efficient than in previous times (Dutta et al., 2022). Researchers are predominantly focused on original publications examining the integration of augmented reality media within mathematics learning. There's a pressing need for studies that explore the implementation of education and learning using technology. Research on the theme of augmented reality in learning is essential to explore the diverse applications of existing technologies (Adnan et al., 2022; Arici et al., 2019; Ariff et al., 2021; Maulana et al., 2021; Moreno Guerrero et al., 2021; Nordin et al., 2022; Yusuf et al., 2019), which notably contribute to enhancing students' grasp of mathematical concepts (Cai et al., 2021; Hirve et al., 2022; Lamounier et al., 2010; S et al., 2022; Sudirman et al., 2020; Wang et al., 2022; Widiasih et al., 2022).

Given the search results from Scopus, a more profound and comprehensive study is warranted. Delving into these publications is imperative to extract valuable insights concerning the integration of augmented reality in mathematics learning and discerning the current publication trends across various categories. One recommended analysis approach is conducting a systematic literature review (S.L.R.). Previous publications highlight analyzing categories like distribution year, research type/method, authorship and keywords, author nationality, international collaborations, and funding (Muhammad et al., 2024).

S.L.R. is a meticulous and transparent review method that involves identifying, synthesizing, and evaluating all available quantitative, qualitative, or both evidence to provide accurate insights (Mallett et al., 2012). S.L.R. offers several advantages to researchers, notably in presenting a comprehensive and clear understanding of the evidence available in databases about researchers' areas of interest. Additionally, S.L.R. aids in identifying research gaps, methodological challenges, and areas necessitating further exploration, fostering new research ideas, and critically synthesizing various references obtained.

Research Problem

In the Scopus Database, we identified three systematic literature review (S.L.R.) articles written in English that center around augmented reality in mathematics education. These S.L.R. articles specifically delve into the impact of Augmented Reality within Mathematics Education (Pahmi et al., 2023), the application of augmented reality to foster mathematical creativity (Hidajat, 2023), and the utilization of Augmented Reality Learning within Mathematics Education (Jabar et al., 2022). All these S.L.R. studies revolve around augmented reality media integration in mathematics education. Pahmi et al. (2023) emphasize the necessity for research on A.R. to extensively explore its widespread usage and enduring effects on mathematics learning. On the other hand, Jabar et al.'s S.L.R. (2022) concentrates solely on the secondary school level and above, setting it apart from this research, which extends its focus across all levels of education rather than targeting a specific level. In contrast, the S.L.R. conducted by Hidajat (2023) is restricted in its scope, primarily examining A.R. applications solely for fostering creativity. Therefore, it can be concluded that no S.L.R. exists that comprehensively examines various facets related to integrating augmented reality media in mathematics learning.

Research objectives

This Systematic Literature Review (S.L.R.) aims to thoroughly analyze and juxtapose a range of research articles sourced from Scopus Database journals. These articles specifically mention the correlation between learning mathematics and the integration of Augmented Reality (A.R.). This S.L.R. intends to substantially contribute to the advancement of A.R. studies, serving as a crucial resource for both researchers and readers focused on mathematics education. We emphasize publishing original articles exploring the intersection of learning mathematics utilizing augmented reality, a unique endeavor that

other researchers haven't previously undertaken. This endeavor aims to establish a foundational research framework while laying the groundwork for addressing and anticipating potential challenges in the education landscape. By examining original research articles exclusively, we aim to provide a comprehensive overview of researchers' focal points and alignment concerning this theme. Our comprehensive overview of the presence and impact of augmented reality in learning is anticipated to serve as a valuable reference for policymakers, practitioners, educators, and the wider community engaged in education and learning.

2. Methods

Research Framework

This study represents a Systematic Literature Review (S.L.R.), aiming to discover, assess, and thoroughly examine various articles available to address specific research inquiries and scrutinize them extensively (Snyder, 2019; Xiao & Watson, 2019). Through a meticulous and deliberate process, the S.L.R. method assists in delivering a concise summary of the scientific subjects discussed by methodically and transparently addressing the research questions.

