Utilization of augmented reality technology in overcoming educational issues in Indonesia

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ABSTRACT

Education in Indonesia faces various challenges, including limited access to quality education, insufficient resources and infrastructure, a shortage of qualified teachers, and limited integration of technology in the learning process. Augmented reality (AR) offers a promising solution by combining real-world and virtual elements to create interactive and immersive learning experiences. This review identifies that AR enhances student engagement, improves understanding of complex concepts, and supports more accessible and personalized learning environments. AR also helps address infrastructure limitations through virtual simulations and mobile-based learning applications. However, challenges remain, including cost and sustainability issues, teacher training needs, infrastructure requirements, and internet connectivity. Therefore, strategic policies, collaboration among stakeholders, and the development of AR-based curriculum content are required to support sustainable implementation. Furthermore, emerging immersive technologies such as mixed reality (MR) offer additional opportunities for interactive learning; however, further empirical research is required to evaluate their effectiveness in Indonesian educational contexts.

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1. INTRODUCTION

Indonesia, as a developing country, confronts several significant challenges in its education system. Access to quality education [1], teacher qualifications [2], infrastructure limitations [3], and technological integration [4] remain critical issues that require urgent attention. These challenges have led to unequal learning experiences and outcomes across regions. The COVID-19 pandemic further exacerbated these disparities, as prolonged school closures disrupted learning for millions of students and widened the digital divide [5]. According to the World Bank's rewrite the future report, Indonesian students risk losing up to one year of effective learning due to the pandemic's impact on schooling continuity [6]. Similarly, UNICEF highlighted that children in remote areas experienced severe difficulties accessing remote learning because of limited internet connectivity and inadequate digital devices [7]. These findings underscore the urgent need for innovative, technology-driven solutions that can ensure equitable access to quality education for both urban and rural communities.

The increasing number of smartphone users in Indonesia provides significant prospects for developing educational technologies [8]. One potential solution that has gained attention is the utilization of augmented reality (AR) technology in creating immersive learning environments [9]-[11]. AR is a technology that overlays digital content onto the real world, enhancing the user's perception and interaction with their environment [12]. Recently, there has been an initiative to implement AR technology in outdoor educational settings to address the limitations found in conventional classroom-based teaching methods [13], [14]. AR has the potential to revolutionize education in Indonesia by creating unified educational settings, changing the location and time of training education, and providing effective and engaging learning experiences for students [15]. AR has shown promising results in enhancing learning achievement [16]-[18], especially in non-traditional learning environments and for individuals with autism and cognitive disabilities [19]. Research on interactive and game-based learning through AR also indicates its potential to support and improve educational experiences nationwide [20], [21].

The integration of AR technology in education has the potential to offer innovative solutions to these challenges [22]. AR technology overlays virtual content onto the real world, creating interactive and immersive learning experiences [23]. By leveraging this technology, educators can enhance the accessibility and quality of education, engage students in active learning, and bridge the gap between theoretical concepts and real-world applications [24]. Here are some of the benefits of using AR in education: i) the use of AR technology and multimedia elements in the development of learning and training applications has intensified, signifying the many educational benefits that both learners and educators can gain [25]. AR technology has been shown to improve student engagement, motivation, and understanding of complex concepts; ii) research has demonstrated that AR can enhance spatial visualization skills, critical thinking abilities, and collaboration among students [26]-[28]; iii) additionally, AR can provide opportunities for immersive and interactive learning experiences [29], enabling students to explore virtual models, simulations, and experiments [30]; and iv) AR can also facilitate personalized learning [31], allowing students to interact with content at their own pace and in their preferred learning style.

The use of AR in education presents both benefits and challenges [32]. On the one hand, AR can enhance spatial visualization skills, critical thinking abilities, and collaboration among students [33], and has been widely reported to improve learning effectiveness across disciplines, including medical and mathematics education [33], [34]. Meta-analytic evidence also indicates that AR-based training can significantly improve performance and engagement in professional learning contexts [35]. On the other hand, there are challenges and considerations that need to be addressed, such as the need for proper infrastructure and access to technology, training, and support for educators, the availability of relevant content and applications, unlimited access to technology, and effective integration into learning objectives. Overall, the use of AR in education in Indonesia has the potential to significantly improve the learning experience for students [34]. However, it is important to carefully navigate these challenges and ensure that the implementation of AR in education is done thoughtfully and effectively [9]. This includes considering the infrastructure and access to technology, providing necessary training and support for educators, ensuring equitable access for all students, addressing ethical and privacy concerns, and aligning the use of AR with curriculum and learning objectives. It is crucial for educators and policymakers in Indonesia to carefully consider these factors and develop a comprehensive plan for implementing AR in basic education.

