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Augmented Reality for Supporting Student's Engagement in Mathematics Education: A Systematic Literature Review

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Abstract: Augmented reality (AR) has gained considerable attention in academic research as a primary instructional tool to enhance learning across various educational levels, including mathematics education. AR enables the overlaying of three-dimensional images onto real-world environments within an academic setting. While AR has demonstrated its potential to improve learning outcomes in academic contexts, there is a need for a comprehensive review to identify, assess, and summarize empirical findings related to student engagement, particularly in mathematics education. Consequently, a systematic review was conducted to examine the uses of AR in student engagement in mathematics education. A thorough electronic search was performed on the Scopus database to retrieve pertinent journal articles. After applying inclusion and exclusion criteria, 18 studies were selected for analysis. The results reveal that AR can facilitate student engagement in three key aspects: interactive, collaborative, and immersive experiences. Although AR offers several advantages for promoting student engagement in mathematics education, its practical implementation in educational settings requires careful consideration of AR application and content design and close collaboration between educators and technology. Furthermore, the successful integration of AR technology relies on the well-planned implementation of learning programs that effectively incorporate AR elements for mathematics education.

Keywords: Augmented reality, Mathematics education, Student engagement, Systematic literature review

Introduction

Augmented reality (AR) has gained significant popularity as an interactive technology in diverse educational contexts over the past decade. One of the primary reasons for the widespread adoption of AR is its compatibility with multiple platforms, including desktops, tablets, smartphones, and notebooks. According to a recent study by Marshall (2023), AR can be defined as the dynamic overlay of context-sensitive virtual information onto real-world contexts. Due to its effectiveness as an educational tool, AR has been extensively studied across various disciplines, such as physics, biology, chemistry, and mathematics. AR generally establishes connections between virtual objects and real environments, facilitating the visualization and comprehension of complex concepts.

Integrating virtual and real-world objects in AR is commonly referred to as "mixed reality," initially introduced in the 1990s as an innovative approach to training and education. Since then, AR has garnered considerable attention and has been the subject of numerous published studies investigating its advantages, limitations, and challenges in educational settings. The interactive and innovative applications facilitated by AR technology have demonstrated significant potential in various subjects, particularly mathematics education.

While previous review studies have primarily focused on enhancing student engagement, a subset of studies has specifically examined the relationship between AR and student engagement. Recognizing this research gap, this paper aims to address the need for further investigation by conducting a systematic review of the AR literature about student engagement over the past decade. The study aims to answer the following research questions (RQs):

RQ1: How has the distribution of AR implementation for student engagement in mathematics education evolved over the years?
RQ2: How does the distribution of AR implementation for student engagement in mathematics education vary across different countries?
RQ3: What research methods have been utilized to investigate student engagement using AR?
RQ4: How does AR technology contribute to facilitating student engagement?

Through this study, we aim to contribute to the existing body of literature by providing comprehensive insights into the use of AR for promoting student engagement, specifically within the domain of mathematics education.

Literature Review

Augmented reality (AR) has gained traction in educational institutions as an immersive technology. Its visual and interactive nature appeals to the current generation of students, Generation Z, providing a comprehensive teaching and learning experience. In education, engagement is crucial and influenced by attention, interest, and motivation. Wiseman et al. (2016) described that engagement refers to students' active involvement and effort in educational activities, encompassing cognitive, behavioral, and emotional aspects. Motivation and engagement are fundamental for attaining educational objectives and goals (Ozhan & Kocadere, 2020). Technology can be utilized as a tool to foster student engagement with learning activities (Puspita et al., 2022; Supriyadi & Kuncoro, 2023). Consequently, engagement in a digital environment becomes significant for researchers, educators, instructional designers, and developers (Wiseman et al., 2016). These researchers also emphasize the importance of fostering engagement to facilitate learning activities and create support mechanisms surrounding them.