Research Question

Establishing research questions serves to delineate the extent and concentrate on specific research objectives. These inquiries are formulated in alignment with the requisites of the selected topic, namely:
RQ1: What are the publication patterns concerning "augmented reality in mathematics learning" within journals indexed in the Scopus Database? Criteria for Article Search and Inclusion.
RQ2: What descriptions are provided regarding incorporating augmented reality into mathematics learning?

Article Search and Inclusion Criteria

The Scopus Database search used "augmented reality in learning mathematics." This systematic literature review (S.L.R.) aims to locate, assess, and thoroughly examine numerous articles to address the research query meticulously and rigorously (Snyder, 2019; Xiao & Watson, 2019). The S.L.R. method offers a concise overview of scientific topics by systematically and transparently answering research inquiries (Kurniati et al., 2022). Data collected were stored in CSV and R.I.S. formats, synchronized into Mendeley, P.O.P. (Publish or Perish), and VOSviewer.

VOSviewer software was employed to present the data visually, enhancing the information's communication, engagement, and clarity. The search history in Scopus involved the query: (TITLE-ABS-KEY ("augmented reality") AND TITLE-ABS-KEY ("mathematics learning" OR "mathematics education")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (O.A., "all")) AND (LIMIT-TO (LANGUAGE, "English")). Using these search terms (conducted in November 2023), 14,755 articles were found out of 47,613 augmented reality-themed articles. The Preferred Reporting Model for Systematic Reviews and Meta-Analyses (PRISMA), referencing Muhammad et al. (2024) and previously published S.L.R.s (Moher et al., 2009), was utilized for the inclusion and exclusion criteria to identify relevant articles. The inclusion criteria included (1) open-access articles only, (2) original research articles, (3) articles of the document type, and (4) publications in English related explicitly to the research topic "augmented reality in mathematics learning."

The inclusion and exclusion process is outlined in Figure 1. Initially, the search yielded 14,755 articles classified as articles. Subsequently, the focus narrowed to publications linked explicitly to "augmented reality in learning mathematics," resulting in 41 relevant articles. After applying the open-access article criterion, 24 articles fulfilled this requirement, indicating 17 documents were excluded. The inclusion was further refined to original articles, excluding literature review documents, resulting in 21 articles meeting this criterion, while three papers were excluded. The subsequent criterion applied was English language inclusion, resulting in a final count of 20 articles that met all the requirements, indicating one document was excluded during this stage of selection by the author. The inclusion and exclusion criteria can be seen in Figure 1.