This literature review will examine previous studies that have explored the utilization of AR technology in addressing education issues in Indonesia, analyzing its impact on improving access to quality education, enhancing teaching methods, making the curriculum more engaging, improving infrastructure and facilities, and integrating technology effectively into the teaching and learning process. To identify gaps, challenges, and opportunities for further research and implementation of AR technology in overcoming these educational issues, the following research questions will guide the systematic literature review.

The research questions in Table 1 guide this systematic review in examining the challenges and opportunities of implementing AR in Indonesian education. The findings are expected to provide insights for educators, policymakers, and researchers in improving learning practices. This review also contributes to the development of AR-based learning to address educational challenges and enhance learning outcomes.

Table 1. Research questions

No	Research questions
1.	How has the AR trend evolved in education over the last five years in Indonesia?
2.	What are the existing AR content and applications that have been utilized in the Indonesian education?
3.	What is the impact of using AR in education, especially in learning environments?
4.	How can the use of AR technology help overcome educational issues in Indonesia?
5.	What are the challenges of using AR technologies in Indonesian education?

2. METHOD
2.1. Research design

This study employed a systematic literature review following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework [24]–[28], to ensure a structured and transparent synthesis of AR research in Indonesian education. As illustrated in Figure 1, records were identified from Scopus, Web of Science, and Google Scholar using predefined keywords, resulting in 203 initial articles. After removing duplicates and irrelevant records, 51 studies were screened, and 32 full-text articles were assessed for eligibility. Based on inclusion criteria such as relevance to AR in education, peer-reviewed status, Scopus Q1–Q3 indexing, and focus on the Indonesian context, 20 studies were finally included in the review. The PRISMA flow diagram was generated using the Watase Uake tool (https://watase.web.id/) to support a transparent selection process [36]–[39].

