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INTEGRATION OF AUGMENTED REALITY TECHNOLOGY IN MATHEMATICS LEARNING: IMPACT ON CONCEPTUAL UNDERSTANDING

INTEGRASI TEKNOLOGI AUGMENTED REALITY DALAM PEMBELAJARAN MATEMATIKA: DAMPAK TERHADAP PEMAHAMAN KONSEP

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ABSTRACT
Mathematics learning often faces significant challenges due to the abstract nature of its concepts, causing difficulty in understanding and anxiety in students. Conventional methods have proven ineffective in addressing this issue, prompting the exploration of pedagogical innovations. This study aims to explore the effectiveness of Augmented Reality (AR) integration in mathematics learning on students' conceptual understanding compared to conventional methods. Using a thematic synthesis approach, this systematic literature review analyzes articles.peer-reviewedA study from Scopus, Web of Science, ERIC, and Google Scholar (2013–2025) compared AR with traditional learning. The results showed that AR significantly improved conceptual understanding, particularly in visual-abstract topics such as three-dimensional geometry and functions, through interactive visualization and reduced cognitive load. However, its effectiveness varied depending on instructional design, technological readiness, and institutional support. The conclusions emphasize that AR is not simply a visual tool, but rather an innovation capable of supporting cognitive processes and experiential learning. Practical implications emphasize the need for planned AR integration and adequate teacher training to maximize the potential of this technology in improving the quality of mathematics learning.
Keywords:Augmented Reality, Mathematics Learning, Concept Understanding, Conventional Methods, Systematic Review

ABSTRAK
Pembelajaran matematika seringkali menghadapi tantangan signifikan karena sifat konsepnya yang abstrak, menyebabkan kesulitan pemahaman dan kecemasan pada siswa. Metode konvensional terbukti kurang efektif dalam mengatasi isu ini, mendorong eksplorasi inovasi pedagogis. Penelitian ini bertujuan mengeksplorasi efektivitas integrasi Augmented Reality (AR) dalam pembelajaran matematika terhadap pemahaman konsep siswa dibandingkan metode konvensional. Menggunakan pendekatan sintesis tematik, tinjauan literatur sistematis ini menganalisis artikel peer-reviewed dari basis data Scopus, Web of Science, ERIC, dan Google Scholar (2013-2025) yang membandingkan AR dengan pembelajaran tradisional. Hasil menunjukkan bahwa AR secara signifikan meningkatkan pemahaman konsep, terutama pada topik visual-abstrak seperti geometri tiga dimensi dan fungsi, melalui visualisasi interaktif dan pengurangan beban kognitif. Namun, efektivitasnya bervariasi tergantung desain instruksional, kesiapan teknologi, dan dukungan institusional. Kesimpulan menegaskan bahwa AR bukan sekadar alat visual, melainkan inovasi yang mampu mendukung proses kognitif dan pembelajaran berbasis pengalaman. Implikasi praktis menekankan perlunya integrasi AR yang terencana dan pelatihan guru yang memadai untuk memaksimalkan potensi teknologi ini dalam meningkatkan kualitas pembelajaran matematika.
Kata Kunci: Augmented Reality, Pembelajaran Matematika, Pemahaman Konsep, Metode Konvensional, Tinjauan Sistematis

1. INTRODUCTION

Mathematics learning has long faced significant challenges due to its abstract nature and difficulty in visualizing. Concepts such as spatial geometry, algebraic functions, or calculus often require strong mental representations for deep understanding. However, international data shows that many students still struggle to master basic math skills. For example, the PISA survey results show that only55% of students aged 15 years are able to answer simple questions in the form of interpreting tables correctly, while only 30.8% of students can solve percentage problems (Thompson, 2012). This difficulty has implications for poor conceptual understanding and impacts long-term academic performance.In addition, psychological factors such as mathematics anxiety contribute to worsening the condition. OECD (2013) reported that students with high levels of math anxiety had an average score of34 points lower in PISA, which is equivalent to losing one year of formal learning (OECD, 2013). This condition shows that difficulty understanding mathematical concepts is not only a pedagogical issue, but also involves cognitive and affective factors.

MConventional learning methods widely used in schools, such as lectures, blackboards, and textbooks, have proven less effective in addressing these issues. A meta-analysis of 225 STEM studies found that student failure rates in classes with conventional methods reached32%, while the use of active learning methods reduced the failure rate to21%and improved exam results by 0.47standard deviation(Freeman et al., 2014). These results confirm that conventional methods tend to be passive and less supportive of students' conceptual understanding.