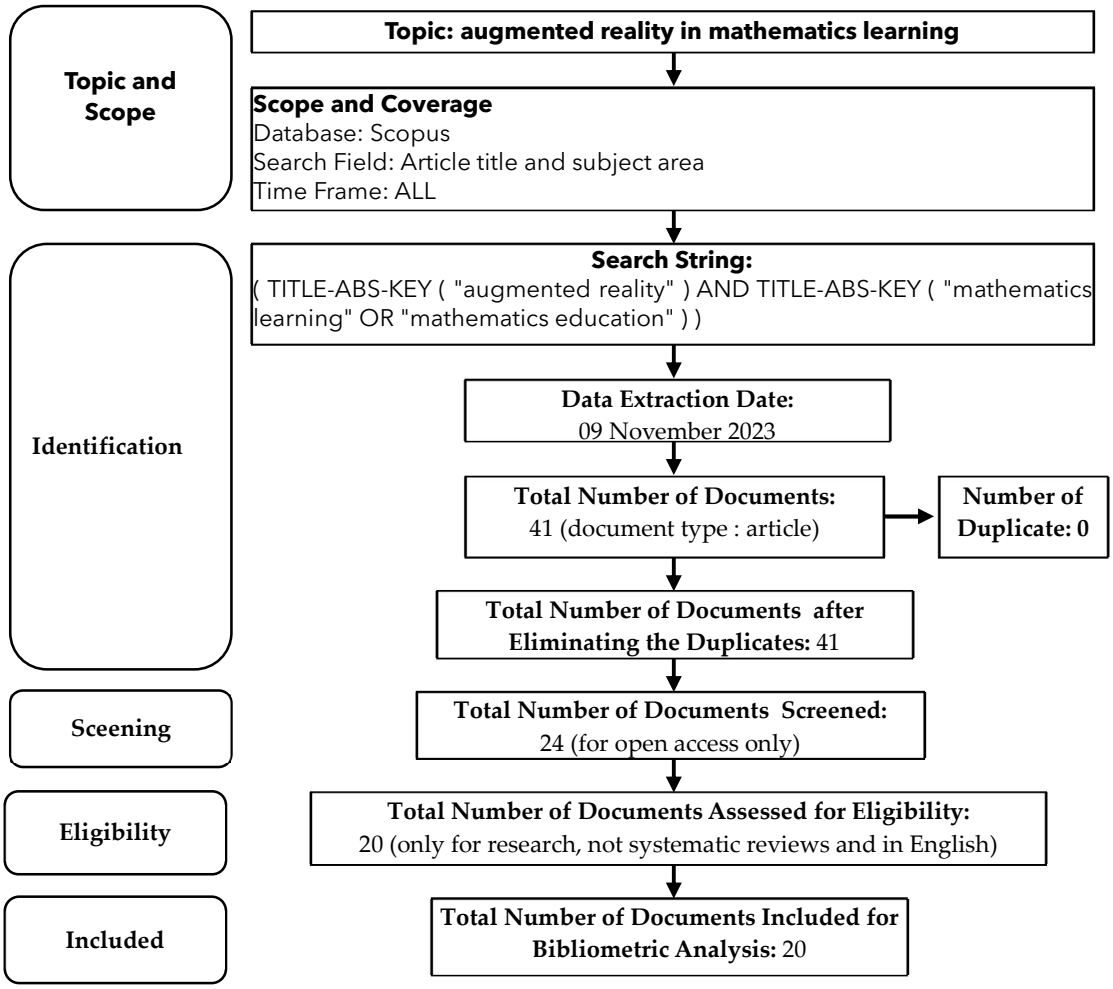

Figure 1. Inclusion and Exclusion Criteria

The author excluded articles related to unsuitable subject areas and deliberately omitted Turkish articles due to the author's inability to understand the language, avoiding potential misinterpretations. Instead of using Google Translate or professional translation services, the authors aimed to prevent translation errors and associated costs, aligning with Morrison et al.'s (2012) suggestion that such restrictions don't introduce bias effects. In the final stage, the authors carefully reviewed articles to ensure relevance to the discussed themes, accessibility of entire texts, and adherence to English publication. As a result, only 20 articles met the established criteria, while 21 were excluded for not meeting these criteria.