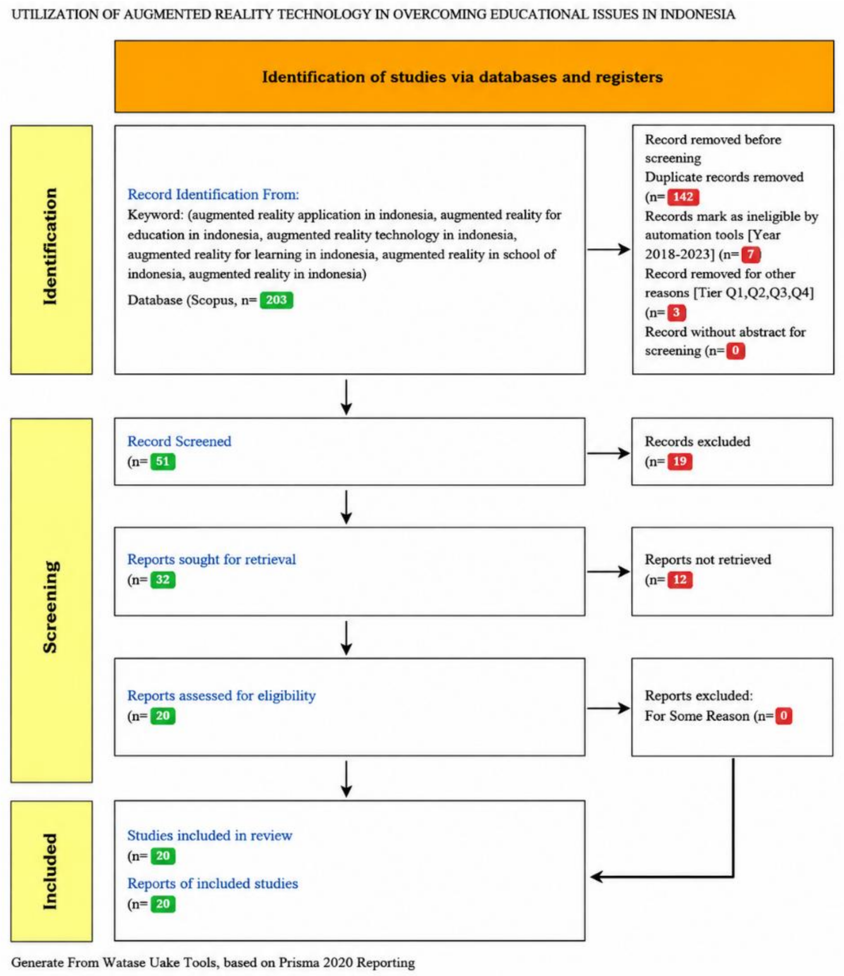


Figure 1. PRISMA framework of this research

2.2. Identification of relevant studies

Relevant studies were identified through searches in Scopus, Web of Science, and Google Scholar using keywords related to AR and Indonesian education. The search was conducted between December 2023 and January 2024, covering publications from 2018 to 2023. Boolean operators were applied, including ("augmented reality" OR "AR") AND ("education" OR "learning") AND ("Indonesia"), along with related variations. The initial search yielded 203 articles (Scopus=120, Web of Science=55, and Google Scholar=28). After removing duplicates and irrelevant records, 51 studies remained, and further screening based on relevance to the Indonesian context resulted in 32 eligible articles. By applying inclusion criteria such as peer-reviewed status, Scopus indexing (Q1–Q3), and focus on AR in education, 20 studies were selected for the final review.

2.3. Selection criteria and screening

Following the identification stage, studies were screened using predefined inclusion and exclusion criteria to ensure relevance and quality. These criteria focused on AR applications in education, particularly within the Indonesian context. The detailed selection criteria are presented in Table 2.

Table 2. Inclusion and exclusion criteria

No	Criteria	Inclusion	Exclusion
1.	Relevance to AR in education	Studies focusing on AR applications in education, learning outcomes, instructional design, or educational technology	Studies not related to AR in educational contexts
2.	Publication year	Published between 2018–2023	Published before 2018
3.	Context	Studies conducted in Indonesian education or applicable to Indonesian context	Studies unrelated to Indonesian education
4.	Publication type	Peer-reviewed journal or reputable conference	Non-peer-reviewed articles, theses, reports
5.	Indexing quality	Indexed in Scopus (Q1–Q3)	Not indexed or low-quality sources
6.	Accessibility	Full-text available	Abstract-only or inaccessible articles

2.4. Data extraction and synthesis

After selecting the relevant studies, data were systematically extracted to capture key information on the application of AR in education. Two independent reviewers conducted the extraction following PRISMA guidelines [40]–[44] and discrepancies were resolved through discussion to minimize bias. Extracted variables included subject area, educational level, AR tools, learning outcomes, pedagogical approaches, technological considerations, and study limitations. The data were then analyzed using both quantitative and qualitative synthesis, where quantitative analysis summarized the frequency of AR applications and reported outcomes, while qualitative analysis examined pedagogical insights and contextual factors to provide a comprehensive overview of AR implementation in Indonesian education [45].

2.5. Quality assessment

The methodological quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018 [46], [47]. Two independent reviewers conducted the assessment, and disagreements were resolved through discussion to ensure consistency. Each study was evaluated based on five criteria according to its research design, with scores ranging from 0 to 5 and categorized as high (4–5), medium (3), or low (1–2).

2.6. Findings and implications

By following the PRISMA framework presented in Figure 1, this systematic literature review provided an overview of the current state of AR in education, with a specific focus on its implications and potential applications within Indonesian education. The findings contribute to a clearer understanding of the challenges, opportunities, and best practices associated with the integration of AR technology in educational settings, while also taking into account the methodological quality of the reviewed studies. Furthermore, the study highlights critical factors influencing the adoption of AR in Indonesian classrooms, particularly technological readiness, pedagogical approaches, and infrastructural support. These insights are expected to inform future decision-making and strategic planning, while acknowledging the methodological limitations inherent in the reviewed literature.

3. RESULTS AND DISCUSSION

3.1. Study selection

The study selection process followed a rigorous systematic approach to identify relevant articles on AR in Indonesian education. An initial search across databases yielded 203 articles. After removing duplicates and applying inclusion criteria, 51 articles remained. Further screening for relevance to the Indonesian educational context reduced the number to 32 articles. Finally, limiting the selection to peer-reviewed studies published in Scopus-indexed journals (Q1–Q3) resulted in 20 high-quality articles included in this review. These results are consistent with the PRISMA flowchart presented in Figure 1. The selected studies were then analyzed to extract insights regarding best practices, challenges, and innovative applications of AR in educational settings.