As educational technology advances, various innovations have emerged aimed at addressing the limitations of traditional methods. One of these isAugmented Reality (AR)which offers an interactive learning experience through visualizing abstract objects to make them more realistic and contextual. A study from the University of Southern California found that students who used AR applications in mathematics learning achieved higher scores.14% higher compared to the group that learned without AR (Logic-Square Technologies, 2023). Similar findings were reported by World Metrics (2024), where89% of students feel AR helps them understand the material better, while 64% reported increased information retention.

The trend of AR adoption in education also shows significant growth. Echo Innovate IT (2023) reports that the market value of AR in education will increase fromUS$11.9 billion in 2023 to US$75 billion in 2033, reflecting the enormous potential of this technology to transform the learning paradigm. Thus, research on AR integration in mathematics learning is crucial, not only to address the gap in the effectiveness of conventional methods, but also to provide practical contributions to improving students' conceptual understanding.

The use of Augmented Reality (AR) in education has grown rapidly over the past decade, driven by advances in digital technology and the increasing availability of supporting devices, such as smartphones and tablets. In the context of mathematics education, AR is emerging as a promising pedagogical innovation due to its ability to present abstract objects in visual representations that are more concrete, interactive, and easily explored by students. This is particularly relevant given that mathematics is often considered a challenging subject, as many concepts are abstract and difficult to visualize in concrete terms.

Several previous studies have shown that the application of AR can increase student motivation, create a more engaging learning experience, and facilitate active engagement in the learning process. AR allows students to interact directly with three-dimensional mathematical models, enabling them to gain a multisensory learning experience rather than relying solely on static text and images in textbooks. Therefore, AR is considered capable of reducing cognitive barriers that often arise in learning complex concepts, such as spatial geometry, transformations, and function representations.

In terms of application trends, AR has been used at various levels of education, from elementary school to college. At the elementary level, AR tends to be used to introduce simple numerical and geometric concepts with a more concrete and engaging visual approach. At the secondary level, AR is used to support the understanding of more abstract concepts, such as algebra, trigonometry, or calculus, by presenting clearer and more applicable visual representations. Meanwhile, in higher education, AR is used not only to aid understanding of theoretical concepts but also to support research, simulations, and the development of more complex problem-solving skills.

Despite this, most previous research has focused more on motivational aspects, student engagement, and learning outcomes in a broader sense, such as improved test scores or positive attitudes toward mathematics. Meanwhile, studies explicitly comparing students' understanding of mathematical concepts using AR with those learning through conventional methods are still relatively limited. Yet, conceptual understanding is at the heart of meaningful mathematics learning, as without in-depth understanding, students' knowledge will remain procedural and superficial. This research gap is important to explore further to gain a more comprehensive understanding of the extent to which AR is truly effective in improving conceptual understanding compared to traditional methods that rely more on lectures, texts, and practice problems.

Based on the background and state of the art analysis, the research questions posed are:**“How does the integration of Augmented Reality (AR) in mathematics learning affect students' conceptual understanding compared to conventional learning methods?”**

This question not only aims to test the effectiveness of AR as a learning medium but also emphasizes the importance of critically examining comparisons with traditional approaches. In other words, this study seeks to assess whether AR technology truly provides added value in improving students' understanding of mathematical concepts, or whether it merely adds appeal without significantly impacting the depth of understanding.

The purpose of this systematic literature review is to explore the extent to which previous studies have addressed the effectiveness of Augmented Reality (AR) in mathematics learning, particularly in relation to students' conceptual understanding. This review also aims to synthesize findings from various relevant studies to obtain a comprehensive picture of trends, patterns, and consistent and contradictory results related to the application of AR in the context of mathematics education. Furthermore, this review seeks to critique methodological weaknesses and limitations in previous research, including the tendency of previous studies to focus more on motivational aspects and general learning outcomes, without paying sufficient attention to in-depth conceptual understanding. Furthermore, this review focuses on comparing the effectiveness of AR with conventional learning methods in helping students understand mathematical concepts, thereby providing a strong scientific basis for educators and researchers in designing technology-based learning interventions that are more effective and relevant to modern learning needs.