3. Results and Discussion

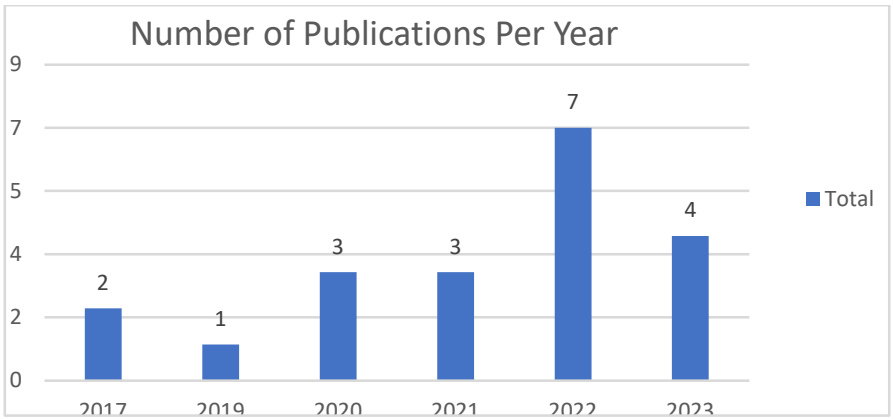

Figure 2. Publication Trends

Figure 2 illustrates the yearly distribution of articles related to augmented reality from 2017 to 2023. A noticeable increase in publications focusing on augmented reality between 2019 and 2022. Although the count in 2021 matches that of 2020, with three articles each, it's plausible that this theme will continue to expand, given the search's cutoff in early November 2023.
With two more months left in 2023, there's a likelihood that the article count might rise if tracked until December 2023's end. Therefore, augmented reality research has garnered significant interest among researchers, reflecting the urgency experts attach to it. This heightened interest might also align with society's acknowledgment of technology's importance in daily life. The trend indicates a rise in publications about augmented reality in mathematics learning. Even though the number of 2023 publications slightly dropped from 2022, consisting of four articles, it's essential to note that the 2023 publication process is ongoing. Hence, it's plausible that the count for "augmented reality in learning mathematics" in 2023 will increase, considering numerous articles yet to be added to the Scopus Database.

Table 1. Type of research

Number	Type of research	References
1	Qualitative	(Bagossi et al., 2022; Cai et al., 2019; Cascales-Martínez, 2017; El Bedewy et al., 2021; Haas et al., 2023; Lindner et al., 2022; Pombo & Marques, 2021; Schutera et al., 2021)
2	Quantitative	(Amir et al., 2020; Demitriadou et al., 2020; Gün & Atasoy, 2017; Ozcakir, 2021; Poçan et al., 2023; Wangid et al., 2020)
3	Mix Method	(Ahmad et al., 2023; Izza et al., 2022; Zuo et al., 2022)

Table 1 outlines the research trends concerning Augmented Reality (A.R.) in mathematics learning. The predominant method utilized in research related to A.R. in mathematics learning is qualitative, accounting for eight articles. Concurrently, a substantial representation of quantitative research comprises six articles. This indicates a balanced exploration of A.R.'s implementation in learning mathematics, accommodating both descriptive, interpretative, and exploratory aspects (qualitative) and analytical and statistical evaluation of A.R.'s impact, effectiveness, or learning outcomes (quantitative).
A notable aspect is the interest in employing mixed methods, evidenced by three articles integrating qualitative and quantitative approaches. This inclination signifies an effort to amalgamate the strengths of both methodologies, offering researchers a more comprehensive understanding of A.R.'s influence on mathematics learning. Hence, it is apparent that research concerning A.R. in mathematics learning embraces diverse research methods, encompassing qualitative, quantitative, and mixed approaches, portraying the multifaceted nature of investigating A.R.'s usage in mathematical learning contexts. The number of documents by school level can be seen in figure number 3.

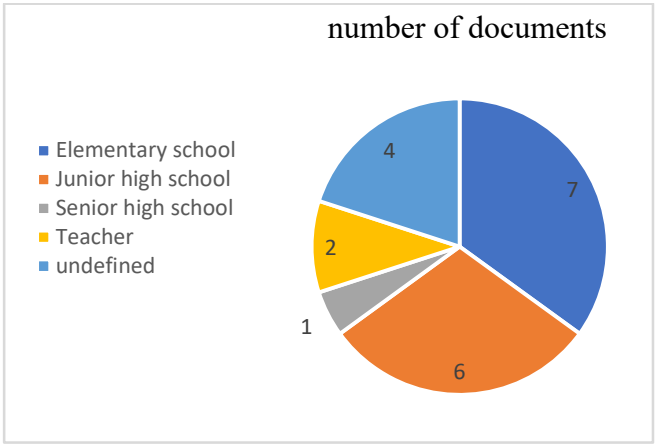

Figure 3. Number of documents by school level

The distribution of documents concerning Augmented Reality (A.R.) research in mathematics education reveals a predominant focus on the elementary school level, with seven articles, followed by six articles