3.2. Trends of augmented reality technologies in Indonesian education

Figure 2 provides an overview of the trends and characteristics of AR technologies in Indonesian education from 2018 to 2023. It summarizes the development and application of AR across the reviewed studies to provide a comprehensive view of its use in Indonesian education. Figure 2(a) illustrates the publication trend from 2018 to 2023. The initial search identified 203 articles across multiple databases, with the majority indexed in Scopus. This trend shows a sharp increase in publications after 2020, coinciding with the COVID-19 pandemic. Since the beginning of 2019, many changes have been made to our daily lifestyle, one of which is the implementation of policies limiting mobility and interaction between people [48]. On the other hand, we as social creatures, rely heavily on interaction to fulfill our needs, and these needs are met with the emergence of the term "augmented reality". This AR technology allows us to interact with other individuals virtually.

3.3. The existing augmented reality that has utilized in the Indonesian education

Table 3 presents a brief summary of the AR applications that are currently available and have been used in Indonesian education, based on the existing literature. These applications demonstrate the diverse ways AR technology enhances student learning experiences, engagement, and skill development. Overall, the study highlights the substantial impact of AR and related technologies on various aspects of education, emphasizing their potential in addressing learning challenges and improving educational outcomes.

Table 3. The AR applications in Indonesian Education (2018-2023)

No	Research	Journal rank	Subject	Result
1	AR-MobileMathTrails program [49]	Q2	Math	Students significantly improved in mathematical modeling, with their average proficiency rising from 49.25 to 75.50 post-intervention.
2	Ecolabel AR on website [50]	Q2	Environmental awareness	Students enrich their knowledge about the environment.
3	Pocketbook based on AR on planetary motion [51]	Q2	Physics	Overall student learning outcomes were noted, with a moderate average gain of 0.63 in learning outcomes.
4	Mobile AR as a didactic and pedagogical source [52]	Q2	3D geometry	The use of mobile AR aided in understanding geometric concepts and positively affected attitudes towards learning, with an average score of 67.5 in a group of 26 students.
5	PicsAR [53]	Q1	Physics	At least 66.67% of students showed proficient abstract thinking skills.
6	AR based Gamelan simulation [54]	Q3	Music	Providing tutorials on gamelan simulation enhanced learnability.
7	Mobile-based AR [55]	Q3	3D geometry	Mobile-based AR (MB-AR) effectively improved students' spatial activity and understanding of 3D shapes, with proficiency increasing from 65% to 78%.
8	AR module [56]	Q3	Vector in math	The AR module significantly improved problem-solving and spatial skills.
9	Integrating AR into the 6E instructional 3D geometry model [57]	Q3	3D geometry	Integrating AR into the 6E I3DGM approach positively impacted cognitive processes related to 3D geometry.
10	Using VR-AR in polytechnic in Indonesia [58]	Q3	Construction engineering	VR-AR technology-based teaching materials received positive user feedback for comfort and engagement.
11	ARGBL [59]	Q3	Chemistry and Biology	ARGBL notably improved literacy and numeracy skills among high school students.
12	AR-based interactive multimedia [60]	Q2	Science	AR-based interactive multimedia in primary school teacher education improved understanding and problem-solving in earth and rock structure science.
13	Mobile AR assisted STEM-based learning [61]	Q2	Scientific literacy	MAR-assisted STEM-based learning methods led to higher scientific literacy and learning outcomes.
14	AR application development [62]	Q3	Cultural artefact education	An AR application developed for cultural heritage preservation in Palembang, Indonesia, received a satisfactory SUS survey score of 78.3 and increased user knowledge by 28.5%.
15	AR in biology learning [63]	Q3	Biology	The study found no significant gender difference in biology learning outcomes, suggesting AR can bridge gender gaps in biology education.
16	Smart Maps Indonesia [64]	Q3	Social studies	Smart Indonesia Maps effectively developed critical thinking, creativity, and 21st-century skills.
17	Electricity using AR [65]	Q2	Electricity	Based on the independent t-test results, student achievement significantly improved in both offline (n=63, M=74.71) and online (n=64, M=71.46) classes with t=1.994, p=0.048. However, students in offline classes demonstrated greater improvement in achievement compared to those in online classes.
18	Mobile AR [66]	Q3	Physics	Students using mobile AR in physics education demonstrated higher achievement than those using textbooks, finding it easier to understand concepts through 3D simulations.
19	AR learning media based on tetrahedral chemical representation [67]	Q2	Chemistry	The development of AR learning media based on tetrahedral chemical representations led to improved learning outcomes.
20	Ethnomathematics AR: android-based learning multimedia [68]	Q3	Geometry	The AR developed in the study significantly enhanced students' creative thinking skills, as indicated by a one-sample t-test result.