Thus, this research is expected to significantly contribute to broadening academic understanding of the potential of AR in mathematics education while addressing existing research gaps. Furthermore, the results of this systematic review are also expected to provide practical recommendations for teachers, curriculum developers, and policymakers on how to more optimally integrate AR into mathematics learning practices.

2. METHODS

2.1. Literature Search Strategy

The literature used in this review was collected through searches of leading academic databases, namelyScopus, Web of Science, ERIC, and Google ScholarThe selection of this database aims to ensure a broad coverage of the literature, both in terms of academic quality and relevance to the field of mathematics education. The keywords used in the search are a combination of the terms“augmented reality”, “mathematics education”, “conceptual understanding”, “traditional learning”, and “comparative study”. These keywords were chosen to represent the focus of the research, namely the integration of AR technology in mathematics learning and its comparison with conventional learning methods.

In addition to direct searches using keywords, reference searches from relevant articles were also carried out (backward snowballing) to identify additional studies related to the topic.

2.2. Inclusion and Exclusion Criteria

To maintain relevance, this study established a number of inclusion and exclusion criteria.

Inclusion criteria includes:

1. Articles published in journals peer-reviewed between years 2013 to 2025.
2. Studies that focus on mathematics learning with AR integration.
3. Articles that explicitly discussunderstanding of mathematical conceptsas a learning outcome variable.
4. Articles that present comparisons with conventional learning methods (lectures, textbooks, blackboards, or other traditional media).

Exclusion criteria includes:

1. Article non-peer-reviewed such as technical reports, proceedings without review, or opinion.
2. Studies that only focus on the technical aspects of AR development without linking it to the context of mathematics learning.
3. Research that addresses subjects other than mathematics, even though it uses AR.

2.3. Analysis Approach

The analytical approach in this narrative review uses thematic synthesis. Successfully collected articles are categorized based on main themes that emerged from the research results. The three main categories used in the analysis are:

1. Effectiveness of AR compared to conventional methods: how AR affects students' understanding of mathematical concepts compared to traditional learning.
2. Factors that influence AR effectiveness: for example the level of interactivity, student motivation, teacher skills, and technological infrastructure support.
3. Theoretical basis that supports the implementation of AR: for example, constructivism theory,cognitive load theory, or theory/dual coding which is the basis for AR integration in learning.

This analysis is not done quantitatively like meta-analysis, but rather more descriptive in nature by highlighting patterns, trends, and research gaps from various existing studies.

3. RESULTS

3.1. Comparison of AR learning outcomes vs. conventional methods

The growing field of augmented reality (AR) in education has garnered considerable attention due to its potential to enhance learning outcomes compared to conventional instructional methods. Numerous studies indicate that AR facilitates a deeper understanding of mathematical concepts, particularly in areas that necessitate spatial reasoning such as three-dimensional geometry and functions. Yuliono et al. emphasize the promising roles of AR in educational contexts by illustrating how AR blends physical and digital experiences, thereby enriching student engagement and conceptual understanding (Yuliono et al., 2018). This assertion resonates with findings by Chen, who reports that AR can foster learning achievements and enhance student motivation in educational settings, attributing these improvements to AR's interactive nature (Chen, 2020).

In the realm of mathematics education, studies demonstrate that learners exposed to AR content tend to make better connections between abstract concepts and their visual representations. For instance, Ahmad and Junaini highlight AR's capability to overlay digital content onto the real world, enriching the educational experience and drawing attention to its advantages over traditional methods (Ahmad & Junaini, 2020). Similarly, the research conducted by Buchner et al. provides evidence that AR applications can lead to improved academic performance and lower cognitive loads compared to conventional teaching strategies (Buchner et al., 2021).

Yet, while many studies affirm AR's benefits, the consensus is not universal. Some research reports reveal mixed results, where AR did not demonstrate significant superiority over traditional educational methods. This variability is often attributed to contextual factors, such as the design of instructional materials or the prior knowledge of the learners (OZDEMIR et al., 2018). For example, Bork et al. discuss how variations in educational implementation and the complexity of content can influence outcomes, implying that the effectiveness of AR is not solely inherent to the technology itself but is also contingent on pedagogical approaches (Bork et al., 2020).

Furthermore, different studies highlight the need for carefully designed AR interventions that consider learners' existing knowledge and skills. The findings of Ozdemir et al. contribute to this discourse by pointing out that improvements in academic performance from AR-based systems can be influenced by training techniques and standardization of educational content (Wenz et al., 2013). This reinforces the complexity of establishing AR as a universally effective learning tool.