According to Chen et al. (2017), AR has the potential to deepen student involvement, increase enjoyment, and foster positive attitudes. It effectively enhances student motivation and engagement (Bacca Acosta et al., 2014). The features embedded in AR technology can effectively engage students in the learning process and improve their visualization skills (Saidin et al., 2015). Positive feedback from participants also indicates their willingness to participate in their studies through AR tools actively. Furthermore, Karagozlu (2018) highlights that engagement with learning materials leads to improved academic achievement.

Method

Research Design

This study examines the role of augmented reality (AR) in enhancing student engagement in mathematics education. The study encompasses four primary objectives: (1) analyzing the distribution of student engagement using AR in mathematics education based on publication year, (2) investigating the distribution of student engagement using AR in mathematics education across different countries, (3) identifying the indicators of student engagement evaluated in AR applications for mathematics education, and (4) determining the evaluation methods utilized for assessing AR applications in mathematics education.

The selection of the systematic literature review (SLR) methodology for this study was motivated by its ability to provide a transparent assessment of the strengths and weaknesses of previous investigations (Xiao & Watson, 2019). SLR studies offer a comprehensive overview by consolidating existing knowledge, revealing the current understanding, and identifying research gaps within a specific field (Okoli & Schabram, 2010). The literature

review conducted in this study follows the guidelines outlined in the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) protocol to ensure the quality and rigor of reporting academic literature (Okoli & Schabram, 2010).

Identification

The search strategy utilized Scopus databases, as outlined in Table 1. It combined keywords, synonyms, and Boolean operators relevant to the research question to encompass all databases.

Table 1. Search query

SCOPUS	("student's engagement") AND ("augmented reality" OR "AR") AND ("mathematics education")

Screening

Based on Figure 1, the screening process resulted in the selection of 18 articles. The screening phase involved evaluating titles and abstracts to identify relevant papers and filtering the entire text based on predetermined criteria. The initial title and abstract screening were conducted by the researchers, with the second author providing validation.

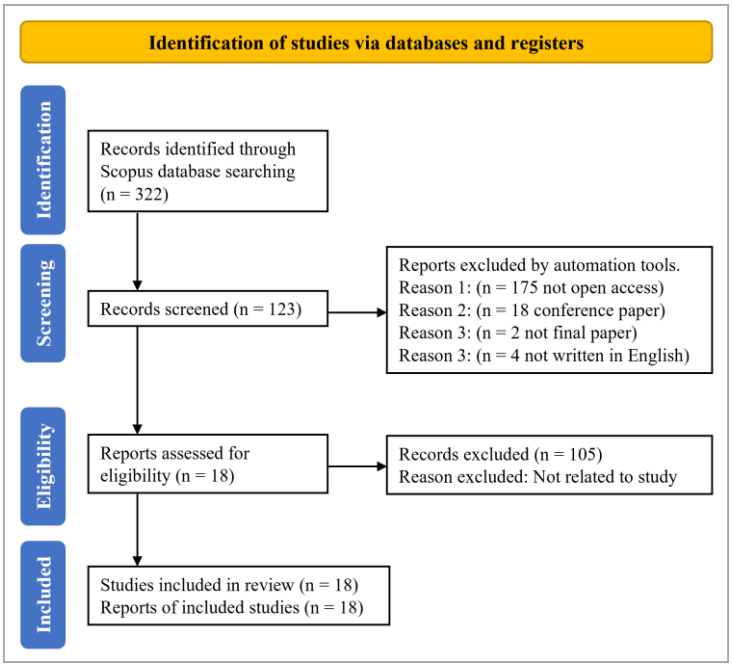

Figure 1. Prisma flow diagram

Table 2. Weight of evidence judging criteria

Level 1-4	Methodology quality	Methodology relevance	Topic relevance
1. Excellent	Excellent research approach and method quality	Excellent use of the research design to answer RQs	Clearly defined research answers Referred to ethics concerning children
2. Good	Good relationship multiple review elements	Sound use of research design	Functional, relates to research questions
3. Satisfactory	It appears logical and relatable	Broadly matched to elements of research questions	Broadly relevant to research questions
4. Inadequate	Research design or analysis not clearly stated	Not suited to research questions	Did not answer research questions

The authors conducted a validation process by randomly selecting ten articles from 18. The inter-rater reliability was found to be very high. Specifically, two papers were thoroughly discussed among the reviewers, while one paper was rejected as two out of three reviewers deemed it unsuitable based on the research inclusion criteria.