pertaining to the junior high school level. This emphasis on elementary education indicates a heightened interest and research inclination, likely attributed to its perceived unique educational requirements and the potential for more effective utilization of A.R. in teaching mathematics at this stage. Additionally, the substantial attention directed towards junior high school-level research, depicted by 6 articles, signifies a noteworthy exploration of A.R.'s role in mathematics education at this intermediate educational level. The distinctions in learning methodologies or student characteristics potentially influence the research interest and focus across these educational tiers.

The article's distribution across school levels highlights the burgeoning interest in exploring A.R.'s integration into mathematics education across various educational tiers. However, the research concentration at the primary and junior high school levels suggests a more substantial potential for A.R. implementation in mathematics education within the early stages of education.

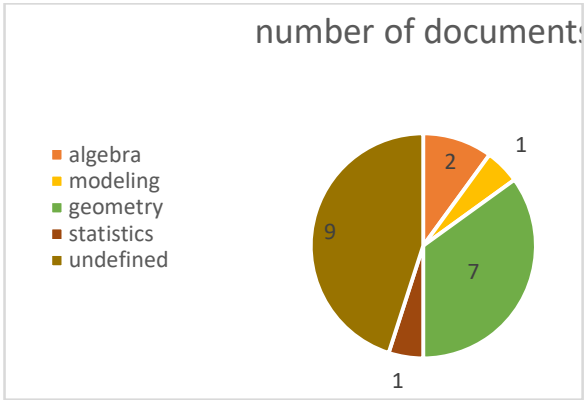

Figure 4. Number of articles based on learning materials

According to Figure 4, augmented reality's application in mathematics education predominantly centers on geometry, with seven articles focusing on this area. There are two articles exploring algebra and 1 article delving into statistics. Notably, nine articles didn't specify the material taught with A.R. In essence, the research on Augmented Reality (A.R.) in mathematics education predominantly delves into integrating A.R. into geometry and matrix-based learning. This emphasis on geometry and matrices signifies considerable attention and exploration within these mathematical domains. While fewer articles focus on algebra and statistics, they still illustrate the diversity in math subjects explored using A.R.

The absence of specific material in 9 articles might suggest a more generalized approach to A.R.'s application in mathematics education, encompassing various subjects without particular delineation. Overall, the research distribution indicates a stronger inclination toward applying A.R., specifically in the context of geometry and matrices within mathematics education. Network visualization can be seen in figure number 5.