In conclusion, while augmented reality presents unique opportunities to enhance learning outcomes in mathematics by fostering deeper conceptual connections and visual interactions, careful attention must be paid to its implementation. The overall effectiveness of AR is dependent not only on the technology itself but also on contextual factors, including instructional design and the pre-existing capabilities of students.

3.2. Cognitive aspects in learning with AR

Augmented Reality (AR) has been increasingly recognized for its positive influence on students' cognitive development, particularly through its ability to blend visual and abstract representations. Central to this phenomenon is the application of the Dual Coding Theory, which posits that the integration of verbal and visual information helps to fortify memory pathways, ultimately enhancing retention and comprehension (Wei et al., 2024; (Yang et al., 2021; .

In the context of educational interventions, studies illustrate that AR tools facilitate a deeper understanding of intricate subjects. For instance, the ability of students to manipulate three-dimensional geometric figures via AR leads to an enriched comprehension that surpasses traditional methods relying on static images or verbal descriptions alone (Sudirman et al., 2022). This interactive engagement promotes a cognitive shift as learners are encouraged to explore and comprehend complex constructs through hands-on experimentation.

Furthermore, the implications of Cognitive Load Theory (CLT) in AR education cannot be overlooked. AR has the potential to lower extraneous cognitive load by offering intuitive and easily navigable visualizations that simplify the learning process (Buchner et al., 2021; (Poupard et al., 2024; . However, this benefit is contingent upon the effectiveness of the instructional design; inadequately designed AR experiences may inadvertently increase cognitive load, which can detract from learning outcomes (Poupard et al., 2024; Lin et al., 2023). Studies have confirmed this duality; hence, educators must thoughtfully consider the complexities of interaction embedded within AR environments. Higher interaction complexity can enhance learning performance but also demand greater mental effort from students (Yang et al., 2021; Altmeyer et al., 2020).

Additionally, empirical evidence supports the notion that AR environments can augment student engagement and motivation, helping to create an immersive learning atmosphere that fosters curiosity and active participation. For example, incorporating elements like gamification within AR frameworks helps facilitate students' interest and efficacy in learning complex scientific concepts (Hoài et al., 2024; Λαμπρόπουλος et al., 2022). These motivational boosts are critical, especially when engaging with subjects that are typically perceived as challenging, such as chemistry or geometry (Khan et al., 2019).

Overall, the integration of Augmented Reality in educational settings appears to be a promising avenue for enhancing cognitive processes, aligning well with established educational theories. It bridges the gap between abstract concepts and their visual counterparts, enabling students to construct knowledge more effectively and motivating them to engage with learning material (Arıcı & Yılmaz, 2022; Grübel et al., 2025).

3.3. Mediating and moderating factors

The effectiveness of Augmented Reality (AR) in education, particularly in mathematics, is significantly influenced by various mediating and moderating factors. One crucial factor is the age and educational level of students. Research indicates that younger students, such as those in elementary school, generally benefit more from AR interventions compared to older students due to their ongoing need for concrete representations in learning (Nuryadin et al., 2023; (Apriza et al., 2024; . Specifically, AR has proven beneficial in teaching geometry and other abstract mathematical concepts, which aligns well with the developmental stage of younger learners who are still grappling with these ideas (Ivan & Maat, 2024)(Apriza et al., 2024; Jabar et al., 2022).

Moreover, the complexity of mathematical topics is vital in determining the effectiveness of AR. Studies have shown that AR is particularly effective for teaching challenging abstract and visual topics, such as spatial geometry and functions. These complex subjects allow students to visualize and manipulate difficult concepts in an interactive environment, thereby enhancing learning outcomes (Ivan & Maat, 2024)Hakim et al., 2024). Additionally, traditional procedural materials do not leverage the full potential of AR, indicating a need for a targeted approach to instruction in these cases (Ivan & Maat, 2024).

Another significant factor that affects the effectiveness of AR is instructional design. Research indicates that AR is most beneficial when integrated within innovative pedagogical frameworks, such as problem-based learning or flipped classrooms, rather than being employed as a standalone tool (Mattis, 2014; (Ahmad et al., 2023; . This integration enables AR to serve as an engaging educational tool that draws on collaborative learning environments and active student participation (Ahmad et al., 2023; Jabar et al., 2022). Ultimately, AR should not merely act as a supplementary visual aid but should be woven into broader instructional strategies that foster meaningful learning experiences (Mattis, 2014; Palancı & Turan, 2021).