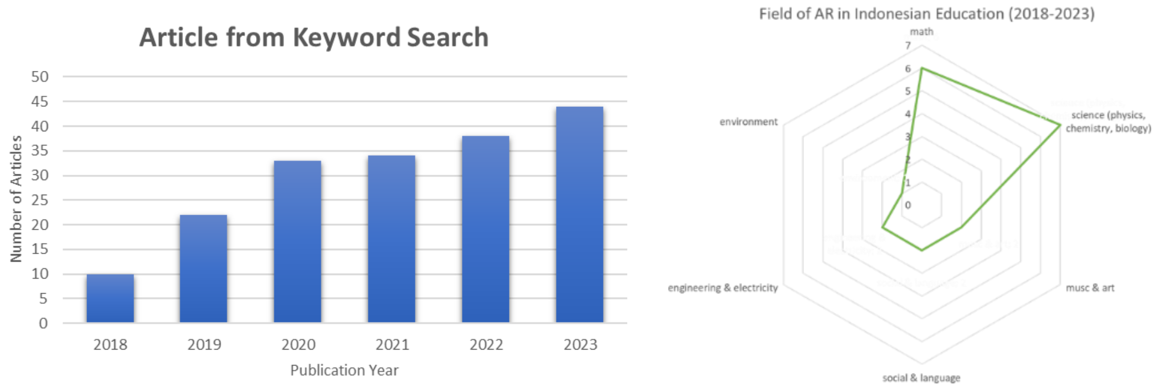
In addition to mapping the domains and applications of AR in Indonesian education (Table 3), a quality appraisal was conducted to evaluate the methodological rigor of the included studies. Table 4 summarizes each study's design, educational level, AR application focus, MMAT score, and quality category using the MMAT 2018 framework [47]. The appraisal revealed that most studies were rated as High quality (n=12), while seven studies were rated as Medium quality (n=7) and one study was rated as Low quality (n=1). This distribution provides an overview of the methodological robustness and potential risk of bias in the reviewed literature, which informs the interpretation of the subsequent findings.

Table 4. Quality appraisal of AR studies in Indonesian education (2018–2023)

No	Research	Study design	Educational level/subject	AR application focus	MMAT score (0–5)	Quality category
1	AR-MobileMathTrails program [49]	Quantitative (Exp.)	Mathematics (Secondary)	Math modeling via AR trails	4	High
2	Ecolabel AR on Website [50]	Quantitative	Environmental Education	AR-based ecolabel learning	3	Medium
3	Pocketbook AR on Planetary Motion [51]	Quantitative (Quasi-exp.)	Physics	AR pocketbook for astronomy	4	High
4	Mobile AR as Didactic Source [52]	Mixed-methods	Mathematics (Geometry)	Mobile AR for 3D geometry	3	Medium
5	PicsAR [53]	Quantitative	Physics	AR app to improve abstract thinking	4	High
6	AR-based Gamelan Simulation [54]	Qualitative	Music	Simulation and tutorial for gamelan	2	Low
7	Mobile-Based AR [55]	Quantitative	Mathematics (3D Geometry)	Spatial activity and 3D shapes	4	High
8	AR module [56]	Quantitative	Mathematics (Vectors)	AR for problem-solving and spatial	4	High
9	AR in 6E Instructional Model [57]	Mixed-methods	Mathematics (Geometry)	Integrating AR in 6E model	3	Medium
10	VR-AR in Polytechnic [58]	Quantitative (Survey)	Engineering	VR/AR teaching materials	3	Medium
11	ARGBL [59]	Quantitative	Chemistry and Biology	AR game-based learning	4	High
12	AR-based Interactive Multimedia [60]	Mixed-methods	Primary Science Education	Multimedia AR for earth/rock structure	3	Medium
13	Mobile AR Assisted STEM [61]	Quantitative (Exp.)	STEM (Scientific Literacy)	AR-assisted STEM methods	4	High
14	AR for Cultural Artefacts [62]	Quantitative (Survey)	Cultural Education	AR for heritage preservation	3	Medium
15	AR in Biology Learning [63]	Quantitative	Biology	Biology outcomes and gender equity	4	High
16	Smart Maps Indonesia [64]	Quantitative	Social Studies	AR maps for critical thinking	3	Medium
17	Electricity Using AR [65]	Quantitative (Exp.)	Physics (Electricity)	Offline and online AR modules	4	High
18	Mobile AR for Physics [66]	Quantitative	Physics	AR vs textbook comprehension	4	High
19	AR Media – Tetrahedral Chemistry [67]	Quantitative	Chemistry	AR for tetrahedral models	4	High
20	Ethnomathematics AR [68]	Quantitative	Mathematics (Geometry)	AR multimedia for ethnomath	4	High