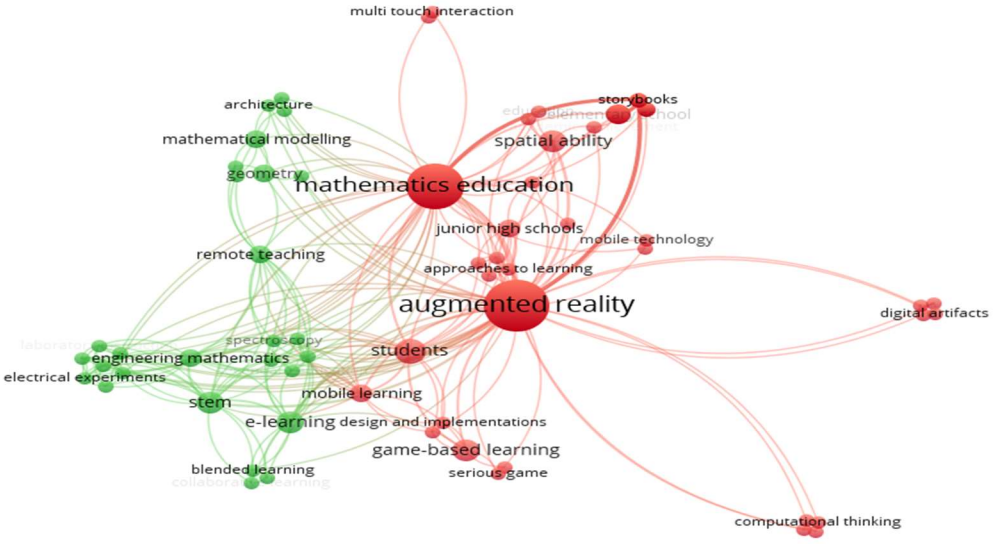

Figure 5. Network visualization

The keywords "augmented reality" and "mathematics education" stand out with the most prominent circles, signifying their central focus in this research. Keywords like spatial ability, game-based learning, student, and e-learning also exhibit prominent circles. Spatial ability emerges as a significant variable, corroborated by Table 2. "Game-based learning" suggests enhancing math learning through interactive gaming approaches. The inclusion of "student" implies a focus on students' learning experiences and their responses to augmented reality in math education.

Furthermore, "e-learning" signifies integrating digital technology into online learning, implying that augmented reality might be integrated into an online learning platform or module. Overall, these emphasized keywords showcase a comprehensive approach, considering the correlation between augmented reality and math education and aspects like spatial ability, game-based methodologies, student experiences, and e-learning within the context of using augmented reality for mathematics learning. This holistic approach aims to better understand the impact and potential of augmented reality in mathematics education.

Table 2. Variables of concern to researchers related to A.R. in mathematics learning

Number	Variables	Number of articles
1	Mathematical Understanding	4
2	Spatial Ability	3
3	Interest and Motivation	3
4	Anxiety	1
5	Problem solving	1
6	Computational Thinking	1

Table 2 emphasizes three critical areas of concern within augmented reality research in mathematics learning. First and foremost, four articles highlight a strong focus on mathematical understanding, examining how the integration of A.R. can impact and enhance students' comprehension of mathematics. This emphasis reflects a desire to assess the potential of A.R. in aiding students' achievement of mathematical learning objectives. Additionally, researchers express interest in motivation and engagement, which is evident from three articles exploring this aspect. This suggests that A.R. research in mathematics education doesn't solely prioritize academic outcomes but also delves into psychological factors such as student motivation.

Another focal point is spatial ability, a subject addressed in three articles. This indicates an interest in comprehending how A.R. application might influence students' spatial skills within the context of mathematical learning. Spatial ability is recognized as vital for grasping certain mathematical concepts, and A.R. is perceived as a potential tool to augment this capacity (Angraini et al., 2023). In summary, the primary research focus within A.R. implementation in mathematics learning centers on three core areas: mathematical understanding, motivation, and spatial ability. This diversity underscores researchers' efforts to comprehend A.R.'s impact beyond learning outcomes, considering psychological and cognitive aspects crucial to student learning.