To ensure the quality and accuracy of the assessment, the criteria for evaluating the article's quality were based on guidelines established by (Gough, 2007), as shown in Table 2.

Eligibility

The review examines the impact of augmented reality (AR) on student engagement and its characteristics. The systematic process undertaken to generate data is visually represented in Figure 1. Specific inclusion criteria were developed to ensure the selection of pertinent studies, as outlined in Table 3. Two electronic databases were utilized as data sources, as indicated in Table 1. A search string was devised to identify relevant keywords within the literature of the past five years, as presented in Table 3. The evaluation of article quality was based on guidelines established by (Gough, 2007), summarized in Table 2. The outcomes of the screening process are depicted in Figure 1.

Inclusion/Exclusion Criteria

The study exclusively incorporates open-access references and aims to explore student engagement facilitated by augmented reality (AR) technology. To achieve this objective, the research reviews literature published between 2013 and 2022 to identify the critical characteristics of student engagement in AR technology. The decision to limit the literature review to this specific timeframe is based on the belief that it would effectively capture the impact of AR on learning over the past decade. The inclusion and exclusion criteria for selecting relevant studies are outlined in Table 3.

Table 3. Inclusion/exclusion criteria

Criterion type	Inclusion	Exclusion
Publication	2014-2022	Before 2014
Quality Assurance	Studies published in peer-reviewed journals	Not published in peer-reviewed journals
Language	English	Non-English text
Topic	Student’s engagement using AR	
Geographical location	Worldwide studies	

Inclusion/Exclusion Criteria

Despite working independently to code the data from the 18 articles, the two authors conducted regular meetings to discuss their findings. Ten articles were randomly chosen to assess the inter-rater reliability, and both authors individually coded them. The coding results were then entered into SPSS to calculate Cohen's Kappa value. The obtained value of 0.545 ($p < 0.01$) indicates a "moderate" level of agreement, as defined by Viera & Garrett (2005). In cases where there were discrepancies in the coding results, the two authors collaborated to review and align the data to ensure complete consistency.

Data Analysis

Information from each study was meticulously documented in an Excel spreadsheet, encompassing details such as author, country, year, participant characteristics, research questions, methods, and findings. Two distinct types of data analysis were employed to organize and synthesize the relevant data findings. Initially, a descriptive analysis was conducted, which involved recording information such as references, study focus, keywords, and context. Subsequently, a thematic analysis was undertaken to categorize and code the data sources into meaningful codes and categories.

Results and Discussion

Results

This criterion applied during the literature review resulted in a reduction from an initial pool of 322 journal articles to a final selection of 18 papers that underwent full-text analysis. The final review encompasses these 18

papers. Please refer to Figure 1 to access the PRISMA flowchart illustrating the process. This study aims to investigate using augmented reality (AR) to enhance student engagement. Student engagement refers to the extent of students' active involvement, interest, and enthusiasm in their learning and classroom activities. Higher levels of student engagement are associated with improved learning outcomes, while lower levels of engagement can impede effective learning. This literature review delves into the significance of this topic, which will be further discussed.

RQ1: How has the distribution of AR implementation for student engagement in mathematics education evolved over the years?

The first research question analyzes the distribution of research studies concerning augmented reality (AR) to support student engagement across various years. The findings in Figure 2 highlight an uneven distribution of research conducted throughout different years. Notably, there is a notable increase in the number of studies conducted in 2020 and 2021 compared to the other years examined.