Figure 2(b) illustrates the distribution of AR implementation across educational fields in Indonesia from 2018 to 2023. The chart shows that AR is most widely adopted in science-related subjects such as physics, chemistry, and biology, likely due to its ability to visualize abstract concepts in three dimensions. Mathematics and environmental studies also demonstrate substantial adoption, as AR supports interactive problem-solving and immersive simulations that enhance conceptual understanding and real-world awareness.

Moderate utilization of AR is observed in social sciences and language learning, indicating a growing interest in creating immersive historical, cultural, and linguistic experiences. Engineering and electricity fields show emerging adoption, mainly for simulating real-world processes in a safe and cost-effective manner. In contrast, arts and vocational education display relatively limited integration, suggesting opportunities for further development. Overall, while AR adoption is strongest in scientific and mathematical domains, the findings highlight significant potential for expanding AR applications across underutilized fields to enhance learning experiences and overcome traditional educational constraints.



(a) (b)

Figure 2. Trends and fields of AR technologies in Indonesian education (2018–2023); (a) publication trends and (b) research fields

3.4. Discussion

3.4.1. The impact of using augmented reality on education

RQ3 examines the impact of AR on education, particularly within learning environments. Figure 3 summarizes the reported impacts of AR across multiple educational domains based on the findings of the reviewed studies presented in Table 3. These findings align with global meta-analyses reporting positive effects of AR on learning performance, motivation, and engagement across science, technology, engineering, and mathematics (STEM) disciplines [69], [70].

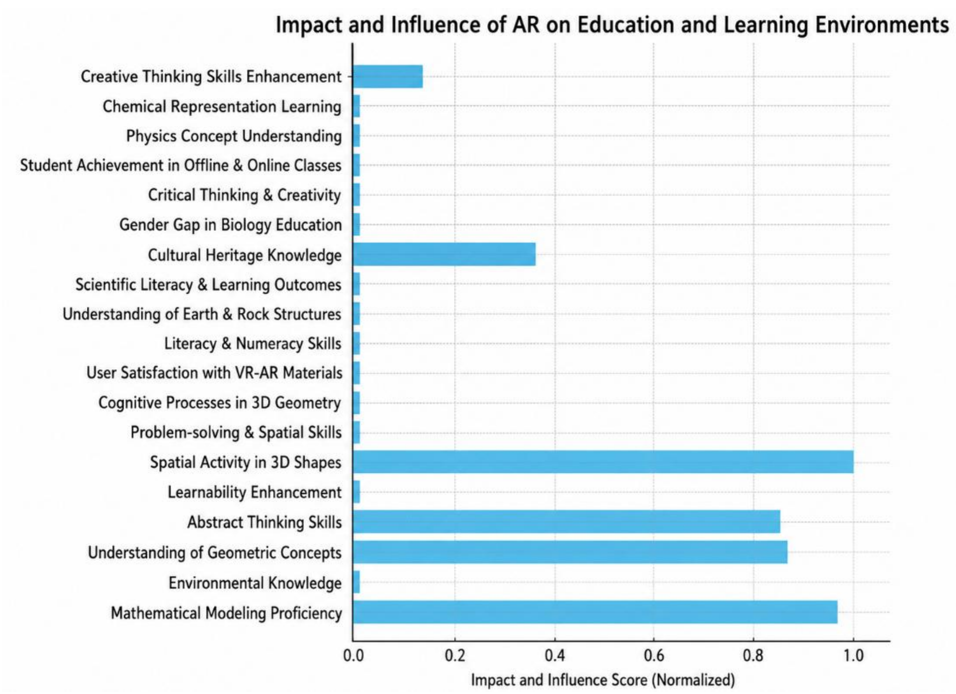


Figure 3. The impact of AR technologies on education (2018–2023)