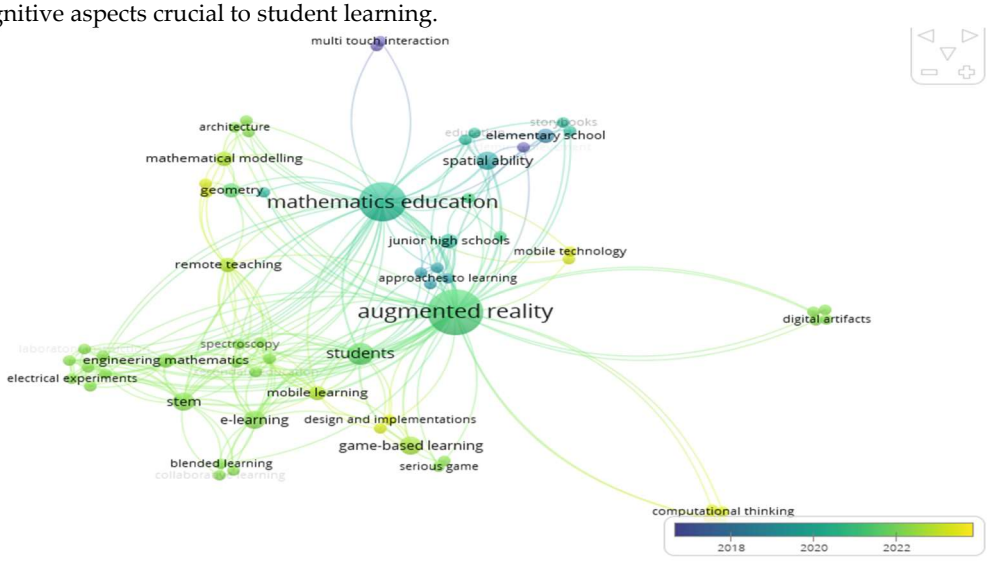

Figure 6. Overlay visualization

The visualization in Figure 6 highlights emerging themes in augmented reality research within mathematics learning, denoted by the yellow-colored circles representing new focus areas. These new themes encompass mobile technology, remote teaching, and learning experiences. Firstly, the keyword "mobile technology" signifies an interest in employing mobile devices for mathematics learning via A.R. applications, enabling flexible and mobile-based learning experiences."Remote teaching" reflects a growing interest in leveraging A.R. for mathematics education in remote or online settings responding to the increasing trend of distance learning. This indicates A.R.'s potential to enhance student engagement and interactivity in remote learning environments.

"Mobile learning" emphasizes using A.R. within math education accessible through mobile devices like tablets or smartphones, aiming to integrate A.R. into math learning experiences conveniently accessible via mobile platforms. Lastly, "learning experience" encompasses research investigating how A.R. impacts students' overall learning encounters in mathematics, exploring elements like interactivity, visual appeal, and student engagement during math learning with A.R. These evolving themes underscore the adaptation of augmented reality research in mathematics education to meet technological advancements and modern educational needs, mainly focusing on mobility, remote learning, and optimizing learning experiences.

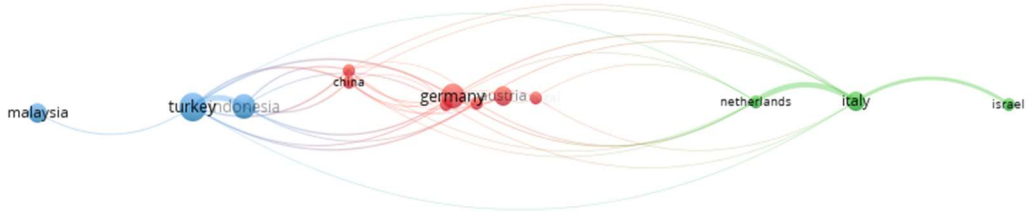

Figure 7. Country Collaboration

Figure 7 displays 13 countries that have contributed articles related to augmented reality in mathematics learning, where the circle sizes correspond to the number of published documents from each country. Germany and Turkey stand out as the top contributors to publishing articles concerning augmented reality in mathematics learning. The larger circle sizes for these countries highlight their substantial involvement and significant contributions to academic literature in this field. This likely signifies a heightened interest, active research endeavors, or practical augmented reality applications within mathematics education in Germany and Turkey. The varying circle sizes for other countries offer insights into their respective levels of engagement and contribution toward exploring the potential of augmented reality as a tool for learning mathematics. Overall, this distribution underscores the global presence of research and interest in utilizing augmented reality within mathematics education, with Germany and Turkey leading in generating related literature.

Research shows that using Augmented Reality in mathematics learning has significant potential in improving students' conceptual understanding. A study by Mustaqim (2017) and Sidik & Vivianti (2021) showed that students who used A.R. to learn wave concepts showed a better increase in understanding compared to the control group. This is in line with the findings of Borman & Ansori (2017) and Setyawan et al. (2019), who stated that A.R. can present information visually and interactively, making it easier for students to understand abstract concepts.