This uneven distribution suggests that the interest and attention towards AR in the context of student engagement have intensified in recent years, particularly in 2020 and 2021. More studies conducted during this period may indicate a growing recognition of AR as a valuable tool for enhancing student engagement. However, it is essential to note that further research is still required to fully understand AR technology's potential impact and benefits on student engagement across a broader range of years.

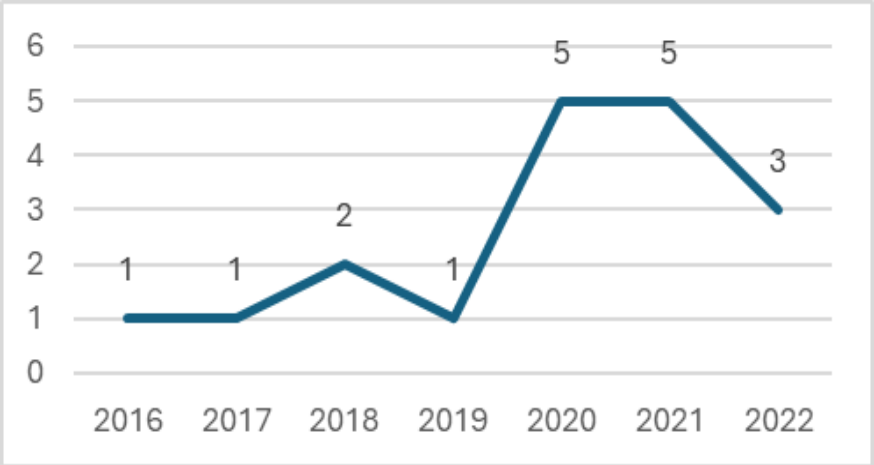

Figure 2. The number of studies published by year

RQ2: How does the distribution of AR implementation for student engagement in mathematics education vary across different countries?

The exploration of augmented reality (AR) to enhance student engagement has garnered attention and involvement from multiple countries. A diverse range of countries participated and contributed to the investigation of this study. Notable countries involved in the research encompassed the United States (US), Malaysia, Finland, Italy, Kuwait, Turkey, Greece, Spain, Indonesia, England, Portugal, Chile, Belgium, and Morocco, as depicted in Figure 3.

The involvement of these countries signifies the global interest in understanding the potential of AR technology in promoting student engagement. The diverse geographical representation suggests a widespread recognition of the importance of incorporating AR into educational practices. By examining the contributions of various countries, this study offers a broader perspective on the utilization of AR to support student engagement. It highlights the international nature of research in this field.

RQ3: What research methods have been utilized to investigate student engagement using AR?

The fourth research question delves into the methodology employed in AR applications to support student engagement. The selection of an appropriate research methodology is paramount for researchers to ensure the

validity and reliability of their findings. Upon analysis, it was discovered that the predominant research approach utilized in AR studies for enhancing student engagement was quantitative, accounting for 67% of the studies. These quantitative methods involve collecting and analyzing numerical data to draw objective conclusions. Additionally, qualitative methods were employed in 28% of the studies, enabling researchers to gather in-depth insights and understand students' subjective experiences and perspectives. Lastly, a smaller proportion of studies (5%) incorporated mixed methods, combining quantitative and qualitative approaches to comprehensively understand student engagement supported by AR technology (see Figure 4).

Figure 3. The number of studies published by the country

The consideration of different research methodologies allows researchers to approach the study of AR in student engagement from diverse angles, ultimately contributing to a more comprehensive understanding of the topic. By employing a mix of quantitative and qualitative methods, researchers can explore both the measurable outcomes and subjective experiences, providing a well-rounded perspective on the effectiveness and impact of AR in fostering student engagement.