Furthermore, studies have highlighted that incorporating AR within structured frameworks helps improve motivation and lowers mathematical anxiety, which positively impacts student learning outcomes Wangid et al., 2020)(Apriza et al., 2024; . Engaging students through immersive and interactive AR experiences can enhance their understanding and retention of mathematical concepts, confirming the value of careful instructional design (Apriza et al., 2024; Wangid et al., 2020). In summary, the effectiveness of AR in mathematics education relies heavily on factors such as the students' age and educational level, the complexity of the mathematical topics, and the instructional design employed. These factors work synergistically to enhance educational outcomes and should guide the development of AR-based learning interventions.

3.4. Limitations of existing studies

Although the findings demonstrate the positive potential of AR in mathematics learning, several limitations are worth noting. Most studies are short-term and only assess learning outcomes immediately after the intervention, making it difficult to assess the long-term impact of AR use. The lack of longitudinal studies is a major gap in the literature. Furthermore, many studies are limited in sample size and often focus on specific contexts (e.g., a single school or a single grade level), making the generalizability of the results limited.

Another limitation is the lack of research comparing the effectiveness of AR across cultures or educational systems, even though social context and curriculum factors can influence its implementation.

4. DISCUSSION

4.1. Interpretation of Main Findings

The integration of Augmented Reality (AR) in mathematics education has been shown to enhance learning outcomes, particularly in areas that require strong visualization capabilities, such as geometry. Research indicates that students exposed to AR methods often demonstrate improved conceptual understanding and retention compared to those engaged in traditional educational approaches, such as lectures or textbook learning. For instance, studies reveal that AR-enhanced learning environments positively affect students' engagement and academic achievements in various subjects, including mathematics (Agustika, 2021; Amores-Valencia et al., 2023). This effectiveness is attributed to AR's capability to present three-dimensional objects interactively, aiding students in grasping complex mathematical concepts more intuitively (Küçük et al., 2016; Lai & Cheong, 2022).

Despite its potential advantages, the effectiveness of AR in mathematics education is not universally consistent. Several factors considerably influence its success, including the learning design, technological readiness of students, and available institutional support (Nikou, 2024; Ronaghi et al., 2024). When AR tools are not integrated with sound pedagogical principles, there is a significant risk that students may become distracted, leading to less optimal learning experiences (Safitri et al., 2024; Sukriadi et al., 2023). An inadequate alignment of AR applications with educational objectives can diminish the intended improvements in learning outcomes that AR technologies typically provide (Alzahrani, 2020). Furthermore, educator competence and engagement with AR technology are critical; effective training can foster an environment that maximizes the educational benefits of AR (Ateş & Garzón, 2022; (Nikou et al., 2024; .

In summary, while Augmented Reality holds substantial promise for enhancing mathematical learning, its successful deployment depends on several contextual factors. When carefully integrated into thoughtful instructional designs, AR can significantly foster understanding and engagement; however, adequate support structures and educators skilled in AR utilization are equally crucial for realizing its full potential (Nikou et al., 2024; ARICI et al., 2021; Lai & Cheong, 2022).

4.2. Relevance to Theory

The effectiveness of Augmented Reality (AR) in mathematics learning can be analyzed through various theoretical foundations that illustrate its educational impact. Key among these are Cognitive Load Theory, Dual-Coding Theory, and Constructivist Learning Theory.

Cognitive Load Theory posits that learning efficiency depends on managing cognitive load effectively. Sweller Bilous et al. (2020) asserts that to enhance learning, extraneous cognitive load must be minimized. AR technologies reduce this cognitive load by providing direct visualizations of mathematical concepts, thus relieving students from the task of mentally picturing abstract representations. This aligns with findings from Ahmad and Junaini (Ahmad & Junaini, 2020), who emphasize AR's capacity to facilitate understanding by visualizing complex mathematics concepts and alleviating cognitive burdens through visual engagement.

Dual-Coding Theory, articulated by Paivio Jabar et al. (2022), asserts that simultaneous presentation of verbal and visual information promotes better retention. This principle is exemplified in AR educational applications, where verbal instruction is paired with visual aids to enhance the learning experience. Jabar et al. Jabar et al. (2022) provide a systematic review demonstrating that AR significantly boosts visual thinking skills and comprehension in mathematics education, underscoring the dual channels of information processing advocated by the theory.