A.R. interactivity allows students to participate in the learning process actively, provides real-time feedback, and creates a more enjoyable learning experience (Arifitama, 2017). Hardiyanti et al.(2020) further explain that A.R. can help students connect theoretical knowledge with real-world contexts, improving memory and understanding.

Research by Hendriyani et al. (2019) and Sirakaya (2018) also highlighted A.R.'s ability to visualize complex mathematical concepts, making it easier for students to understand the structure and relationships between concepts. Yanuarto & Iqbal (2022) added that A.R. can bridge the gap between theory and practice, creating a richer and more meaningful learning experience. A more comprehensive literature review by Sirumapea et al. (2017) and Wardani (2015) shows that implementing A.R. in education is consistently associated with improved academic performance, motivation, student engagement, and positive attitudes toward learning.

Research Implications

The research holds significant implications within mathematics education, particularly for educational

practitioners, policymakers, and future research endeavors. The findings underscore the potential benefits of integrating Augmented Reality (A.R.) technology in improving students' grasp of mathematical concepts. Hence, educators might consider incorporating A.R. into their teaching methodologies as an innovative tool to enhance student engagement and comprehension of mathematical principles. Utilizing AR in education could also create a more enjoyable and captivating learning atmosphere, potentially fostering increased student enthusiasm and participation in the learning process.

Secondly, for practitioners, this study sheds light on pivotal factors like mathematical comprehension, student motivation, and spatial ability. These insights could serve as guiding principles for designing educational programs that leverage A.R., considering psychological and cognitive elements that influence student learning outcomes.

Thirdly, concerning policymakers, the findings advocate investing in and supporting the advancement of A.R. technology within mathematics education to impact educational quality positively. Accordingly, educational policies could bolster technological infrastructure conducive to A.R. application across different education levels. Additionally, allocating resources and training to aid teachers and educators in effectively adopting and utilizing this technology could be beneficial.

The study's implications offer valuable guidance for advancing a more innovative, inclusive, and technology-driven approach to mathematics education. Moreover, they lay the groundwork for future research endeavors to delve deeper into specific facets of A.R. utilization in mathematics learning. This could involve further exploring prominent focus areas, refining more effective A.R. methodologies, or conducting cross-national studies to comprehend variations in the technology's impact across diverse global educational settings.

4. Conclusion

The utilization of Augmented Reality (A.R.) within mathematics education has emerged as a prominent area of investigation. Current research trends prefer employing qualitative and quantitative methodologies, showcasing the multifaceted nature of exploring A.R.'s application in mathematics learning. Analysis of educational levels reveals a primary focus on elementary schools, followed by junior high schools. This indicates a potential for heightened A.R. integration at early education stages, particularly within matrix/geometry material, influencing a better understanding of specific mathematical concepts. Notably, research concentrates on three core variables: mathematical comprehension, student engagement, and spatial abilities, signifying an attempt to comprehend A.R.'s impact beyond academic outcomes, delving into psychological and cognitive dimensions relevant to student learning.

The emergence of new themes in research signifies an expansion in exploring A.R. within mathematics learning, encompassing mobile technology, remote teaching, mobile learning, and learning experiences. Lastly, the geographic distribution of research highlights Germany and Turkey as significant contributors to AR-related publications in mathematics education, reflecting substantial interest and research activity in these nations. Overall, this study offers crucial insights into the evolving landscape and research trajectories concerning A.R.'s integration into mathematics education, establishing a groundwork for further advancements in the field. The study implies that employing Augmented Reality (A.R.) can augment mathematics learning by positively influencing student understanding. Its implications extend to practitioners designing AR-infused lessons, encouraging educational policies to embrace this technology, and guiding comprehensive research on pivotal variables shaping AR's effectiveness in mathematics education.

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