Figure 3 provides a comprehensive overview of the diverse impacts and influences of AR on education and learning environments. Several key insights can be drawn from this visual representation: i) high proficiency in mathematical modeling — the most significant impact noted is in mathematical modeling proficiency, where students showed a remarkable improvement. This finding aligns with previous global studies reporting AR's effectiveness in improving students' analytical and spatial reasoning skills [69] and is supported by national studies such as [71], which confirmed that AR-based mathematics media significantly improved problem-solving skills in Indonesian classrooms; ii) moderate gains in environmental knowledge — the use of AR in environmental education shows moderate gains, consistent with [72], who noted that the impact of AR in contextual learning depends heavily on content design and implementation fidelity; iii) positive influence on geometric understanding and abstract thinking — AR has notably enhanced students' understanding of geometric concepts and abstract thinking, consistent with findings from [34], who observed improved conceptual understanding in science classes using AR visualization; iv) enhancement of learnability and cognitive processes — AR's role in enhancing learnability and cognitive processes in 3D geometry is significant, reaffirming [70] conclusion that AR fosters cognitive engagement through immersive environments; v) high user satisfaction with AR materials — high user satisfaction with AR materials indicates that these technologies are well-received and effective in sustaining engagement, which has also been observed in [72] study on AR for biology learning in Indonesia; vi) improvement in literacy and numeracy skills — the positive impact on literacy and numeracy skills through augmented reality game-based learning (ARGBL) supports earlier evidence that game-based AR enhances interactivity and learning outcomes; vii) balanced gender impact in biology education — the absence of significant gender differences in biology learning outcomes suggests AR's potential to support equitable learning, a pattern mirrored in [70] global meta-analysis; and viii) cultural heritage knowledge enhancement — the use of AR in cultural heritage education has significantly increased students' contextual understanding, aligning with [72], who emphasized AR's role in connecting cultural identity with educational content.

Overall, Figure 3 confirms AR as a versatile educational tool that enhances mathematical modeling, spatial reasoning, and conceptual understanding across various subject areas, while also promoting engagement and equitable learning. However, variations in impact indicate that effectiveness depends on implementation quality and methodological rigor. As shown in Table 4, although most studies were rated as high quality, several medium-quality studies reported mixed results, likely due to limitations such as small sample sizes or short intervention periods. These findings suggest that future research should employ more robust designs to validate long-term effects and strengthen evidence of AR's role in advancing Indonesia's learning landscape.

3.4.2. Addressing Indonesian educational issues with augmented reality

RQ4: How can the use of AR technology help overcome educational issues in Indonesia? The implementation of AR technology in Indonesian education, as evidenced by the reviewed studies, offers innovative pathways to address several persistent educational challenges. These challenges include limited access to quality education, insufficient infrastructure, shortages of qualified teachers, and unequal access to technological resources. The following discussion contextualizes these findings with national and international literature to illustrate AR's transformative potential within the Indonesian educational landscape.

a. Enhancing access to quality education

AR enables interactive learning experiences in remote or under-resourced areas through mobile devices, making educational content more accessible without reliance on physical materials. This is supported by studies in rural Indonesian schools [68], [73], as well as international findings highlighting improved accessibility and motivation in low-resource settings [69], [70].

b. Compensating for insufficient resources and infrastructure

AR enriches learning environments without requiring costly facilities by virtualizing complex phenomena. Applications such as AR-based simulations allow students to explore abstract concepts, aligning with findings that AR bridges infrastructure gaps in developing countries [72], and supports practical learning without expensive laboratory equipment in Indonesia [60].

c. Addressing the shortage of qualified teachers

AR can supplement instruction by providing structured visual explanations, particularly in STEM subjects, helping students understand complex concepts regardless of teacher expertise. This supports evidence that AR functions as a co-teaching aid and reduces dependence on teacher availability [6], [74].

d. Integration of technology in learning process

AR supports Indonesia's education transformation by enhancing digital literacy and integrating technology into learning [75], while aligning with Education 4.0 initiatives [76]. AR-based projects also foster problem-solving and technical competencies, consistent with findings on improved digital skills and self-directed learning [70].

e. Bridging educational gaps

AR promotes equitable learning by standardizing materials across diverse socioeconomic and geographic contexts. This is particularly relevant in Indonesia's urban–rural disparities [77], with studies showing AR reduces gender and regional inequalities [73], [78] consistent with global evidence on educational equity [72].

f. Enhancing student engagement and learning outcomes

The immersive nature of AR increases motivation and learning retention. Indonesian studies on ARGBL and mobile AR-assisted STEM learning report improvements in academic performance and scientific literacy [34], [79], consistent with international reviews demonstrating enhanced engagement and cognitive performance [70], [80].

g. Facilitating remote and online learning

AR supports learning continuity during disruptions such as the COVID-19 pandemic by maintaining interactivity in remote settings. Indonesian studies highlight effective mobile and web-based AR learning, aligning with global findings on virtual laboratories and remote simulations [81].