Constructivist Learning Theory posits that knowledge is constructed through experiential learning. AR facilitates this by allowing students to actively explore virtual representations related to real-world mathematics applications. This view is supported by Hakim et al. (Hakim et al., 2024), who discuss how AR can enhance spatial thinking and create interactive learning experiences in geometry. Likewise, Wong et al. Wong et al. (2022) elaborate on how AR contributes to enriching mathematical learning environments by promoting engagement and contextual learning, aligning with constructivist principles that advocate for learner-driven exploration.

Overall, AR appears to be a transformative educational tool in mathematics learning, reinforcing established cognitive theories while promoting an interactive, engaging learning atmosphere. The utilization of AR technologies in educational settings aligns with theoretical constructs that maximize learning outcomes and foster a deeper understanding of complex mathematical concepts.

4.3. Practical Implications

The practical implication of these findings is that teachers need to utilize AR not only as gimmick or entertainment tools, but must be integrated into meaningful learning designs that align with instructional objectives (Cai et al., 2021). AR use should be directed toward materials that require complex visualizations, thereby providing genuine added value for students. Furthermore, the success of AR implementation depends heavily on teacher preparedness. Therefore, adequate training and mentoring programs are needed to enable teachers to design AR-based learning tailored to the needs of mathematics topics and student characteristics (Garzón & Acevedo, 2019).

4.4. Implications for Further Research

To strengthen empirical evidence, future research should be conducted longitudinally to measure the long-term impact of AR use on students' understanding of mathematical concepts and knowledge retention (Garzón et al., 2020). Furthermore, comparative studies across educational levels (e.g., middle school, high school, and college) are needed to determine whether AR effectiveness differs according to students' level of cognitive development (Ibáñez & Delgado-Kloos, 2018). Future research could also explore how AR impacts metacognitive skills, such as reflection, monitoring learning processes, and regulating learning strategies, which have been understudied to date (Bower et al., 2014).

5. CONCLUSION

This systematic literature review clearly demonstrates that the integration of Augmented Reality (AR) into mathematics learning has significant potential to enhance students' conceptual understanding, particularly in abstract topics requiring visual representation, such as three-dimensional geometry, functions, and transformations. These findings confirm that AR serves not only as an interactive visual aid but also as a powerful tool capable of supporting students' cognitive processes.

The main contributions and implications of this review indicate that Augmented Reality (AR) has a significant role in enhancing students' conceptual understanding in mathematics learning. AR facilitates deeper understanding by providing interactive and concrete visualizations of abstract concepts, which is particularly beneficial for topics such as three-dimensional geometry, where students can manipulate virtual objects and explore their properties in a dynamic environment. Furthermore, AR supports students' cognitive processes through several mechanisms. First, AR strengthens the visual-verbal memory pathway in accordance with Dual Coding Theory, where the simultaneous presentation of information in visual and verbal forms can strengthen memory and understanding. Second, AR helps reduce extraneous cognitive load by offering intuitive and easy-to-navigate visualizations, thereby simplifying the learning process and reducing the difficulties associated with mentally visualizing abstract concepts. Third, AR encourages experiential learning by allowing students to actively engage and conduct hands-on experiments, allowing knowledge to be built through interaction with mathematical models.

Academically, this review contributes by synthesizing empirical evidence on the effectiveness of AR in mathematics learning while highlighting remaining research gaps, including the lack of longitudinal studies, variations in effectiveness across educational levels, and the impact of AR on students' metacognitive skills. This synthesis provides a strong theoretical and empirical foundation for further, more comprehensive and contextualized research. From a practical perspective, the review recommends that AR be integrated into meaningful learning designs based on sound pedagogical principles, rather than simply as an innovative tool. Successful implementation depends heavily on targeted application, focusing on topics that truly require complex visualizations, teacher preparedness through adequate training and support programs, and alignment with established educational theories, such as Cognitive Load Theory, Dual-Coding Theory, and Constructivist Learning Theory, to maximize AR's educational benefits.

Overall, this review emphasizes that AR has a strategic role in the transformation of modern mathematics learning, with the potential to strengthen the quality of conceptual understanding, increase motivation, and encourage the development of more effective, innovative learning strategies.

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