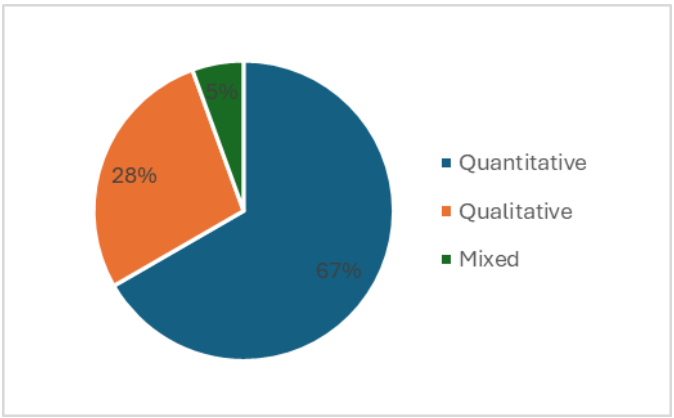

Figure 4. Research methods applied

RQ4: How does AR technology contribute to facilitating student engagement?

The study explores various aspects of student engagement that can be supported through augmented reality (AR) technology. Three main aspects identified in the selected studies are interactive, collaborative, and immersive engagement. These aspects are consistently observed across most studies, as presented in Table 4. By examining the aspects of student engagement in the selected studies, this research provides valuable insights into the different dimensions of AR-supported engagement. The consistent presence of interactive, collaborative, and immersive elements underscores the effectiveness of AR technology in fostering active and immersive learning experiences for students.

Table 4. Aspects of student engagement

Authors and Year	Aspects of Student Engagement
(Chung et al., 2021)	Interactive, Collaborative, Immersive
(Cesari et al., 2021)	Interactive, Immersive
(Sofianidis, 2022)	Interactive, Collaborative, Immersive
(Halili et al., 2021)	Interactive, Collaborative, Immersive
(Rosa-Dávila et al., 2021)	Interactive, Collaborative, Immersive
(Purwaningtyas et al., 2022)	Interactive, Collaborative, Immersive
(Allcoat et al., 2021)	Interactive, Immersive
(Walker et al., 2017)	Interactive, Collaborative, Immersive
(Jesionkowska et al., 2020)	Interactive, Collaborative, Immersive
(Pombo & Marques, 2020)	Interactive, Collaborative, Immersive
(Nadeem et al., 2020)	Interactive, Collaborative, Immersive
(Sirakaya & Cakmak, 2018)	Interactive, Collaborative, Immersive
(Saundarajan et al., 2020)	Interactive, Collaborative, Immersive
(Capone & Lepore, 2022)	Interactive, Collaborative, Immersive
(Nguyen et al., 2018)	Interactive, Collaborative, Immersive
(Badilla-Quintana et al., 2020)	Interactive, Collaborative, Immersive
(Saltan & Arslan, 2016)	Interactive, Collaborative, Immersive
(Elmqaddem, 2019)	Interactive, Collaborative, Immersive

Discussion

Our study shows that research related to AR for supporting student engagement has increased every year (see Fig. 2). Research on AR has increased every year because this technology has the potential to be used in various fields, including education. This is also supported by improvements in the availability of AR hardware, such as smartphones and tablets, which make these technologies more accessible to students in the classroom.

AR technology is rapidly developing its use in the education sector for several reasons. From a visualization perspective, AR can provide rich and interactive visualizations of abstract concepts, such as human body systems, molecular mechanisms, and geographic networks (Adedokun-Shittu et al., 2020; Ewais & Troyer, 2019; Sural, 2017). AR can be used to create learning projects that allow students to learn through exploration and experimentation (Cai et al., 2021; Jesionkowska et al., 2020). AR can connect concepts taught in schools with real environments, enabling students to learn in real locations (Adedokun-Shittu et al., 2020). AR can increase student motivation and participation by providing exciting and interactive learning experiences (Papanastasiou et al., 2019). AR also helps students to learn independently freely because AR provides more opportunities for students to learn interactively and visually (Anderson et al., 2021). Other research has also shown that using AR in education can improve student learning outcomes in various fields.