In conclusion, AR technology, through its innovative and context-sensitive applications, holds significant potential to alleviate some of Indonesia's critical educational challenges. However, its effectiveness is contingent upon contextual factors—such as teacher readiness, digital infrastructure, and institutional support—as well as methodological rigor in implementation, as indicated by the study quality distribution in Table 4. Most reviewed studies were of high quality, yet variability in design and limited longitudinal data remain key limitations. Therefore, sustainable integration of AR in Indonesian education should emphasize teacher professional development, equity of access, and alignment with national digital education policies to maximize its transformative impact.

3.4.3. Challenges of using augmented reality in Indonesian education

RQ5: What are the challenges of using AR technologies in Indonesian education? Despite the significant potential of AR to enhance learning, several contextual and structural challenges limit its implementation in Indonesia. These challenges include infrastructure limitations, digital literacy gaps, financial constraints, content development issues, and assessment complexities.

Limited access to high-speed internet and adequate digital devices remains a major obstacle, particularly in rural and eastern regions where infrastructure development lags behind the national average [6], [82]. Similar barriers have been reported in other developing countries [72], indicating that AR adoption is closely linked to technological readiness and may lead to unequal learning opportunities. Persistent digital inequalities highlighted in the UNESCO Global Education Monitoring Report [77] further emphasize the need for coordinated policies, infrastructure investment, and device provision programs to prevent widening educational disparities.

Teacher preparedness and digital literacy also influence AR integration. Many educators lack sufficient training in technical operation and pedagogical implementation [73], and studies report difficulties in instructional design and troubleshooting despite positive student responses [78]. In addition, effective AR content development requires collaboration among educators, designers, and programmers, yet there is a shortage of professionals with combined pedagogical and technical expertise. Limited culturally contextualized content further reduces engagement, supporting evidence that localized learning materials enhance relevance and retention [74].

Financial and resource limitations constrain AR implementation, as developing and maintaining applications requires substantial investment, making large-scale adoption difficult for schools with limited budgets. Although mobile-based AR offers a cost-effective alternative, long-term sustainability remains challenging, particularly in rural areas with minimal ICT funding. In addition, assessment and curriculum integration remain complex, as many studies—especially those rated medium quality in Table 4—used short-term interventions without control groups, limiting generalizability. Therefore, establishing standardized evaluation frameworks and aligning AR with national curricula are essential to avoid fragmented implementation. Overall, sustainable AR integration in Indonesia requires addressing financial constraints, infrastructure gaps, teacher competence, localized content development, and rigorous assessment practices, supported by long-term digital education strategies and future research focusing on scalable frameworks, longitudinal evaluations, and capacity building.

4. CONCLUSION

This literature review highlights the growing adoption of AR in Indonesian education and its potential to address key educational challenges. Over the past five years (2018-2023), AR applications have expanded across various subjects and educational levels, demonstrating their effectiveness in enhancing student engagement, improving conceptual understanding, and providing interactive and immersive learning experiences. AR also contributes to increasing access to quality education, overcoming resource limitations, and supporting personalized learning, indicating its important role in Indonesia's digital education transformation. Despite these benefits, several challenges remain, including infrastructure limitations, financial constraints, teacher preparedness, and sustainability issues, which require coordinated policy support, investment in digital infrastructure, and continuous professional development for educators.

Furthermore, emerging immersive technologies such as mixed reality (MR) may offer additional opportunities for enhancing interactive learning in the future; however, their implementation in Indonesian education remains limited and requires further empirical investigation. However, this review is limited by the availability of empirical studies and variations in methodological quality among the included research, which may affect the generalizability of findings. Therefore, future research should focus on scalable frameworks, longitudinal evaluations, and evidence-based implementation strategies to ensure inclusive, sustainable, and effective integration of immersive technologies in Indonesian education.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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