Meanwhile, regarding the geographical distribution of selected articles, augmented reality (AR) in education is spread worldwide. The analysis in this study shows that AR has contributed to student engagement in various countries such as the USA, Italy, Greece, Malaysia, Spain, Indonesia, England, Belgium, Portugal, Kuwait, Finland, Turkey, Chile, and Morocco. Although AR is used in education in various countries, the amount of use and use is still different. Further research is required to determine how it is implemented effectively in education.

Answering the third research question, the quantitative method is the most common method related to AR for supporting student engagement in the studies examined. Qualitative and mixed research types follow this number. In quantitative research on the use of AR in education, the existing research evaluated the differences in learning outcomes between the AR and non-AR groups using statistical analysis. In a qualitative study of AR in education, the selected study evaluated students' perceptions of AR technology, conducted observations of students using AR, and conducted interviews about their AR experiences. While the mixed is a combination of both. All of these methods have been used to evaluate the use of AR in education, but the choice of method depends on the research objectives, research focus, and type of data desired (Leighton & Crompton, 2017; Papanastasiou et al., 2019).

In terms of pedagogical contribution, AR is proven to attract students' interest, increase enjoyment, and increase their involvement in teaching and learning (Pahmi et al., 2023). AR is also proven to support Aspects of Student Engagement, such as interactive, collaborative, and immersive. AR can support student interactivity in learning

(Molnár et al., 2018). AR provides rich and interactive visualization of abstract concepts (Roopa et al., 2021). This visualization can make concepts easier to understand and interesting for students. With AR technology, teachers can create projects that allow students to learn through exploration and experimentation (Arvola et al., 2021). This can increase student engagement with content and make learning more enjoyable. In addition, AR can also be used to connect concepts taught in schools with real environments, enabling students to learn in real locations (Adedokun-Shittu et al., 2020). This can make learning more relevant and exciting to students. AR allows direct interaction with virtual objects and the actual environment, increases students' active participation in the learning process, and provides more opportunities to learn interactively and visually, thereby making students feel more involved in the learning process (Kamarainen et al., 2018).

Regarding collaboration, AR can create learning situations that allow students to collaborate to explore and try out concepts (Radu & Schneider, 2019). For example, AR can be used to create games that allow students to work together to complete tasks or challenges (Nadolny, 2017). Good communication can also be built through AR technology in the classroom (Leighton & Crompton, 2017). Students can share information and ideas with their friends through AR applications used in learning (Weng et al., 2020). This will also create a fun and exciting learning experience, making students more interested in working with their friends.

AR can support immersive learning experiences in the learning process in several ways (Kiryakova, 2020). Visualization through AR can make concepts easier to understand and enhance an immersive learning experience for students (Kazanidis et al., 2021). AR can also present virtual objects that interact with real environments. This can enhance immersive learning experiences for students (Papanastasiou et al., 2019). Although AR has several benefits in student engagement, effective implementation in learning requires good design and manufacture of AR applications and content and good collaboration between teachers and technology. It must be supported by good planning of the implemented learning programs and can integrate AR technology well (Chang et al., 2019).

Conclusion

AR has been increasing and receiving attention from educational institutions. This is due to the technology's visual and interactive nature. Several studies have provided evidence that AR technology has motivated and engaged learners with visual and interactive features, which made the learning process more active and effective. Since engagement is crucial for learning, examining how AR technology facilitates student engagement is essential. AR technology incorporates instructional design methods, interactive and collaborative features, and immersive visualization experiences to stimulate students' learning. The study showed that diverse and multiple features in each category were integrated, from touch interface to panning zooming and rotation navigation, voice and gesture recognition, model rendering, contextual visualization, augmentation and annotation, optical character recognition, and text recognition, which are frequently used. Students preferred more interactive features and creative options to be included so that there is the possibility of creating new things by the students. This study is expected to reveal the importance of engagement in AR-integrated learning environments and explain how technology enhances students' engagement with learning activities. Also, this study is anticipated to benefit those integrating AR into educational institutions.

Scientific Ethics Declaration

The authors declare that the scientific, ethical, and legal responsibility of this article published in EPESS journal belongs to the authors.

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